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ZÁPADNÉ KARPATY

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CONTENTS - OBSAH

Západné Karpaty, sér. hydrogeológia a inž. geol. 11, p. 9—22,
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ZOLTÁN SPIŠÁK

Slope failures fringing some effusive and shallow intrusive volcanic bodies in the northern Slanské vrchy Mts.

(8 figs., slovak summary)

A b s t r a c t. The article gives a brief characteristics of a geological-geomorphological structure favourable for the formation of slope failures. It also describes a few typical localities where this structure and slope failures are developed. The structure's characteristic signs include effusive and shallow intrusive volcanic bodies cutting Neogene and Paleogene sedimentary formations as well as deformations and subsequent slope failures in these sediments. In the Slanské vrchy neovolcanic region, there structures make up two belts and are particularly widely distributed in the marginal parts of the mountains. The article concludes with a brief description of the formation and evolution of landslides in this geologic-tectonic structure.

Introduction

Regions composed of Tertiary volcanic complexes and their marginal parts on the Slovak territory are characterized by the presence of very extensive slope failures disturbing the volcanic complexes as well as earlier sedimentary formations underlying or fringing the volcanics.

A typical example of such area are the Slanské vrchy Mts. where Lower to Upper Miocene sediments are interlaced with a few separate volcanic structures.

The emplacement of solid volcanics and volcanoclastics amidst plastic sediments of Neogene and partly also Paleogene age, but mainly the neotectonic uplift of differentiated volcanic structures, created favourable conditions for the formation and further development of extensive slope failures (NEMČOK et al., 1974). The failures can be classified as creep, slide, flowage and rolling. The areal extent of slope failures in this region is considerable, and earlier works (MALGOT, 1977) estimate that they disturb 120 km^2 on the periphery of the Slanské vrchy Mts.

The extent and intensity of slope failures on the periphery of the volcanic structures are enhanced by the presence of deeply-seated effusive and shallow intrusive volcanic bodies of different lithologies and shapes cutting the sedimentary or

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volcanosedimentary formations. The emplacement of these volcanic bodies and subsequent volcanic activity gave rise to a geologic-geomorphological structure very favourable for the formation of gravitational slope failures on the periphery of these bodies. Such slope failures in this region were noted by Malgot (1969), while Spišák and Polaščinová (1991) described in more detail the characteristic slope failures between Hubošovce and Kapušany.

Location of the effusive and shallow intrusive bodies

The location of the effusive and shallow intrusive igneous bodies is closely associated with the course of an elongated NW–SE-trending graben structure (Kaličiak, 1989).

The marginal faults fringing this structure became supply channels through which lithologically differentiated volcanic masses ascended. The activity of these faults culminated in the Lower and Middle Sarmatian. The graben structure is understandably lined with two separate belts of volcanic bodies. The first belt lies on the SE to E margin of the Slanské vrchy from Hubošovce as far as Juskova Voľa with a possible SE continuation. This northern belt comprises a number of separate bodies between Hubošovce and Kapušany as well as Maglovec, Oblík and Oblá bodies and some minor ones.

The second belt is situated in the SW Slanské vrchy and is separated from the first one by the main volcanic massif. This belt extends from V. Šariš to Ruská Nová Ves through a large effusive complex near Brestovo and further on through Kecerovce to Herľany (Fig. 1).

The activity of the marginal faults defining the graben structure, however, did not end in the Neoge-Neogene. Morphological structures on the periphery of the mountains, vast slope failures and thick accumulations of slope sediments suggest that the fault activity persisted until the Quaternary. The late movements frequently compensate for the Neogene ones along the same structures and their direction is opposite (Janočko, 1989).

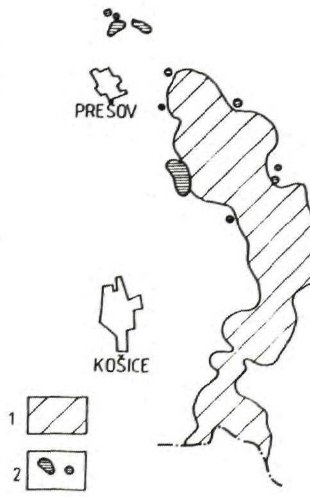

Fig. 1 Location of effusiva and shallow intrusive bodies on the periphery of the Slanské vrchy Mts
1 — Slanské vrchy volcanic mountains, 2 — some effusive and shallow intrusive volcanic bodies in marginal parts of the mountains, 3 — state boundaries

Brief characteristics of the structure

As noted in the introduction, the geologic-geomorphologic structure in question resulted from the emplacement of the volcanic body through earlier formations in the period of volcanic activity. The knowledge obtained so far by field mapping makes it possible to distinguish two stages in the development of this structure.

In the first stage, the volcanic body penetrated through the plastic sedimentary or volcanosedimentary complex and a morphostructural elevation was thus formed (Fig. 2). The emplacement of the volcanic body resulted in strong fracturing and deformation of the sedimentary formations and, in many places, torn of sedimentary blocks formed isolated xenoliths amidst the volcanic matter. Hornfels and porcelanites were formed at the contacts.

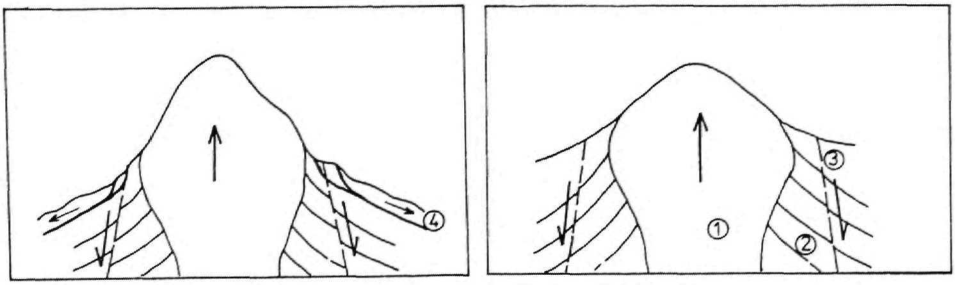

Fig. 2 Evolutionary stages of landslide structure fringing a volcanic body
1 — effusive to shallow intrusive volcanic body, 2 — distrurbed formations, 3 — active marginal faults, 4 — landslides on the slopes

The emplaced bodies strongly compressed the adjacent sedimentary formations and the stress field considerably changed in favour of pressure stresses. The formerly subhorizontal formations were erected to a nearly upright position, dipping at 70–80°. The first stage was concluded by the beginning uplift of the morphostructure along the marginal active faults.

In the second stage, the whole morphostructure was uplifted and subjected to erosion. As the uplift and erosion continued (the process is still under way), pressure stresses in the compressed formations were released and tensile zones were formed primarily in the source portions of slopes. These tensile zones triggered intensive weathering to substantial depths in the fractured sedimentary formations and volcanic bodies slike. Meteoric waters percolate through a system of tensile fractures in the volcanic bodies as far as the contact with the underlying plastic sediments thereby adding water to the creep zone of the deformed formations. As a result, shear strength of earths underlying the fractured massif considerably decreased. These processes along with other factors gradually undermined slope stability on the periphery of the volcanic bodies until the critical values was exceeded and fairly fast slope failures took place. The blockdiagram in Fig. 3 shows the spatial position of an

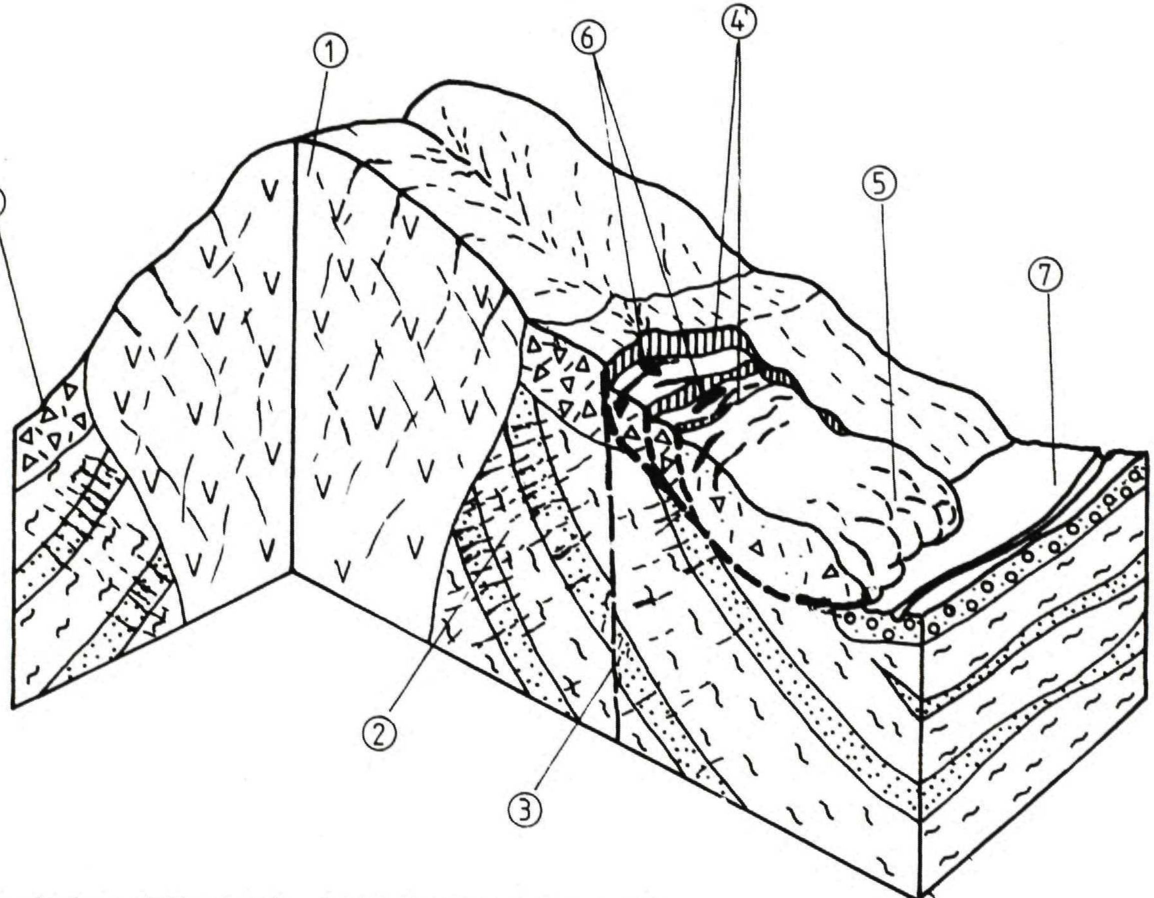

Fig. 3 Blockdiagram showing spatial location of a volcanic body and surrounding landslides
1 — effusive to shallow intrusive volcanic body, 2 — disturbed sedimentary formations, 3 — active marginal fault lines, 4 — divisional planes and tensile cracks of the landslide, 5 — accumulation part of the landslide, 6 — springs and swamps, 7 — alluvial plain with fluvial deposits, 8 — thick loamy-talus deposits

igneous effusive and shallow intrusive body cutting the sedimentary complex and the formation of landslides on the periphery of the body.

Some typical examples of landslide areas

Several more or less separate bodies within the northern volcanic belt from Hubušovce to Zamutov were selected to characterize slope failures on the periphery of the deeply seated effusive and shallow intrusive igneous bodies.

The volcanic bodies of variegated lithology in this region occur amidst Paleogene and Neogene sediments of Neogene volcanosedimentary formations.

The enclosed maps of the selected landslide areas sufficiently illustrate the geological structure of the area and the character of slope failures.

Lysá Stráž

The volcanic body Lysá Stráž (Fig. 4) lies on the periphery of the conspicuous NW –SE horst structure composed of Inner-Carpathian Paleogene sediments. The volcanic body itself represents the NW end of a belt of separate volcanic bodies of variable size stretching from Hubušovce to Kapušany (Kaličiak et al.., 1988).

Petrographically, the body consists of pyroxene-amphibole diorite porphyrite cutting Inner-Carpathian Paleogene (claystone-siltstone development of Huty Formation) and Eggenburgian formation (claystone-sandstone development of Čelovce Formation), (Molnár et al., 1986). The first map illustrating the evolution of landslides on the periphery of the Lysá Stráž body was compiled by Malgot (1969).

Slope failures fringing the volcanic body can be classified as sliding. Field mapping and drilling have proved that shear planes at the contact between Quaternary sediments and underlying rocks or in strongly weathered zone of subjacent sediments are rotational-planar ones. The landslides have sheet-like or elongated flow-like shapes. The accumulation portions of some landslides reach as far as the local base level. The geomorphologic manifestations suggesting landslide area and the degree to which it is disturbed confirm the potential state of landslided with signs of their partial activation.

Maglovec

The volcanic body Maglovec of conspicuous oval shape elongated in the NW–SE direction (Fig. 5) is situated in the northernomost part of the Slanské vrchy.

This shallow intrusive body consists of amphibole-pyroxene diorite porphyry dissected by blocky joints passing into columnar jointing. The body cuts Lower Neogene (Karpatian) claystone and claystone-sandstone formations. The enclosed map clearly shows the marked difference between the evolution of the northern slopes characterized by landslides and the southern part with extensive proluvial gravel accumulations. The thick Pleistocene andesite proluvial gravels buried the contact between the volcanic body and plastic Neogene sediments and therefore the area is

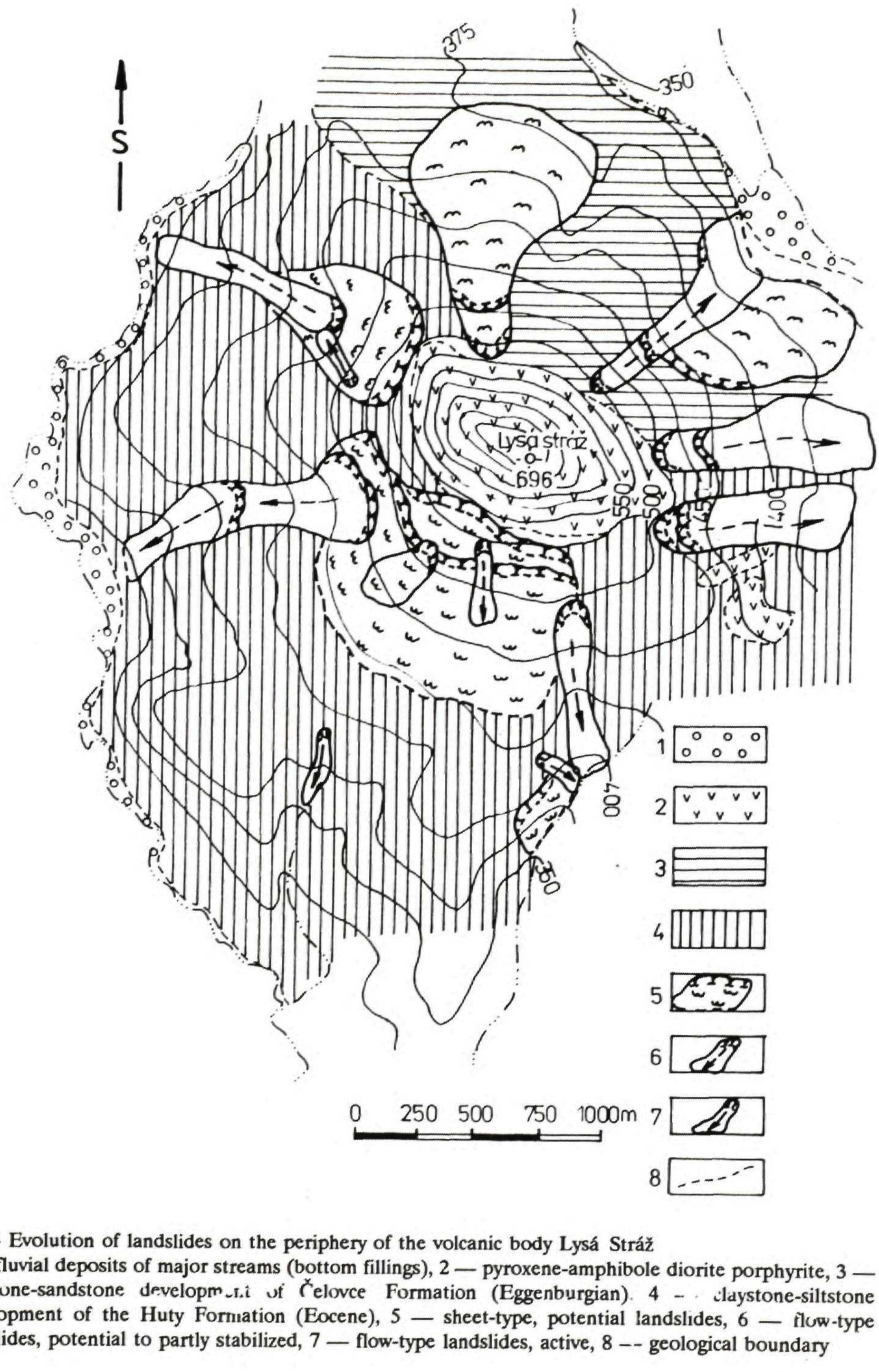

Fig. 4 Evolution of landslides on the periphery of the volcanic body Lysá Stráž
1 — fluvial deposits of major streams (bottom fillings), 2 — pyroxene-amphibole diorite porphyrite, 3 — claystone-sandstone development of Čelovce Formation (Eggenburgian), 4 — claystone-siltstone development of the Huty Formation (Eocene), 5 — sheet-type, potential landslides, 6 — flow-type landslides, potential to partly stabilized, 7 — flow-type landslides, active, 8 — geological boundary

stable. In contrast, Neogene sediments and Quaternary slope deposits on the northern slopes which stretch as far as the village Severná were disrupted by areal landslides. On the eastern margin of the volcanic body there occur landslides, too. Like in the previous case, the landslides here are of potential character, the active forms being developed only locally. The morphology of the landslide area suggests that the shear planes are rotational-planar and curved in their basal part.

The landslide areas contain undrained depressions and swamps, predominantly in the upper portions of landslides.

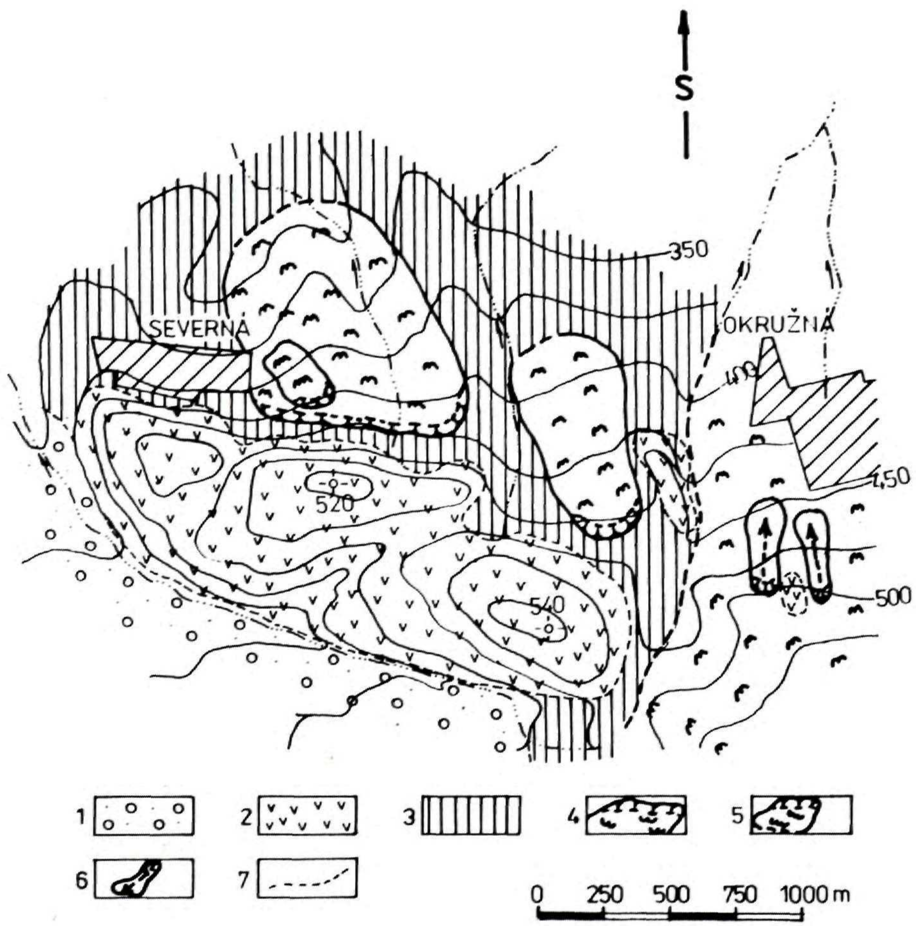

Fig. 5 Slope failures fringing the volcanic body Maglovec
1 — Pleistocene accumulations of proluvial gravels, 2 — amphibole-diorite porphyry, 3 — claystone-sandstone formation (Karpatian), 4 — sheet-type potential landslides, 5 — sheet-type active landslides, 6 — flow-type landslides, potential, 7 — geological boundary

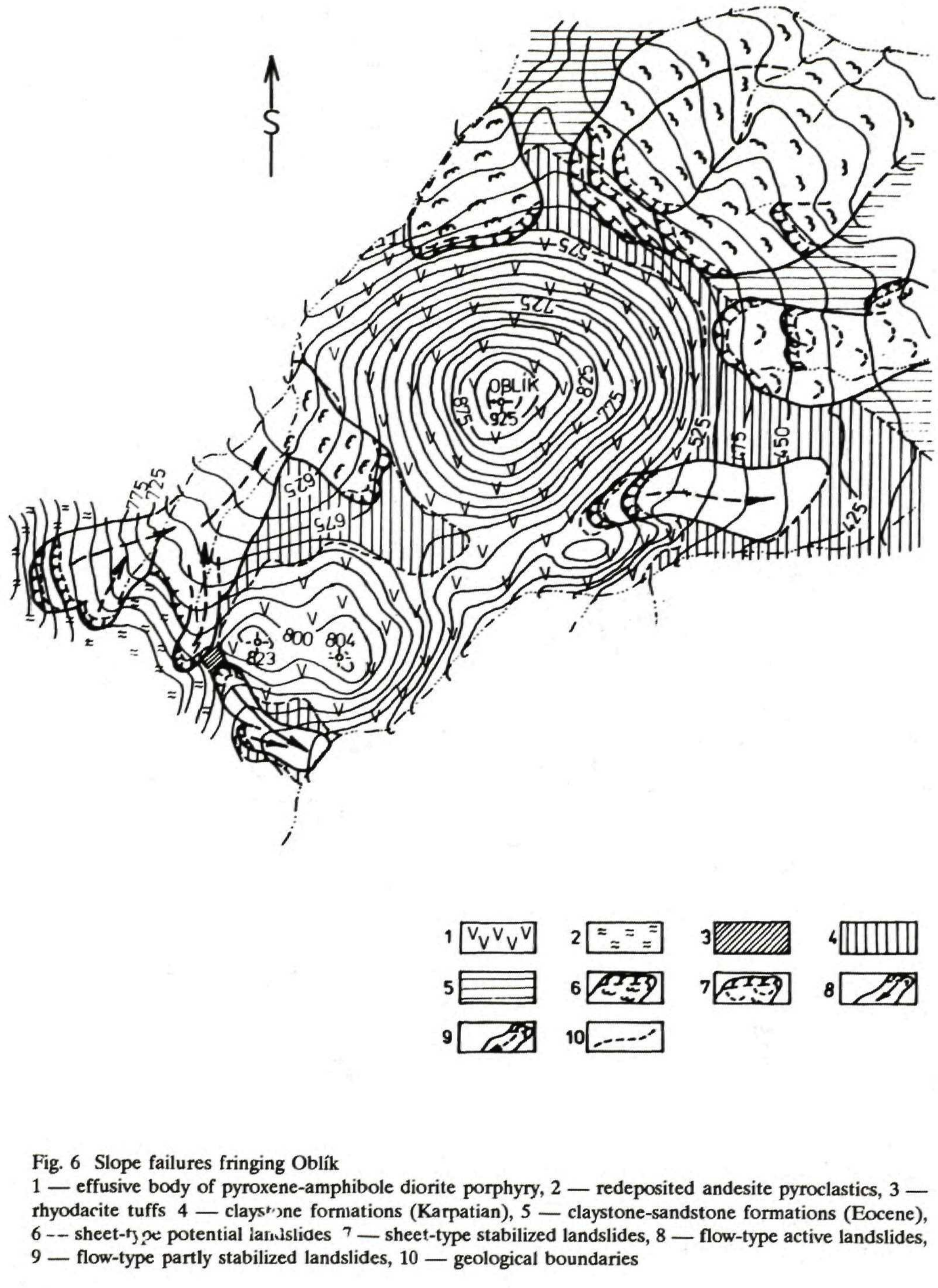

Fig. 6 Slope failures fringing Oblík
1 — effusive body of pyroxene-amphibole diorite porphyry, 2 — redeposited andesite pyroclastics, 3 — rhyodacite tuffs 4 — claystone formations (Karpatian), 5 — claystone-sandstone formations (Eocene), 6 — sheet-type potential landslides 7 — sheet-type stabilized landslides, 8 — flow-type active landslides, 9 — flow-type partly stabilized landslides, 10 — geological boundaries

Oblík

This volcanic body forms a very conspicuous round domal elevation rising to 925 m above sea level (Fig. 6).

The body composed of pyroxene-amphibole diorite porphyry can be described as shallow intrusive passing into an effusive equivalent. The ascending magma made its way through Karpatian claystone formations and the Paleogene claystone-sandstone Huty Formations. It the SW tract of the contact between the volcanic body and sedimentary formations there occur manifestations of contact thermic metamorphism.

Slope failures disturbing vast areas on the periphery of the volcanic body are classified as landslides with rotational-planar shear planes (MALGOT, 1969).

The landslide divisional planes locally extend as far as the volcanic body and disturb the surrounding extremely thick loamy-stony accumulations. Areal landslides prevail, with flow-type forms being developed only locally.

The divisional part of landslides is characterized by the presence of sunken blocks of slope accumulations with vertical displacements measuring up to several hundreds of metres. The accumulation portions of the landslides mostly spread as far as the local base level. Numerous swamps and undrained depressions were formed on the slopes disturbed by landslides and a number of major springs occur in the source portions of the landslides.

Oblá

The small volcanic body Oblá lies SW of the village Zamutov, on the periphery of the Makovica stratovolcano. The shallow intrusive body of andesite-diorite porphyry cuts Badenian claystone and claystone-sandstone formations (Fig. 7). The body has a round and domal shape. Its NE and E margins were disturbed by landslides whose accumulation portions spread as far as the local base level and their divisional planes sometimes disturb the volcanic body itself.

The wawy morphology forms a typical landslide relief with a variable amplitude between the positive and negative landforms. Like elsewhere, these slopes are also covered with a number of swamps and undrained depressions, and several springs have been noted on sliding slopes on the periphery of the volcanic body thus reducing their stability.

Valenčica

The last example of slopes around volcanic bodies disturbed by landslides is the small body Valenčica located north of Zamutov.

The volcanic body composed of light gray to pinkish rhyolite forms a domal round morphologic elevation. Near the surface, the body cuts Badenian formations dominated by claystones with layers of fine-grained sandstones (Fig. 8).

The attached map clearly illustrated the extent of slope failures fringing the rhyolite body.

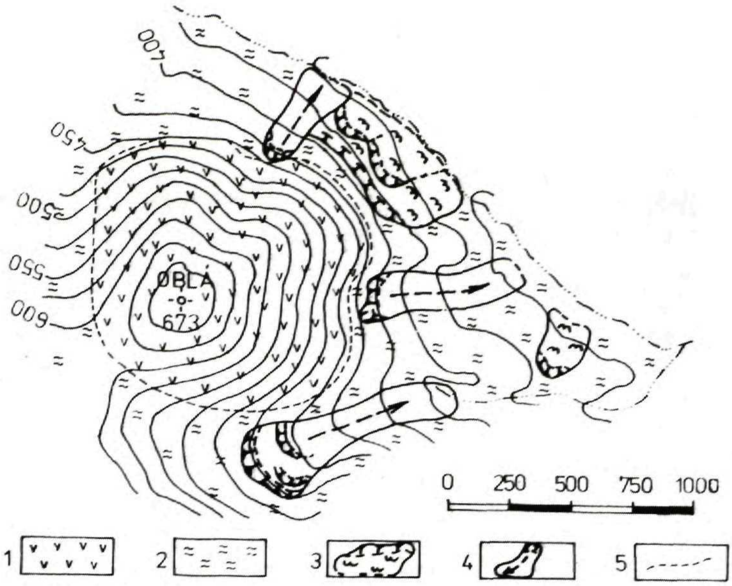

Fig. 7 Landslides around the volcanic body Oblá
1 — andesite-diorite porphyrite, 2 — claystone-sandstone formations (Badenian), 3 — sheet-type potential landslides, 4 — potential flow-type landslides, 5 — geological boundaries

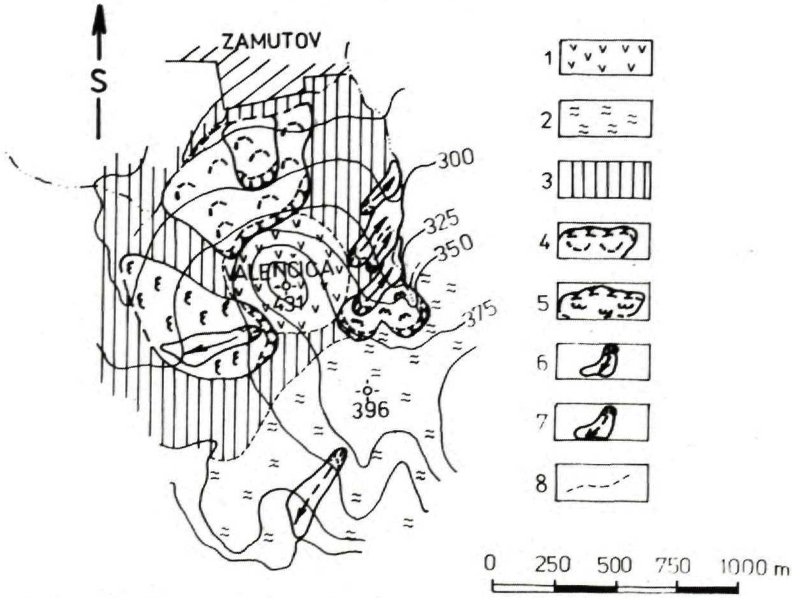

Fig. 8 Landslides around the volcanic body Valenčica
1 — rhyodacite, 2 — epiclastic volcanic breccias, 3 — claystones interbedded by sandstones (Badenian), 4 — areal stabilized landslides, 5 — areal potential landslides, 6 — flow-type active landslides, 7 — flow-type landslides, potential to partly stabilized, 8 — geological boundaries

Although the area is smaller than the above-described ones, the extent of landslides here is the largest. Most landslides spread as far as the rhyodacite body and their divisional planes strongly disturb its margins.

The landslides largely have an areal or flow-like shape and their accumulation portions extend as far as the local base level.

Extent of landslide areas

The extent of the areas disturbed by landslides around the volcanic bodies is shown in Tab. 1.

In addition to the areal extent of landslide slopes, the table also gives the total area (including slopes stretching as far as the local base level or opposite slope), area disturbed by active landslides and area occupied by the individual volcanic bodies.

The table clearly illustrates the extent of slope failures around the volcanic bodies and their share of the total area.

The table also indicates that the relative extent of landslide areas increases, if the area of the volcanic body is subtracted from the whole area. This subtraction can be applied because the volcanic bodies, except for their strongly disturbed margins, may be regarded as stable.

To make the information on the formation and evolution of slope failures around volcanic bodies more complete, we note that similar structures in almost equal geological setting were also formed in the SW volcanic belt with related vast landslide areas in the vicinity of Ruská Nová Ves, Brestov complex and east Rankovce and Herľany. This structure partly caused landslides near Slanec and extensive slope failures at Izra.

Table 1 Areal extent and percentual portion of damaged slopes and volcanic bodies to entire area of surface

Locality	Entire area of surface	Landslides damaged surface		Surface of active landslides		Surface of volcanic bodies	
	km^2	km^2	%	km^2	%	km^2	%
Lysá Stráž	8.432	2.784	33	0.208	2.5	0.516	6.1
Okružná	4.080	0.860	21	0.040	1	1.40	34.3
Oblík	9.90	4.192	42	0.036	1	3.376	34
Oblá	2.988	0.532	18			1.060	35
Valenčica	1.200	0.532	44	0.160	13	0.184	15

Evaluation of conditions under which slope failures form and evolve

The formation and evolution of slope failures are controlled by the natural setting comprising a set of climatic, morphologic, hydrogeologic and geologic factors and conditions.

The geological conditions are of prime importance. The significant role of the geologic and/or geologic-tectonic structure in relation to slope failures was emphasized by Nemčok (1977). The effect of the geological structure on the formation and evolution of slope failures in the region concerned was illustrated on the foregoing pages of this article.

The climatic conditions are characterized mainly by temperature and precipitation.

Seasonal temperature changes in this region significantly influence the weathering process in the volcanics as well as plastic sedimentary and volcanosedimentary rocks. The changes in temperature and related ones in moisture cause major volume changes – swelling and contraction in the uppermost layer of the weathered zone particularly in disturbed formations with a high content of clay fraction. As a result of tensile stresses, mainly in the upper parts of slopes, these volume changes reach to considerable depths.

The amount of precipitation is one of the most significant factors controlling the evolution of slope failures because percolating rain water considerably affects the hydrogeologic groundwater cycle and thereby also slope stability.

Long-term observations of reactivated slope failures confirmed a direct relationship between the evolution of active landslides and the amount of rain- and snowfall. Prolonged measurements in a Hydrometeorologic Institute monitoring station at Zlatá Baňa confirmed a four- to six-year precipitation cycle within which the long-term average was exceeded by 20 to 37 %. Periodic growth in the annual precipitation is well illustrated in the next table.

Year	1960	1966	1970	1974	1980	1985
Precipitation (mm/yr)	981	972	962	1 010	1 009	1 053
% of long-term average	128	127	120	132	131	137

The long-term precipitation average calculated over the period 1951–1986 is 766 mm. In 1985, the long-term average was exceeded by 37 % and consequently a number of dormant landslides in the northern Košice Basin and on the foothills of the Slanské vrchy became active.

The geomorphological setting is characterized mainly by significant differences in relief energy between the volcanic body and adjacent disturbed slopes. Steep slopes of andesite bodies pass into a gentle relief of plastic formations disturbed by landslides. The changing relief energy also affects erosional-denudational and erosional-depositional processes which give rise mainly to thick accumulations of loamy-talus slope sediments piled up at the foot of the volcanic bodies.

The geomorphologic position of the volcanic bodies as conspicuous elevated landforms was partly caused by tectonic uplift of the volcanics and Kapušany–Hubušovce horst in the uppermost Neogene and Quaternary along a system of marginal faults.

The hydrogeological conditions of the structure in question are controlled largely by the amount of rain- and snowfall which are the main sources recharging ground waters. Other factors include the volume of water coming from the effusive complexes, fracturing of the volcanic bodies and the character of permeability of the disturbed formations.

Percolating ground waters mostly enter the deep cycle and eventually discharge onto the surface through springs of variable yield located largely at the contact between thick Quaternary accumulations and plastic formations at the foot of the volcanic bodies which supply water to landslide slopes. These springs frequently form swamps in the divisional portions of landslides. The rain water is likely to partly enter the deep groundwater cycle thus reducing slope stability largely because of its buoyancy.

Conclusion

Owing to their geological position and differentiated tectonic pattern, volcanic complexes of the Slanské vrchy Mts. are extremely favourable for the formation and evolution of slope failures in the mountain range concerned and its periphery. A thorough knowledge of the geologic-tectonic and/or geologic-geomorphologic structures (favourable for slope failures) is an essential precondition to successful activity of any kind on these landslide areas. One of such favourable structures is represented by volcanic bodies cutting older sedimentary and volcanosedimentary formations giving rise to landslides around these bodies.

As shown on the foregoing pages of this article, the intensively disturbed slopes around the volcanic bodies and the presence of active landslides suggest that the region concerned has a high potential for the reactivation of dormant landslides and formation of new ones. This fact should not be overlooked particularly by engineering geologists investigating this region for various purposes.

The landslide hazard also affects farming and forestry in the area in question.

Translated by L. Böhmer

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Zoltán Spišák

Svahové deformácie po obvode vulkanických telies v Slanských vrchoch

Resumé

Územia budované terciérnymi vulkanickými komplexmi, ktoré vznikli v prostredí sedimentárnych súvrství neogénu a paleogénu, sú často porušené rozsiahlymi svahovými deformáciami, ktoré porušujú rigidné časti vulkanických štruktúr a vytvárajú poruchy blokového typu, resp. porušujú plastické súvrstvia sedimentárneho podložia so vznikom rôznych foriem zosuvov. Najväčšia časť týchto deformácií sa viaže na okraje vulkanických komplexov, kde v priebehu geologického vývoja vzniklo niekoľko charakteristických geologicko-tektonických štruktúr, ktoré vytvárajú veľmi priaznivé podmienky pre ich vznik a rozvoj. Jedna z takýchto priaznivých štruktúr vznikla prienikom plytkointruzívnych až extruzívnych vulkanických telies cez staršie sedimentárne súvrstvia neogénu a paleogénu. Prienikom telies došlo k silnému porušeniu a deformácii prerážaných súvrství a stlačením deformovaných súvrství k výraznej zmene napäťového poľa v prospech tlakových napätí.

Sedimentárne súvrstvia z pôvodného subhorizontálneho uloženia boli vztýčené do polohy s úklonom 70—80°. Postupným výzdvihom územia, najmä v období kvartéru a následnou eróziou, dochádzalo k uvoľňovaniu tlakových napätí stlačených súvrství a k vytváraniu ťahových zón po obvode vulkanických telies. Intenzívnymi zvetrávacími procesmi dochádzalo k výraznej zmene fyzikálnomechanických vlastností porušených súvrství a k vzniku rozsiahlych zosuvov.

V severnej časti vulkanického pohoria Slanských vrchov bol takýto typ geologicko-tektonickej štruktúry priaznivej pre rozvoj svahových deformácií zmapovaný v dvoch pásmach. Prvé prebieha na sv. až v. okraji Slanských vrchov od Hubošoviec až k Juskovej Voli s možným jv. pokračovaním, druhé pásmo prebieha v jz. časti pohoria od V. Šariša až ku Kecerovciam a Herľanom. V článku sú podrobnejšie opísané geologické pomery plytkointruzívnych až extruzívnych vulkanických telies a vývoj zosuvov po ich obvode na lokalitách Lysá Stráž, Maglovec, Oblík, Oblá a Valenčica v sv. pásme vulkanických telies. Intenzita porušenia svahov po obvode týchto telies poukazuje na vysoký stupeň náchylnosti týchto území na reaktivizáciu upokojených zosuvov, resp., vznik nových zosuvov.

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Geol. Úst. D. Štúra, Bratislava, 1993

MIKULÁŠ KRIPPEL

Long-term monitoring of selected slope failures in Slovakia

(5 figs., slovak summary)

A b s t r a c t. The article deals with the objectives of long-term slope-failure monitoring on the Slovak territory, describes applied methods and gives a brief characteristics of eight selected localities.

Introduction

Like the Titanic catastrophe, which had very favourable impact on the security of marine transport, the consequences of the disasterous Handlová landslide can now, some decades later, also be highly appreciated. While prior to 1961 geologists paid little attention to landslides, the Handlová disaster triggered extensive research, survey and stabilization of landslides, which required much work and finance. This can well be illustrated by the fact that landslide survey, survey-stabilization and stabilization works in 1970–1980 cost some Kčs 380 million (NEMČOK–ANDOR–FUSSGÄNGER–MALGOT, 1981). Such precautions still cost 4–5 times less than the subsequent landslide stabilization excluding direct and indirect damage caused by activated landslides (NEMČOK–ANDOR–FUSSGÄNGER–MALGOT, 1981). This proves how significant the preventive measures are and that is why our knowledge of slope failures in Slovakia is so thorough.

The research and survey of Slovakia's slope failures is performed on three levels: nation-wide, regional and local. The former includes slope-failure registration whose results are stored at Geofond, Bratislava. This register contains all known landslides, each of them being characterized by its areal limits shown on a 1:25 000 map and a registration card which provides data on the type and activity of the slope failure concerned, damaged and threatened objects, hydrogeological data, information on the geology and geometry of the sliding slope, detailed description of the slope failure and the cause which gave rise to it and – if it was stabilized – the ways of its stabilization. The register is computerized. The third stage of the registration is being concluded right now and so we may say that only a minimum number of slope failures has not yet been registered.

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Slope failures are not evenly distributed on the Slovak territory. Some geographic units are particularly richly endowed with landslides (in some areas they disturb more than 60 % of the total area). In such areas, landslides belong among major adverse factors limiting construction. They frequently extend across the area's borders and therefore such geographic units are investigated on regional scale, which comprises mapping on scales 1:10 000 or 1:5000 and technical works (drilling, geophysical and geodetic measurements and/or special drillhole logging) at characteristic localities and subsequent laboratory tests (soil-mechanic and hydrogeochemical analyses), sometimes even trial stabilization, and therefore the investigations at some of these localities resemble those performed on the local level. In addition to the final report, the investigations also result in three maps – those of engineering geological condition, engineering geological zoning and documentation points Handlová, Liptov and Žiar basins have been illustrated on these three kinds of maps.

The local-level investigations focus on landslides which threaten or damage some objects (roads, railway lines, residential areas, mines etc.). The extent of works performed varies from one place to another but it mostly includes mapping, surface geophysics, core drilling, test pits, laboratory analyses of waters and soils, geodetic measurements and/or also special surface measurements (e. g. measuring residual surface stress) or measurements in specially equipped drillholes (geoacoustics, inclinometric surveys). These works subsequently allow to compile a geologic-morphological map on scale 1:1000 or 1:2000, characteristic engineering-geological sections including stability calculations before and after the implementation of the stabilization works and a summarizing final report. Aside from the stabilization elements, such local-level investigations also comprise equipping most drillholes either for piezometric or special measurements and setting up fields of geodetic points. The local-level survey evidently is a good start for consequent long-term slope-failure monitoring.

Long-term slope-failure monitoring

Any complex long-term slope-failure monitoring must pay attention to all basic types of slope failures. The slope failure registration was carried out in accordance with a slope-failure classification scheme put forward by Nemčok–Pašek–Rybář (1974). This classification divides slope failures into 4 major groups according to their rate of movement and mechanism: creep, sliding, flow and rock-falls. Understandably, flows and rockfalls are too fast to be monitored for a long time and therefore our long-term monitoring focused exclusively on creep and sliding slope failures.

Monitoring of creeping slope failures

As creeping slope failures are very slow (several mm/yr) and mostly occur on high mountains or on inaccessible places (upper parts of slopes), they do not pose a major threat to man (mine shafts in block fields and rifts of the Vtáčnik Mts. are an

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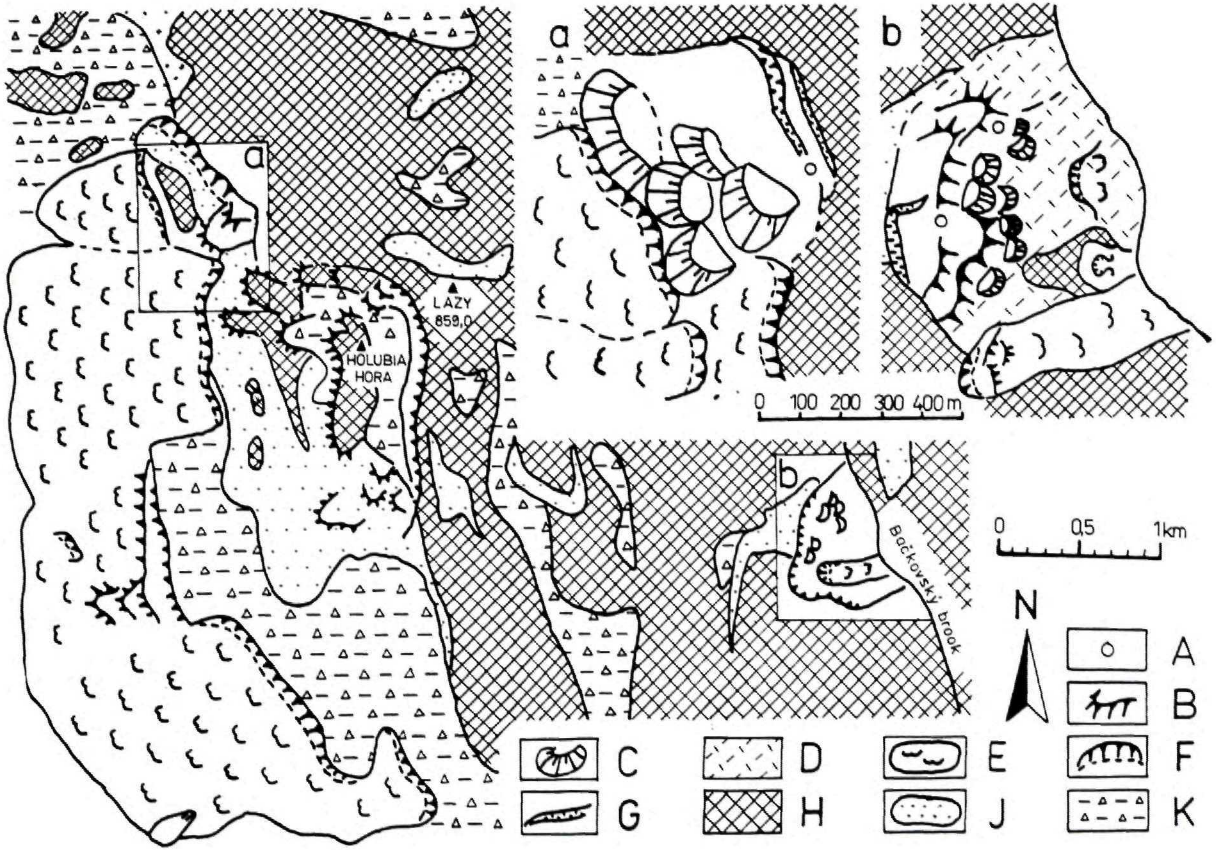

Fig. 1 Monitoring of creeping slope failures: Localities: a — Borda, b — Sokol: A — target gague TM-71, B — block rifts, C — morphologically important blocks, D — block fields, E — landslides, F — main scarps of landslides, G — cracks, H — andesites, J — tuffs, K — deluvial deposits

exception from this rule). The monitoring of such slope failures is therefore aimed to prove that the mountain ranges concerned or their parts are being uplifted. We assume that any, even the slightest vertical movement (uplift) results in changing stress conditions on the slope which in turn will activate slope failures. The economic importance of such monitoring is evident e. g. at Borda where proved uplift may adversely affect the construction of the Kecerovce nuclear power plant. Our objective, of course, is to monitor the dynamics of the slope failure in question. Selected localities are investigated by crack gauge called Target meter TM-71 based on mechanic-optical principle (Košťák, 1979). The gauge is lowered into cracks 0.5 to 3 m wide, its rods being anchored in both blocks adjacent to the crack. The relative movements of the blocks are passed through the rods into the measuring gauge itself which consists of two disks equipped with optical nets. The relative movement of the blocks makes the nets eccentric which in turn gives rise to mechanic interference that allows derive the rate of the movements. The inaccuracy of such measurements does not exceed 0.1 mm/yr (Košťák, 1979). As the gauge contains two disk sets in two planes perpendicular to each other (horizontal and vertical), repeated measurements give information on relative movements of blocks in space.

Aside from the measurement results, geological records from each locality also comprise a schematic section of the slope failure to explain the mechanism of its movement and a geological map of the wider area around the slope failure concerned on scales 1:10 000 or 1:25 000.

Two localities (Borda and Sokol) in the Slánske vrchy Mts. have so far been equipped and monitored in this manner. The locality selection and monitoring in both cases were performed by Z. Spišák.

At the locality Sokol a volcanic zone composed of volcanoclastic material and lava flows is gradually broken down. A failure plane as much as 40 m high is thus formed (Spišák in Kaličiak et al., 1986) and so is a block field with distinct blocks which move downslope on subjacent clays into the Bukovský potok brook. Although the absence of blocky crevices suggests that the most intensive movements have already ceased, the existence of open cracks and measurements in them have shown that this slope failure is still active.

The locality Borda similarly consists of a complex of andesite breccias and lava flows which, however, does not rest on clays but on epiclastic rocks. The andesite complex was broken to blocks which partly sank into the plastic epiclastics, but the slope failure morphology is less obvious (fissures up to 1 m thick, local rockfalls, but no block fields). Our measurements at both localities revealed movements in the opposite directions (the localities are situated on the opposite slopes of the ridge and are only slightly more than 3 km apart; Fig. 1), which proves the uplift of the area concerned (south of Strechov stratovolcano).

Monitoring of sliding slope failures

Unlike the creeping slope failures, the sliding ones increasingly threaten man-made structures. That is why a monitoring grid was built in the landslide body. In this case, local aspects of long-term monitoring are equally significant as the regional ones, but their objectives, methods and criteria to select localities for long-term monitoring are different.

The objectives of long-term monitoring of selected landslides may be summarized as follows:

1. Monitoring of changes (e. g. changes in the effectiveness of dewatering elements in time, changes in surface morphology reflecting landslide activization or further evolution) and relationships (e. g. changing positions of geodetic points with respect to rainfall or pore pressure).

2. Prognosing further development of the landslide and verification of the prognosing in practice. Provided that the measurement density is sufficient (currently is not), critical warning levels may be defined and subsequently verified.

3. Informing the owner of the endangered structure about major changes related to the landslide (silting of a drainage element, formation of new cracks, faster movements of geodetic points etc.) and about their consequences and/or proposal of a remedial action.

4. Regional generalization of the knowledge and its application in territories of the same geological structure.

To achieve the above objectives, the following methods will be employed:

1. Mapping
2. Measuring movements of selected surface points
3. Measuring subsurface movements
4. Regime monitoring
5. Regular water sampling and hydrochemical analyses
6. Repeated measurements along selected profiles.

An example of monitored landslide is represented on Fig. 2.

Mapping

The mapping includes geological mapping of wider area around the landslide on scale 1:25 000 aimed at providing information on the geological setting in the landslide's vicinity and repeated geologic-morphological mapping of the landslide itself on scales 1:1000 and 1:2000. The objective of the geologic-morphological mapping is to provide basic data for subsequent works (characteristic sections, proposing location of follow-up works) and to register changes in the surface morphology relative to the initial state and possibly to explain them on the basis of other observations and measurements (e. g. to explain the formation of partial landslides due to extreme precipitation, silting of drainage system, changes in the distribution of surface stresses etc.). The initial state is the state of the slope failure on the date of the first mapping. If the landslides selected for long-term monitoring were investigated on the local level (Handlová, Harvelka, Ľubietová, Okoličné, Oravský Podzámok), then maps compiled during the earlier investigations serve us as the initial data. The repeated geologic-

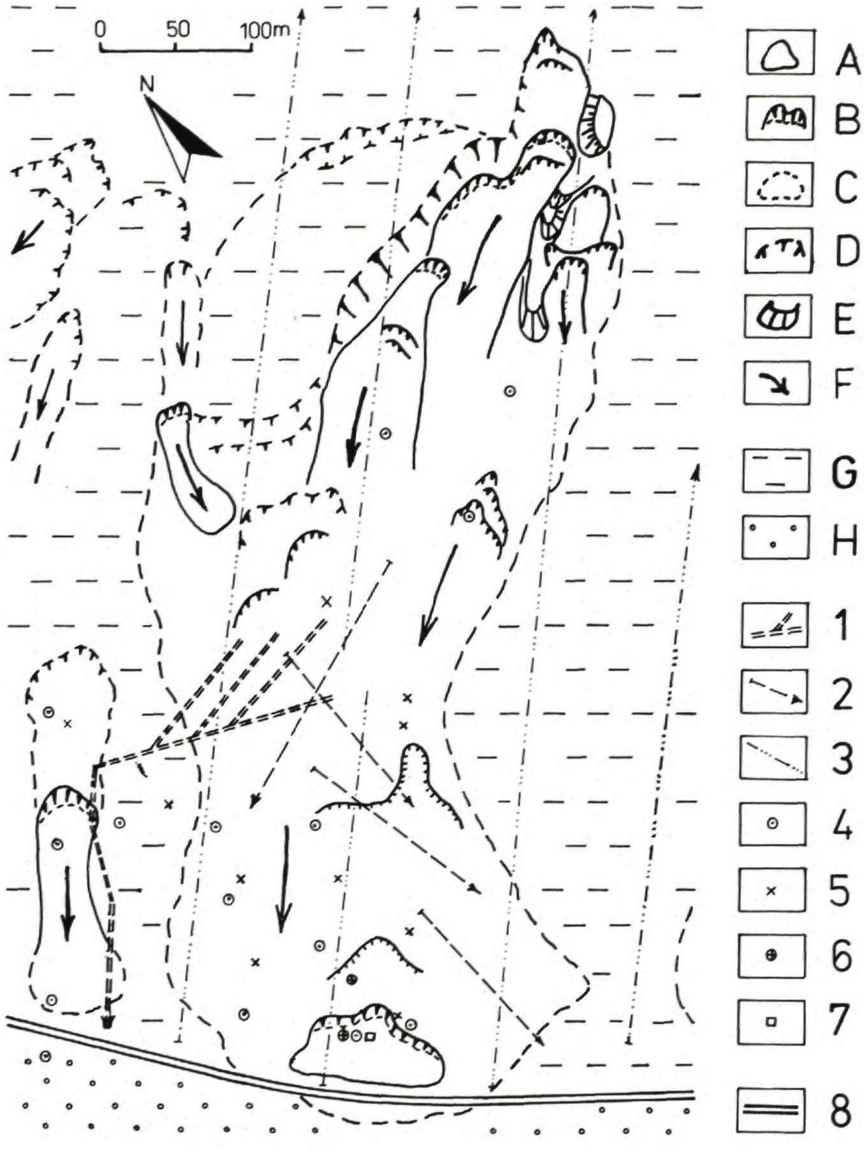

Fig. 2 An example of landslide monitoring — locality Okoličné (adapted according FUSSGÄNGER et al., 1976):
A — active parts of landslide, B — main scarps of landslide active parts, C — potential parts of landslide, D — main scarps of landslide potential parts, E — morphologically important blocks, F — direction of feed, G — deluvial deposits on Flysch substratum, H — Váh river terrace, 1 — subsurface drainage, 2 — subdrainage borings, 3 — regularly remeasured geophysical profiles, 4 — points of geodetical net, 5 — piezometres, 6 — inclinometric drill holes, 7 — pore pressure gauge, 8 — railway line (Bohumín) — Žilina—Košice

morphological mapping mostly will not cover the whole area. Its objective is to record local changes in the landslide morphology.

Measuring movements of selected surface points

The measurements of surface movements include two techniques-geodetic methods and measurements along a line of complex geodetic points. The former are used to quantify the changes in the location of selected points on the surface of the monitored slope failure. This allows to derive changes in the movement dynamics which are the best indicator of changing landslide activity in the observed point. If their frequency is sufficient (at least twice a year), such measurements can be used to establish critical warning levels. The geodetic methods require the existence of a geodetic point field. All localities selected for prolonged monitoring are currently equipped with a geodetic point field, except for Fintice where it is under construction. The geodetic point field in each locality consists of fixed points used to derive the movement of monitored points evenly distributed on the landslide surface. The movements of the monitored points are measured by various techniques, the selection of which depends on the geodetic net character. The calculated mean errors of location changes seldom exceed 15 mm and those of vertical changes 10 mm. The movement of each point is verified by testing. Basic data on the geodetic point fields and geodetic surveys on landslides selected for long-term monitoring are given in Tab. 1.

Table 1 Basic data on geodetic point fields and geodetic surveys at monitored localities (as on October 31, 1991)

Locality	Landslide area (km^2)	Number of points		Date of initial measurements	Number of further survey stages
		Fixed	Moni-tored		
Handlová	1.5	9	51	May 1969	6 to 12
Harvelka	0.35	6	31	October 1972	12
Hlohovec	9.5	6	31	July 1979	8
Klieštiná	0.11	4	19	August 1989	6
Ľubietová	0.32	5	25	November 1987	4
Okoličné	0,16	2	21	December 1971	12
Oravský Podzámok	0.065	2	26	December 1971	14

Measurements along a line of complex geodetic points are much easier (but also less accurate) than geodetic surveys. In this case, monitored objects are complex geodetic points, i. e. special stakes. The distance between individual stakes is measured by an extensiometric band with the accuracy of tenths of mm. Unlike geodetic surveys, we do not measure absolute movements but only movements of individual stakes relative to other stakes. The monitored points are situated along downslope lines (the points presumably move along these lines) and the distance between two adjacent points cannot exceed 20 m (length of extensiometric band) and thus the repeated measurements provide us with a clear picture of the movement dynamics along the monitored line, which is the objective of the investigations. If such a line is situated on a characteristic profile, along which most other measurements will be made, it will reveal the relationship between the movement of the landslide (or its parts) and its causes.

Measuring subsurface movements

Subsurface movements can be measured in three ways: inclinometric, geoacoustic or extensiometric drillhole logging. These surveys are aimed at assessing changes in the activity (geoacoustics) and the rate of movement of subsurface parts of landslides (inclinometry, rope extensiometry).

The inclinometric surveys are based on measuring deformations of a plastic tube due to lateral movements in soil. The tube deformations are monitored by means of an inclinometric probe capable of registering the casing's dip at predetermined depth intervals (largely 1 m). The measurements can be made in two mutually perpendicular directions (in practice, however, the measurements are made only in the direction of assumed movement), the measuring direction being set by grooves inside the tube. Dips in individual depth intervale reflect the course of casing, and thus the repeated measurements made it possible to derive the movements in individual levels of the slope failure and thereby also to determine the depth of failure plane.

The geoacoustic method measures elastic waves of extremely low amplitude caused by ongoing microfracturing of the rock massif. In geoacoustic drillholes, such waves are caused by a brittle clay-cement grouting between the rock and casing in bent or compressed intervals. The casing is filled with water which passes the impulses onto geophones. Geoacoustic impulses per a time unit and their relative amplitude, i. e. sum total of impulse amplitudes per time unit, are measured. An example of the survey evaluation is illustrated in Fig. 3.

The inclinometric and geoacoustic surveys can be performed in a single drillhole which, however, must meet the following requirements: the casing must be impermeable (for geoacoustic reasons), grooved, with the grooves open throughout the casing length and must bottom at least 6 m below the lowermost failure surface (for inclinometric reasons). Such a geoacoustic-inclinometric drillhole is schematically illustrated in Fig. 4.

Unlike the two foregoing methods, the evaluation of rope-extensiometer readings is very simple: the movement of an anchor drifting amidst the sliding earth is passed through a rope to a reading device which directly shows the movement in a given place. Devices manufactured in Czech republic allow to make measurements in 6 levels at a time. The method is handicapped by the fact that the measurement levels must be determined in advance. On the other hand, this technique makes it possible to take readings in very short time periods.

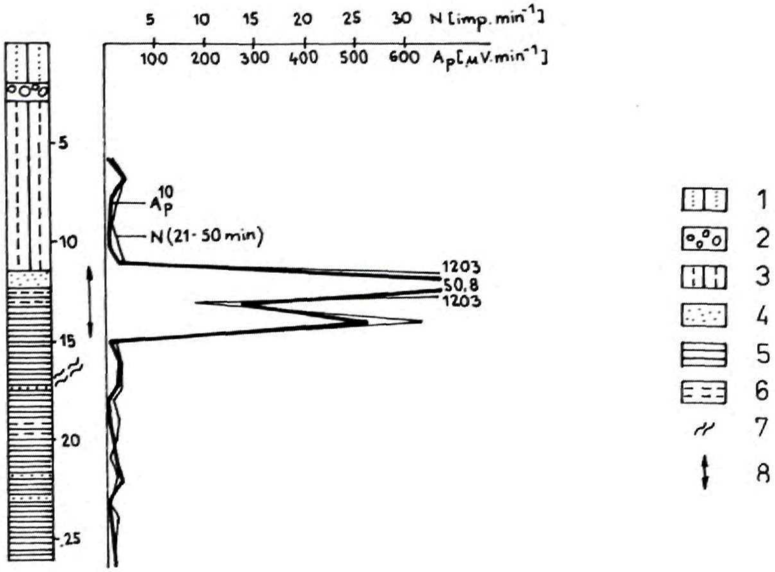

Fig. 3 Geoacoustic borehole evaluation — borehole J 25 A, locality Harvelka (NEŠVARA—BLÁHA, 1985: 1 — clay, 2 — sandstone boulders, 3 — clay loam, 4 — sandstone, 5 — mudstone, 6 — weathered mudstone, 7 — failure surface according the drill core, 8 — failure surface according geoacoustics

Regime monitoring

The regime monitoring entails monitoring groundwater level in piezometric drillholes and the yield as well as temperature of water flowing from nearly horizontal dewatering drillholes. From a professional viewpoint, the measurements of groundwater level should reveal its relationship to landslide activity expressed by the movement rate of surface or subsurface monitored points. A practical result of such research is defining the critical groundwater level. Such critical warning levels, when exceeded, require various measures ranging from increased frequency of readings to immediate stabilization works. Another objective in the groundwater level monitoring in a landslide is to verify the effectiveness of stabilization elements. The local-level investigations mostly end as soon as dewatering reduced groundwater level to an acceptable depth. The dewatering elements, however, gradually become silted or otherwise damaged, which results in increased groundwater level.

At present, all monitored landslides except for Klieština are equipped with piezometric to indicate groundwater levels. Nevertheless, we have so far failed to perform the regime monitoring regularly. Our surveys 2 to 6 times a year are only of an orientative character and are insufficient to make conclusions on the relationships or to determine critical warning levels. The observations should be made regularly

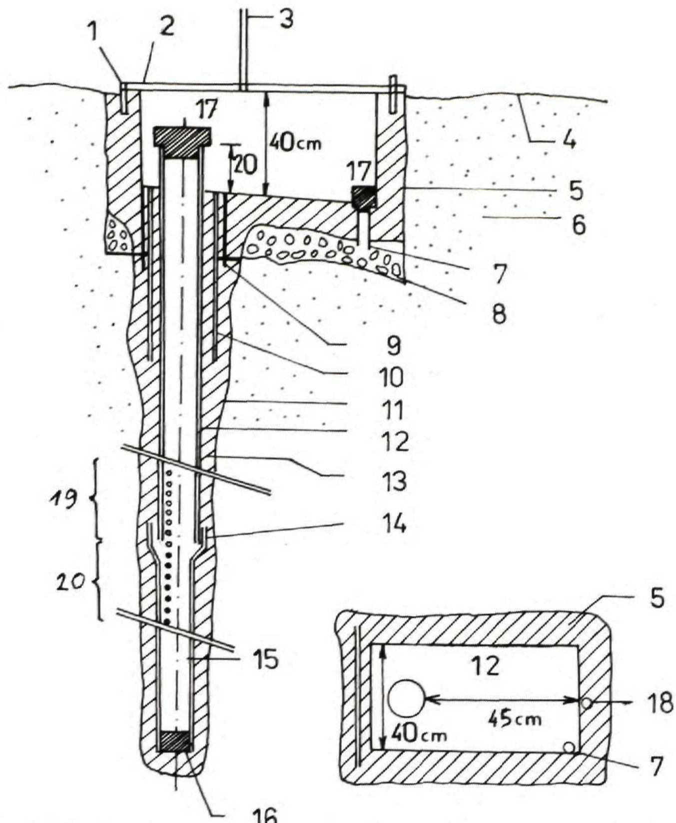

Fig. 4 The geoacoustic-inclinometric drillhole equipment: 1 — hinge, 2 — hinged lid, 3 — dismantleable signal rod, 4 — terrain surface, 5 — concrete, 6 — terrain, 7 — discharge hole, 8 — gravel layer, 9 — water proofing, 10 — iron casing pipe, 11 — drill hole surface, 12 — plastic casing pipe — minimum inner average is 50 mm, 13 — cement or clay-cement grout, 14 — water-proof casing joint, 15 — pure water, 16 — water-proof borehole sealing, 17 — plug, 18 — closure, 19 — measure series number i, 20 — measure series number i+1

(preferably 1 to 2 times a week) by a local operator or automatically, which is the most urgent task. In addition to measuring groundwater levels, it is also highly desirable to measure pore pressure. This technique, however, is so far only seldom used to investigate Slovakia's landslides.

Regular water sampling and hydrochemical analyses

Hydrochemical analyses of selected samples are aimed to confirm changes in the groundwater regime. The samples for the hydrochemical analyses are collected from nearly horizontal drillholes at four localities (Handlová, Harvalka, Okoličné and Oravský Podzámok) largely twice a year.

Repeated surveys on selected profiles

The objective of the repeated measurements on selected profiles is to obtain a great number of readings made as frequently as possible. Understandably, because of limited capacities and finance, it is impossible to cover the whole landslide surface with measurements of desirable density. The concentration of the measurements on a selected profile is therefore a compromise between the research needs and realistic possibilities, and so the above described surveys will be made on selected profiles. The profile should contain one or two points of the geodetic point field and piezometers. The other elements should also be concentrated on this profile. This applies to drillholes equipped for monitoring subsurface movements or to a line of complex geodetic points which should essentially be identical with the profile. Furthermore, repeated geophysical surveys (resistivity profiling and pulsed electromagnetic emission method) and measurements of horizontal surface stress should be made on the profile. The fundamental precondition to these surveys is to remove earth from the centre of the measuring cross. A hole 20 cm across and 30–40 cm deep is thus formed. The hole is being filled with earth at pressure stress and widened at tensile stress. A comparison between the measurements on the profile and those on an undisturbed slope at an equal distance from the hilltop or ridgetop will provide us with a good review of pressure and tensile zones on the profile.

The prolonged monitoring of selected landslides will result in a set of information on each landslide. If we manage to realize all the planned works at each locality, the information set will comprise:

1. A geologic-morphologic map on scale 1:1000 or 1:2000 along with maps showing changes in the landslide morphology over time on the same scale. This model will show the morphologic evolution of the investigated slope failure over time.

2. A characteristic section of the slope failure expressing the mechanism of the landslide movement and describing its geologic structure and geometry, which can serve us as a basis for stability calculation.

3. Stability calculations on a characteristic profile and stability calculations with respect to changes taking place in the landslide (e. g. changing landslide activity or groundwater level).

4. Databases: a database of physical-mechanical properties, a database of readings on geodetic point fields, a database of groundwater level readings, a database of yield of dewatering elements, a precipitation database and a database of landslide information which contains all data on landslides stored at Geofond, Bratislava (at the moment 413 reports, 3 to 150 pages each plus graphic enclosures). All the databases use programme DBASE IV. In all but one (latest) database, each locality makes up a separate set.

5. Final reports assessing observations and readings made during a certain period of time.

Locality selection

Understandably, our selection of localities for long-term monitoring was based primarily on a regional criterion – abundance of slope failures in a given area. The map in Fig. 5 shows Slovakia's principal engineering-geological division (MATULA–PAŠEK, 1986) into taxonomic units of the 1st and 2nd order – regions and areas. In addition, Tab. 2 characterizes the slope-failure distribution. Obviously, slope failures are unevenly distributed in the Slovak territory. In volcanic mountains and flysch hilly countries, slope failures disturb more than 10 % of the whole area and that is why the majority of landslides selected for prolonged monitoring is situated in these terraines. Localities Fintice, Handlová, and Ľubietová are located in volcanic mountains, while Harvelka, Klieštiná, Okoličné and Oravský Podzámok lie in flysch hills. Slope failures are fairly abundant in high core mountains as well. However, the slope failures here are mostly represented by creep, the survey of which requires different techniques. Situated in an area where landslides occur only exceptionally, the last locality – Hlohovec consists of an 18 km long belt between Hlohovec and Sereď which, aside from tectonic activity, is also affected by erosion of the Váh river and therefore the whole area some 1.95 km^2 large is covered with slope failures of different activity.

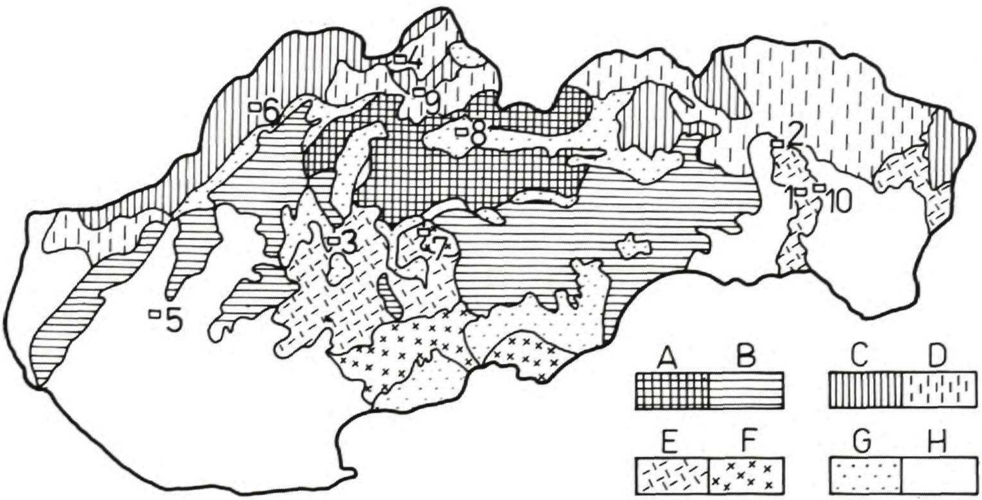

Fig. 5 The ingeneering-geological regions and areas map of Slovakia (MATULA—PAŠEK, 1986) with indicated monitored localities:
Region of core mountains: A — area of high core mountains, B — area of core highlands. Region of Carpathian Flysch: C — area of Flysch highlands, D — area of Flysch uplands. Region of Neogene volcanics: E — area of volcanic highlands, F — area of volcanic uplands. Region of neogene tectonic depressions: G — area of intra-mountain depressions, H — area of intra-Carpathian lowlands. Localities: 1 — Borda, 2 — Fintice, 3 — Handlová, 4 — Harvelka, 5 — Hlohovec, 6 — Klieštiná, 7 — Ľubietová, 8 — Okoličné, 9 — Oravský Podzámok, 10 — Sokol

Table 2 Distribution of slope failures in individual regions of the Slovak Republic (NEMČOK, 1982)

1st order taxonomic units	2nd order taxonomic units	Number of failures	Area of failures (km^2)	Share of failures on the whole area (%)
Region of core mountains	- Area of high core mountains	691	160.6	5.7
	- Area of core highlands	40	30.0	0.36
Region of Carpathian Flysch	- Area of Flysch uplands	147	51.4	1.17
	- Area of Flysch highlands	4392	774.0	11.6
Region of Neogene volcanics	- Area of volcanic uplands	2500	366.9	12.0
	- Area of volcanic highlands	75	42.0	1.6
Region of Neogene tectonic depressions	- Area of intra-mountain basins	1265	80.7	0.86
	- Area of intra-Carpathian lowlands	51	5.0	0.036

Table 3 Characteristics of selected landslides

Locality	Landslide area (km^2)	Landslide length (m)	Width +			Difference in elevations (m)	Average slope (°)
			Accumulation area (m)	Transport area (m)	Source area (m)		
Fintice	0.85	2450	340	180	340	265	6
Handlová	1.5	2250	800	100	250	350	9
Harvelka	0.35 ++						
Hlohovec	1.95 ++						
Klieština	0.11	600	60	35	85	100	9
Ľubietová	0.32	1200	80		400	170	8
Okoličné	0.16	750	240	170	260	230	17
Oravský Podzámok	0.065	540	150	80	220	154	16

+ For flow slides only

++ Area of landslide territories

Table 4 Review of installed monitoring and stabilization objects

Type of object	Fintice	Handlová	Harvelka	Hlohovec	Klieština	Ľubietová	Okoličné	Oravský Podzámok
Number of installed piezometers	5	34	64	36	0	11	36	40
Number of functioning piezometers	5	23	35			6	27	8
Year of installation	1990	1972, 1979 1992	1977	1982		1977	1975	1982
Number of points in geodetic point field	0	60	37	37	23	30	23	28
Other functioning survey objects	5 geo-acoustic-in-clino-metric drillholes	5 inclino-metric drillholes 4 geoacous-tic inclino-metric drillholes					2 inclino-metric drillholes 2 pore-pressure gauges	
Number of subdrainage borings	0	29	29	19	0	11	9	10
Length of subsurface drain-age (m)			120				260	
Length of surface drainage ditches (m)		16 390+	1540			4200+	440	495

Estimated from a map

Further criteria to select the localities comprise the amount of data available on them, hazards related to them and their activity. As regards the former criterion, localities investigated on the local level were selected (Harvelka, Hlohovec, Ľubietová, Okoličné, Oravský Podzámok). As far as the amount of drilling and stabilization works is concerned, Handlová landslide could also be assigned into this group, but the works performed at this locality are incomplete. The landslides at the above localities are of economic importance because they threaten or damage major roads (Handlová, Oravský Podzámok), railway (Okoličné) or a planned water reservoir (Hlohovec). The extensive investigations at Harvelka were performed because a road here was threatened. However, a bypass was later built because of the construction of the Nová Bystrica reservoir, a future source of potable water. Today, the landslide complex should be monitored due to landslides disturbing the banks of the reservoir which have identical geological structure. Like Handlová, an earthflow at Ľubietová was once proclaimed a natural disaster. When the brook Hatná was covered, the danger to the village of Ľubietová diminished. Nowadays, it is interesting to study the effects of the recultivation on slope stability. The locality Fintice was selected for long-term monitoring because a road and gas pipeline are damaged here. At that time no landslide in the Eastern Slovakian Neovolcanics was investigated on a local level although the territory is one of the worst affected regions in Slovakia. An earthflow at Kliežtiná was neither investigated nor had economic impacts. It was chosen for the long-term monitoring thanks to its activity. Our monitoring started soon after the bulk of the landslide had broken loose. Brief characteristics of the geological setting at the investigated localities and the state of their equipment are described below and in Tab. 3 and 4.

Fintice

In the Sarmatian, Karpatian claystones were cut by andesite extrusions (hills Stráň, Maliniak). During the Pleistocene glacial ages, the domal andesite bodies weathered intensively and loamy-stony talus several metres thick piled up around them. These talus accumulations along with the parent domes form a large infiltration area supplying springs on the talus periphery which add water into the surrounding fractured claystones. Aside from the uplift of its upper tract as well as presence of fractured claystones and water, the flow slide was also triggered by blasting in nearby quarries.

The flow slide itself consists of two parts. The upper one is dominated by sliding blocks of loamy-stony talus, while the lower one (which damaged a gas pipeline and a road) is composed of clays.

Handlová

The flow slide here is developed in a Middle Sarmatian formation of the "hanging-wall clay" overlain by a detrital volcanic formation present in the upper portion of the landslide. Andesites and agglomeratic tuffs which form the uppermost parts of the slope are tectonically dissected and individual blocks sink into the unconsolidated sediments of both formations and slide downslope. These slides at a maximum rate of mm per year are powered by tectonic uplift-sinking movements which persisted from the end of the Sarmatian till the present day. Block rifts and block fields are formed in this manner. Clays in valleys between transversal ridges disrupted by the block movements slide. Flow slides are thus formed whose starting scars sometimes extend into the upper third of the slopes. A major activation agent is water infiltrating into highly fractured andesite block rifts and block fields which thus recharges the adjacent upper portions of the landslide. Poor maintenance of dewatering elements and extremely high precipitation resulted in the reactivation of one of such flow slides. The disasterous Handlová landslide now monitored by us was thus formed.

Ľubietová

The structure of this flow slide is affected primarily by the pre-Mesozoic Ľubietová zone running in the valley of brook Hutná. Germanotype tectonics, parallel as well as perpendicular to this zone, is responsible for the fact that the area no more than 0.32 km^2 in size is composed of Mesozoic rocks (Lower Triassic quartzites below the front), Paleogene flyschoid filling of the Ľubietová depression (claystones, siltstones, marlstones underlying nearly the whole landslide) and a Neogene volcano-sedimentary complex present in the immediate vicinity of the landslide. Its oldest member (clays, tuffaceous deposits, sands) underlier and surrounds the starting scar and landslide track. A volcanic complex (agglomeratic tuffs, tuffaceous sediments) forms mighty blocks and block fields fringing the landslide from above and from both sides. Polymictic gravels in the uppermost parts of the slope recharge the whole landslide with water. Like in Handlová, alo here three factors gave rise to the landslide: tectonic activity, sliding blocks disrupting the underlying plastic deposits, and water. Owing to the presence of huge andesite blocks in its neighbourhood, the flow slide has a noteworthy morphology: material from three large landslide scars concentrates to form a single flow.

Harvelka

The slope failures here are underlain by the Magura flysch Bystrica unit sediments, namely the Zlín Member (Middle to Upper Eocene). The member is dominated by claystones prevailing over sandstones, and therefore physical-mechanical properties of its deluvia are favourable for the formation of landslides. Nevertheless, the most significant phenomenon which decisively contributed to the formation of slope failures here is tectonics: starting scars are mostly identical with tectonic lines.

The landslide area consists of several slope failures of different types ranging from sliding earth blocks to flow slides. Geodetic surveys suggest that none of these flow slides is stabilized. Although the whole locality will be monitored, the majority of our long-term surveys will focus on a single characteristic profile of one flow slide so that the surveys are as thorough as possible.

Klieštiná

The earth flow lies on the contact between the Klippen Belt (Kysuca succession) and Magura Paleogene (Biele Karpaty unit). Obviously, tectonics plays a significant role in the flow activation. The Kysuca succession is composed of variegated marlstones and claystones of Lower Campanian age which underlie the flow accumulations. The starting scar and sliding portion of the landslide rest on Eocene formations of the

Magura Paleogene characterized by alternating sandstones and marlstones. Water infiltrating into the sandstones is intercepted by impermeable Kysuca succession marlstones and recharges in the place of landslide scar. As a result, water is another key destabilizing agent aside from tectonics.

Okoličné

The flow slide rests on a clay formation of the Central Carpathian Paleogene (Zakopané Member) composed largely of fine-sandy clays. Highly tectonically fractured sandstone intercalations amidst impermeable clays act as aquifers facilitating deep water circulation in the landslide concerned. They are recharged through the sandstone Chocholowa Member in the highest parts of the slope. The aquifers are confined and locally their groundwater level is markedly positive. Aside from the groundwater buoyancy and tectonics, the slope stability is also adversely affected by a railway cut in the landslide front which activated the landslide in 1949. Another destabilizing factor is the clogged subsurface drainage system. On the other hand, loamy gravel of one of the Váh river low terraces acts as a stabilizing factor because it drains the landslide front. The active tracts of this flow slide include its starting scar and a sheet slide immediately above the railway line.

Oravský Podzámok

The flow slide and its neighbourhood are assigned into the Inner Klippen Belt. The territory is composed of rocks of the Magura Flysch Orava-Magura unit: Posidonia Member (marly shales below the accumulation), a Tithonian–Neocomian formation in the Kysuca-series development (marly limestones, cherts, shales below the central tract of the landslide), a flyschoid formation of Albian-Cenomanian age (marlstones interclayered with limestones and sandstones underlying the upper portion of the slide) and finally the Paleogene (variegated claystones to marlstones in which is the landslide scar). Alluvial gravels below the landslide front naturally drain the lower part of the slope. The downslope movements of the landslide deluvia on their clayey-marly substratum were caused mainly by tectonic movements and Orava River lateral erosion, which is suggested by the fact that the landslide front is currently active whereas the movements slow down with increasing distance from the river.

Hlohovec

Alternating highly plastic impermeable clays and fine-grained water-bearing sands in the Pliocene beds of the Nitra Upland form a structure favourable for slope-failure occurrences. On its western side, the structure is continuously undercut by lateral erosion of the Váh river. This gave rise to an 18-km-long belt between Hlohovec and Sereď continuously covered with slope failures of different types (from block movements, through slides to earthfalls into the river) and different activity (active to stabilized), some parts of which are currently being reactivated. An important role in the formation of the slope failures is also played by precipitation which recharges permeable sandstone beds. The groundwater reduces slope stability by its weight, buoyancy (in the structure there are 2 to 3 horizons of confined groundwater positioned one above another), flow pressure (washing out and removing fine sand), destructing structures (dissolving calcareous cement) and changing state of clays (OTEPKA et al., 1983). Of the whole stretch, only a part betweeen Hlohovec and the village of Posádka was selected for prolonged monitoring because it may cause problems by the construction of a planned water reservoir.

Conclusion

Only landslides previously investigated on the local level were selected for our long-term monitoring. The expenditures were thus considerably reduced, but still financing of the project remains a key problem. Of the total amount of planned works, we have so far realized mapping, equipped most localities with geodetic point fields and with a set of piezometers for monitoring groundwater levels in the landslides. We still have to choose some creep slope failures for long-term monitoring and equip them with target gauges, to set up lines of complex geodetic points on selected landslides, to drill and equip holes for monitoring subsurface movements at most localities and possibly replace damaged piezometers. But most importantly, we must make the measurements regularly. Our employees are only able to carry out the works at creep slope failures, repeated mapping and regime observations (but not of ideal frequency), surveys on a line of complex geodetic points and hydrochemical analyses. The other works will have to be done by a contractor, and steady financing will therefore be needed over a period of several decades. It is the only way to do the survey continuously. As slope failures are widespread in the Slovak territory, we think that such spendings are fully justified. If we manage to realize all the proposed works, they will provide us with valuable information on the relationships between precipitation, surface stress, pore pressure and movement dynamics of slope failures, and furthermore slope stability above significant man-made objects will thus be guaranteed.

Translated by M. Böhmer

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MIKULÁŠ KRIPPEL

Dlhodobé sledovanie vybraných svahových deformácií na Slovensku

Resumé

Autor článku sa zaoberá dlhodobým sledovaním svahových deformácií na území Slovenska, kde svahové deformácie sú najrozšírenejším a najnebezpečnejším geodynamickým javom. Dlhodobé sledovanie sa zameriava na deformácie zo skupiny plazenia a deformácie zo skupiny zosúvania. Cieľom dlhodobého sledovania svahových deformácií zo skupiny plazenia je jednak sledovať pohyb konkrétnej deformácie, jednak preukázať vertikálne pohyby vybraných oblastí. Meranie sa vykonáva na puklinách dilatometrom, ktorý pracuje na optickom princípe.

Cieľom dlhodobého sledovania zosuvov je sledovanie závislostí medzi rôznymi meranými veličinami a následná prognóza správania sa zosuvu a jej zovšeobecnenie na celú oblasť. Metódami dlhodobého sledovania sú opakované mapovacie práce, meranie pohybu bodov na povrchu (geodetické merania a merania na línii komplexných geodetických bodov), merania podpovrchových pohybov (presná inklinometria, geoakustika, extenzometrické merania), režimové pozorovania a pravidelné odbery vôd a ich hydrogeochemické analýzy. Výsledkom meraní sú súbory a banky nameraných údajov zhodnotené v záverečných správach.

Západné Karpaty, sér. hydrogeológia a inž. geol. 11, p. 43—58,
Geol. Úst. D. Štúra, Bratislava, 1993

Mária Fischerová–Igor Modlitba

Slope deformation occurrences in Žilinská kotlina basin and their use

(12 figs., slovak summary)

A b s t r a c t. Comparison of number of occurrence of slope deformations in Žilinská kotlina basin with other basins of Slovakia places this territory among those with higher frequency of occurrence. 201 places devastated by slope deformation of different type are shown in (Fig. 1). Devastated area covers approximately 40 km^2, or 9.4 % of entire area of basin (Tab. 1). Devastated areas had been used as meadows, pastures, forests and as fields (Tab. 2). Habilitation of mentioned areas is rather difficult and requires professional interest of agriculturalists and engineering geologists. Rehabilitation consists mainly of draining ground and underground water and application of special soil cultivation technology and of growing of plants with high transpiration ability. On some occasions, an original use of devastated area will be hate to be changed, into recreation purpose, for example.

Introduction

Renewal of slope deformation causes negative impact on environment (disruption ecological balance, deterioration of aesthetic level and decrease of land value), and limits its original use as land for farming, building, lumbering or recreation.

As a result of compiling of slope deformation sites, performed by geologists of Dionýz Štúr Institute of Geology, Bratislava within the territory of Slovakia during the period from 1982 to 1990, there have been listed over 13,000 localities of different size effected by slope deformation. The destroyed area is bigger than 4 % of entire area of Slovakia. It is nothing extraordinary when somewhere (basins, valleys and uplands built by flysh) devastated land covers 30–50 % of entire area. For this reason slope deformations and associated phenomena are significant fraction of our country. A land use of devastated area will decide whether slope deformations become negative phenomena or, after man's purposeful activity, (draining, recultivation, exploitation) a positive phenomena. We should not allow to turn devastated land into fallow and be satisfied with idea, that these areas will be used only as less useful land. We should consider it as undifferentiated part of an entity with specific characteristics and conditions of its use. Unfortunately, in reality, it has been turned into less valuable land. The reason is not only in development of natural hazards themselves but in

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man's disinterest to solve this problem, in his amateurish attempts at solving and in his unwillingness to subordinate to nature. Specifically to accept given natural conditions of country. The nature can easily punish cruelly man's indifference to hazards by magnifying originally solvable hazards of catastrophic dimensions.

The effort to change a devastated area into a positive element of the land has two aspects:

The first one can be called "aesthetic". It involves solving problems associated with efforts to return environmentally damaged area into original state. Its results are the attainment of acceptable aesthetic value and ecological balance of the land.

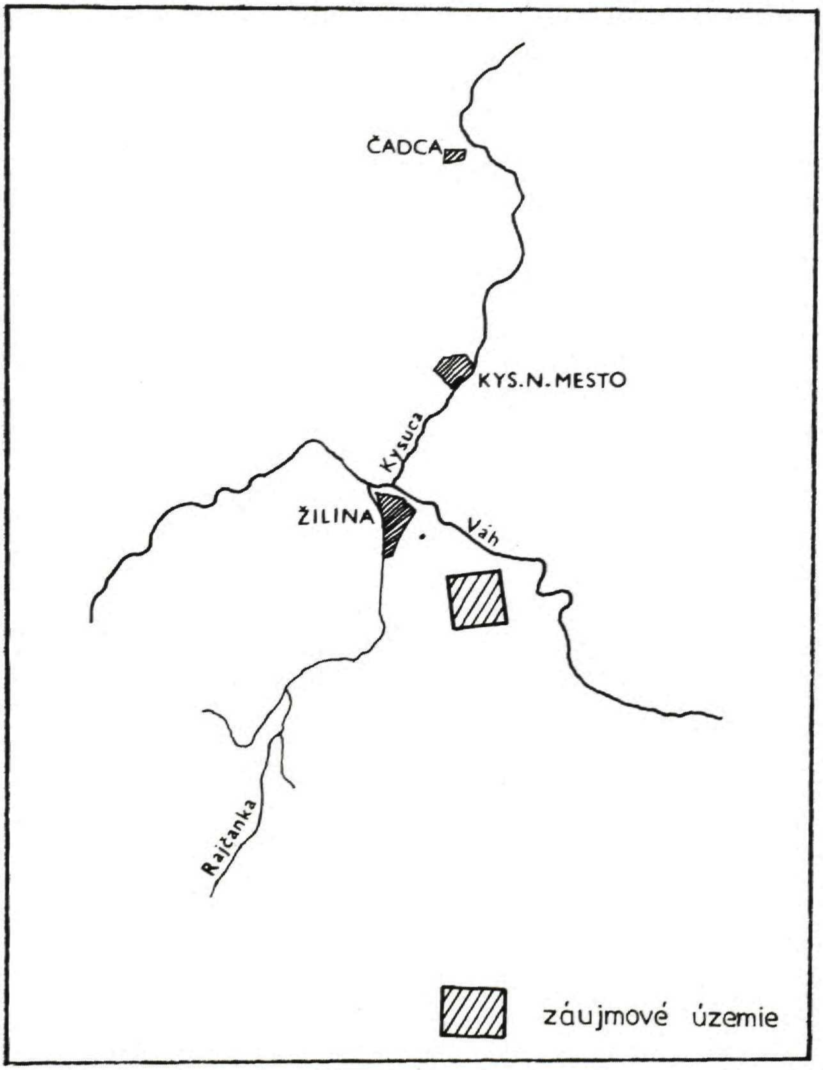

Fig. 1 Location map of investigated territory

The second one can be named "economical". It attempts to solve a range of problems aimed towards returning the land to economical use. The result is renovation of geological environmental and attainment of possible economic use.

The goal of this article is to suggest, through analysis of selected issues, the necessity of efficient solution of the problem in part Žilinská kotlina basin, and using it as a model area. Size of model area is 20 km^2 and it includes central and northern part of basin.

Conditions of slope deformations arising

Geological structures of slope deformation

Kapasný (1983) has specified six geological structures which create suitable conditions for landslides in Žilinská kotlina basin.

As *type A* he has selected complex of horizontal beds position (Fig. 2) in which beds of different thickness, grain size, strength and permeability alternate. They are most often composed from alternating of Quaternary gravel, soils, clays, sand and their variations. Existence of water-bearing layers is relevant to sliding as well. Water can saturates soils (mainly cohesive soils), and significantly decrease their strength, and through hydraulic pressure, it can play a decisive role in sliding. Terrace drifts of the river Váh in territory of Mojšová Lúčka and Varín villages are a typical example of such a structure. Frontal and areal landslides with rotational surface of rapture are characteristic.

As *type B* he has suggested a geological structure composed of flysh (alternating of mudstone, claystone and sandstone) where beds typically dip into slope. The angle between the dip of beds and the dip of slope is from acute to right angle. This structure can be classified into a group of "insequent" geological structures (Fig. 3).

Complex of these beds can be characterized as alternation of impermeable, massive unstable soils and semihard rocks with moderate plasticity and low strength with fragile, permeable (pore and crack permeability) massive stable hard rocks of relatively high strength.

Other important features of both rock types relative to revival of slope deformation is their resistance factors of physical weathering. The most relevant factors are frost resistance and sensitivity to physically bound water in rocks. Slope deformations arise mainly in places where dipping bedding was cut by erosion or by acta of man (road cut).

Type C is typical form in tectonically disturbed rocks, mainly in geologically young and probably still active faults (Fig. 4). Along such faults a zone favourable for development of surface of rupture can arise. Favourable conditions for it are created by decreased shear strengths of souils caused by more intensive physical and chemical weathering, by increased of dip angle of slope and by accumulation of underground water. Beside a tectonics, topography and a plastic sub-base play an important role in development of slope deformation.

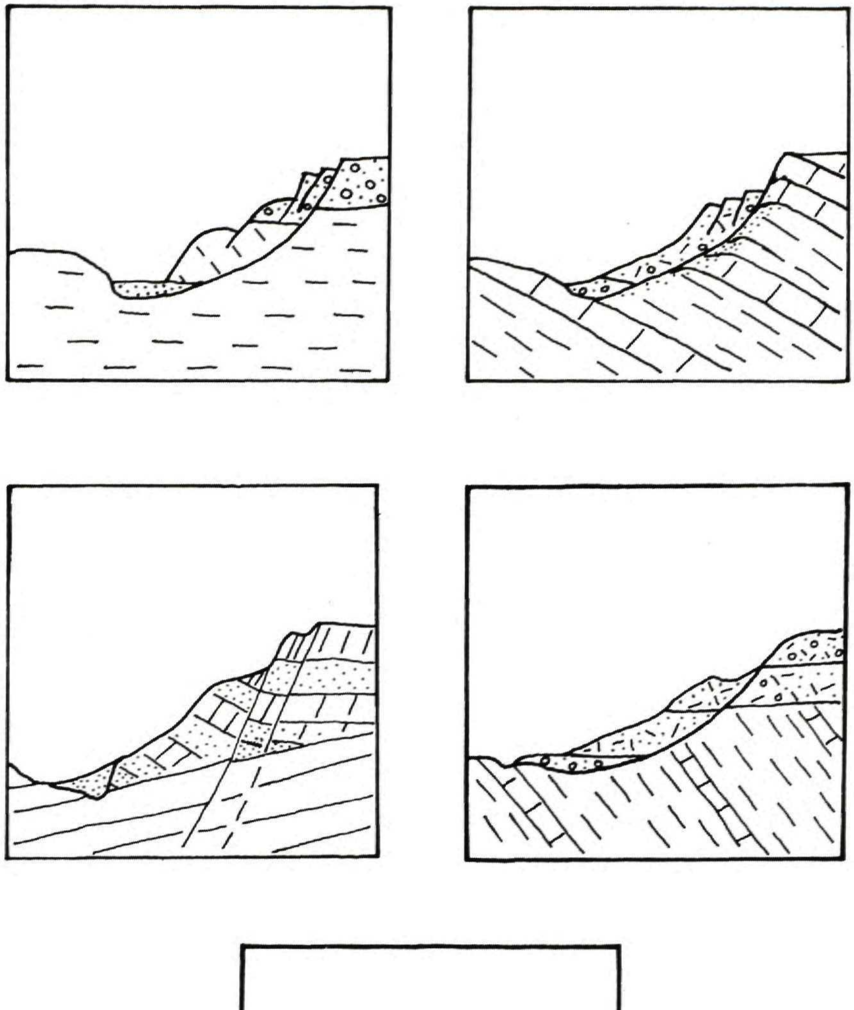

Fig. 2, 3, 4, 5, 6 Geological structure favourable for genesis of slope movement (M. KAPASNÝ, 1983)

These structures has been identified on the border of Žilinská kotlina basin with Malá Fatra mountain (for example in area between Kunerád and Višňové).

Type D consists of older Tertiary and Cretaceous flysh beds (envelope of Bradlo Belt) covered by thick layers of eluvial, deluvial, and proluvial (soils, debris, clay), which are characterized by the dependence of shear strength on contained water and by specific hydrogeological conditions. The favourable conditions for development of surface of rupture are clays of middle to high plasticity, and with soft consistence, especially if they overlay bedrock (Fig. 5).

Areal and flow-shaped slides are the most common type of slope deformations of this structure. It occurs most parts of Žilinská kotlina basin (Stránske, Rosiny, Nededza, Gbely, Hôrka).

Type E is represented by structures of hard rocks in which system of cracks and intensive ravelling makes good conditions for rockfall in oversteepened slopes. This structure is only found in valleys of Malá Fatra mountain and near village Lietava (Fig. 6).

Occurrence of slope deformations

Mass movement such as block gliding, landsliding, and rockfall have been identified last few years as result of cataloguing of slope deformations, engineering geological mapping, investigation and stabilization of landslides:

Block gliding has occurred mainly in eastern part of locality "Dubeň" (north edge of Žilina, between Teplička nad Váhom and Žilina town). Its occurrence is connected with a geological structure which bears typical features of structure of B type. In its upper part there are mostly hard rocks with non-plastic deformation i. e. fragile rocks such as sandstone. In its lower part are found prevailingly softer, lower strength semihard rocks soils, which are characteristic plastically deformed. Typical example of this type of structure is on locality Dubeň. Its lower part is built from soil envelope of "Bradlo Belt", and its upper part is limestone. Erosion of Váh river and tectonics faults are an important factor causing instability of this locality as well. Topography of terrain, mainly the height of main scarp indicates great vertical movements, and it appears that this movement have been relatively fast compared to slope deformation of block type at other localities.

Condition for their developing probably arose in Pleistocene, mainly due to erosion of Váh river and tectonic movement. Occurrence of block gliding is accompanied by intensive and significant loosening of rocks in upper part of slope. As result of this loosening there are deep and widely open cracks parallel to the mountain range. For example in locality Dubeň they can be traced westward from Teplička nad Váhom village. They are 50–170 m long. A loosening is probably based on overpressed zone of tectonic fault along the river.

Other occurrences of block deformation were found in Kunerádska valley eastward from Turiec village in Lúčanská Malá Fatra mountains and in Kriváňska Malá Fatra mountains, and are bound with some type of Mesozoic rocks. Indications

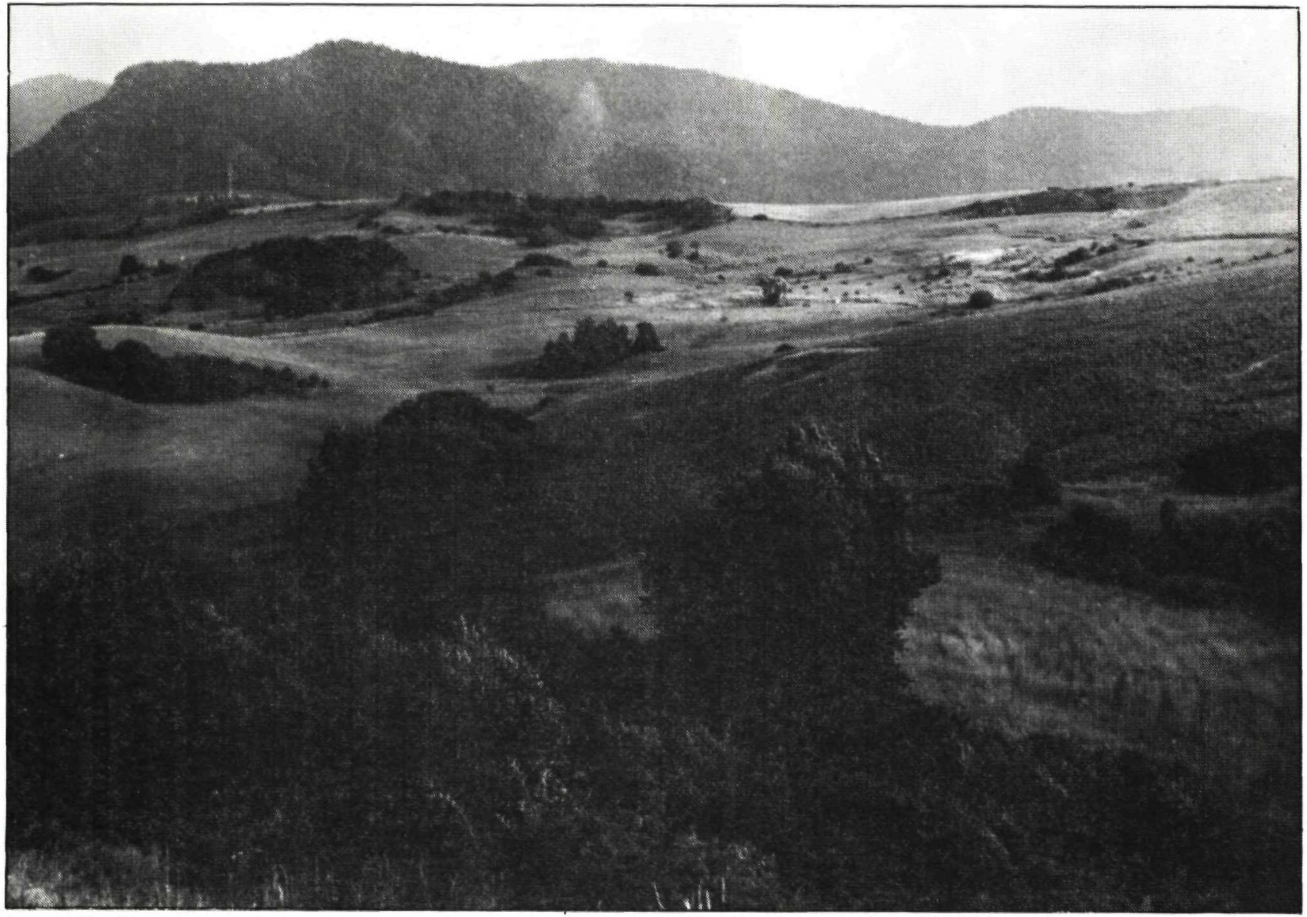

Fig. 7 Typical topography of sliding slope in Žilinská kotlina basin, eastward from Žilina. Photo by M. Kapasný.

of above mentioned loosening of structure were recorded in Paleocene basal conglomerate beneath castle Lietava.

Landsliding is connected with development of thick surface deposits (deluvial-eluvial deposits) of Žilinská kotlina basin, i. e. territories covered with clayey debris and clayey soils. These deposits are products of Pleistocene periglacial weathering and solifluction.

This type of slope movement has devastated area of about 40 km^2 of Žilinská kotlina basin (Kapasný, 1983): 13.2 % is devastated by active landslide, 83.2 % is in danger of reactivation of landslide and only 3.6 % of area can be considered as completely stabilized.

Landslides occurs mainly on slopes with gradient range from 10° to 15° (inclination of a join of highest and lowest point of a slope). Occasionally occurrence of landslides were recorded on slopes with dip angle less then 4° and from 15° to 25°, Kapasný, 1983).

From the stand point of development of landslides in the investigated area Kapasný (1983) has distinguished two evolutionary generation:

a) stabilized and potential landslides with blank smooth topography. Their beginning can be dated into historical time of man.

b) still active landslides with variable topography which have arisen recently or have been reactivated in recent history. Their topography significantly differ from topography of surrounding area.

According to shape landslides of investigated territory can be divided into three types:

a) sheet landslides which include 70.3 % of entire number of landslides (documented near villages Kunerád, Stránske, Poluvsie),

b) flow-shaped landslides (18.2 % documented near village Divina),

c) frontal-type landslides which count 11.5 % of the entire number of landslides. They were identified on river-terrace of Váh river near villages Varín, Stráž and Mojšová Lúčka, and on river terrace of Rajčianka river near Lietavská Lúčka village, and on stream-terrace of Varín stream northeastern from Belá village.

Rockfall is rare type of slope movement in the area. Only one occurrence was recorded near Lietava village (on cliff bellow Lietava castle). But many of them were recorded in valleys of Malá Fatra mountains surrounding Žilinská kotlina basin.

Number of slope deformations

Quantity of occurrence of slope deformations is directly dependant upon geological construction so they are spread out irregularly. It has been found out, that average of 9.42 5 of entire area of Žilinská kotlina basin is devastated by slope deformation, which is twice the Slovak average.

The next table shows ratio of devastated area and area of particular geological complex of Žilinská kotlina basin. It points out the significant slope deformations in "Central Carpathian Paleogene Flysh" and by "Bradlo Belt".

Table 1 Extent of area devastated by slope deformation in Žilinská kotlina basin as factor of geological conditions

Geological complex	Entire area (km²)	Area of slope deformation (km²)	Occurrence of slope deformation (%)
Central Carpathian Paleogene	100.0	17.0	17.0
Flysh	27.5	4.5	16.5
Mesozoicum — Krížna Nappe	19.0	1.7	8.9
Mesozoicum — envelope of Malá Fatra Mts.	60.0	4.6	7.6
River-Terraces	20.0	1.5	7.5
Envelope of "Bradlo Belt"	148.0	10.45	7.0
Basal Paleogene	6.0	0.35	5.8
Fluvial of Rivers and Streams	31.0	0.0	0.0
Total	421.5	40.0	9.4

Use of devastated slopes

As it was stated previously, entire area of studied territory is about 201 km^2 and 11.6 % (2.1 km^2) of it is devastated. Use of this land during our research (1986–1988) is shown in shown in Table 2. It suggests that biggest part of slope deformation are on meadows and pastures (7.9 %). Majority of them are used either extensively or not at all. The areas are overgrown by wind-seeded trees and bushes (Fig. 8, 9, 10). Many of them have seasonal surplus of moisture, mainly during Spring and Winter. This moisture causes slower heating of earth's surface after Winter, and delays the beginning of vegetation growth. It causes an intensive soil erosion removing nutriments and other elements necessary for the growth of plants, because erosion is more intensive in muddy soil (Juva et al., 1984).

Grass growth is not uneven because of difficult access to the effected area. Gradually, vegetation unsuitable for pasture has grown on meadows and pastures; mainly acid kinds of grass with hard skin and sharp thorn covered with $HSiO_2$ acid. Among these grasses belong, for example, *Carex, Juncus, Deschamp Caespitos* act.

Fig. 8 Pasture deteriorated by landslide. Upper part of landslide is overgrown by wind-sown wood. Locality Konská. Photo by M. Fischerová.

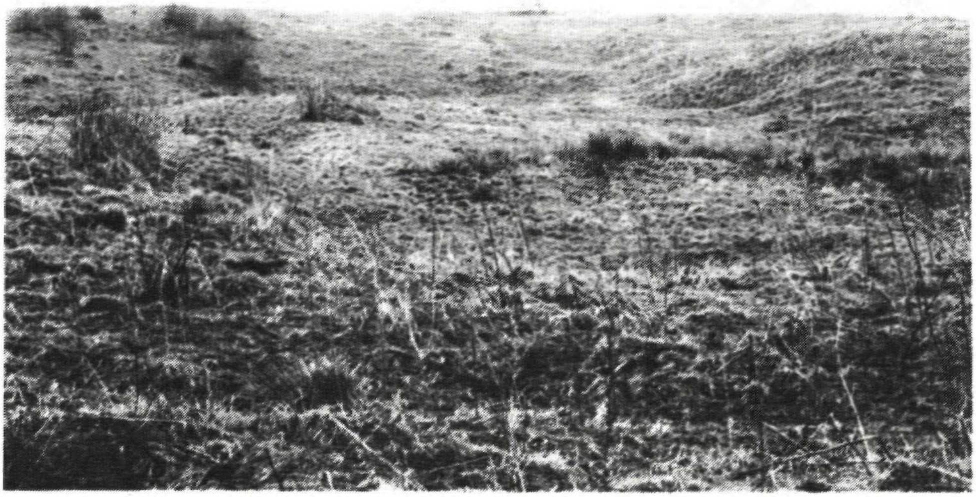

Fig. 9 Landslide with typical topography and wetland. Locality Biterová. Photo by M. Fischerová.

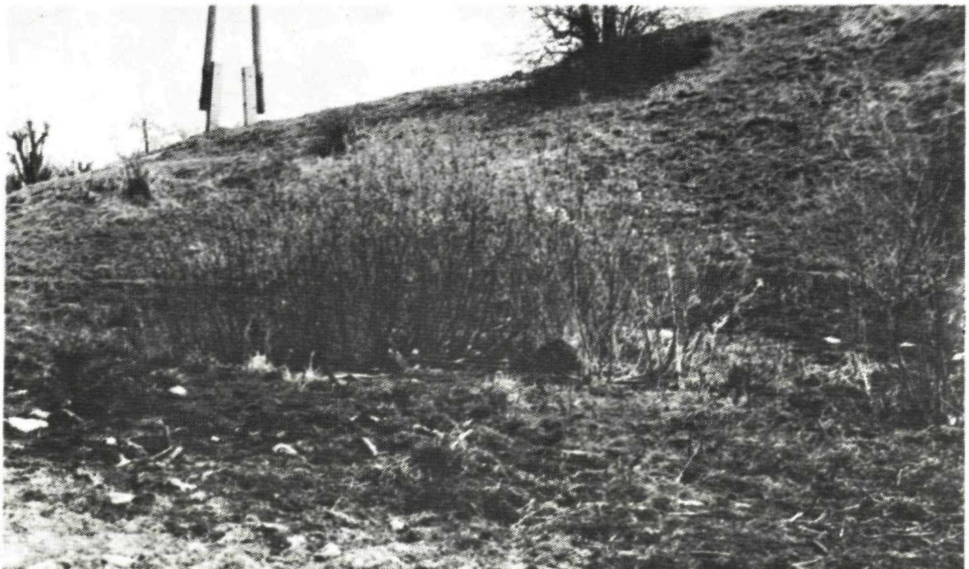

Fig. 10 Wet areas overgrown by typical wet-land vegetation. Locality Krasňany. Photo by M. Fischerová.

Table 2 Use of devastated land of study area

Use of Land	Area (ha)	Percentage of devastated Area (%)
Meadows and Pasture	888.85	37.91
Forests	830.70	35.76
Fields	375.40	16.03
Unused Ground	125.05	5.83
Gardens and Orchards	78.40	3.37
Built up Area	32.50	1.40
Others Areas	3.40	0.15

Note: Category "meadows and gardens" includes area of cottages with gardens as well; "built up area" includes all areas with buildings, constructions sites, roads, railways act.; unused ground includes areas which are not used for farming, lumbering or in another way because of steep slope or rocky surface and land which is temporary not in use because of devastation by landslides.

But pasture on unstable land is not suitable only because of low grass quality, but also because of dangerous scarps. Another danger for livestock is swamp water which is found on slope deformed land.

Grazing livestock themselves have negative impact on slope stability. They walk along level lines and graze grass resulting in parallel and steppy "girland ground" (Fig. 11). Such devastated land is near Krasňany village, where the surface of accumulation zone of landslide is totally without vegetation, resulting from intensive erosion during rainfalls.

There are two factors resulting from neglect of pastures and meadows:

1. In the past, former private farmers took care of their small fields, which were threaten by slides. They built very simple but useful protective elements (for example draining ditches), to control the run off of the surface and underground water and to drain swamps resulting from nearby landslides. Fields used to look like little terraces elongated along level lines, which contributed to protection slopes. Thus controlled slopes had been plowed, and used for growing of crop. Slopes with occasional revival of movement were used as meadows or gardens (Nemčok, 1982). But this early activity of our ancestors required effort and hard work. The people willing to do it were farmer owners, who were dependent on efficient utilization of their ground. But establishment of colossal state farms with huge fields has neglected these good habits. Since slopes damaged by sliding were in accessible to big earth works machines, the interest of socialist farmers these lands has been gradually lost. They turned this devastated land into pasture and unused fallow and finally, they took it out of farming practice entirely.

2. Regulation of devastated land surface and its stabilization requires high financial investment, which is only slowly repaid. And when on many occasions this cost has not brought expected rewards a fear to invest in this way has arisen. For big socialists farms it was more convenient (paradoxly more economical as well) to leave this land rather than struggle to return it to its former function.

However Jůva et al. (1984) affirms that properly done, though financially and technically exacting draining of land is highly efficient. He predicted that as result of draining, harvest can be potentially increased 70–120 %. Additionally he indicated that draining can decrease "the coefficient of erosional danger K". The next table shows that land with several years of grass decreases the coefficient "K" 12.5 times a year after sowing, 33.3 times 2 years after sowing and 100 times 3 years after its sowing, compared with ungrassed land.

Table 3 Coefficient of erosional danger "K" of different plants (Jůva et al. 1984)

Plant	Coeff. "K"	Plant	Coeff. "K"
uncultivated fallow	1.00	pea, lentil	0.35
sugar beet, maze	0.85	grass of several years:	
potatoes, sunflower	0.75	1 year	0.08
grain	0.50	2 years	0.03
ensilage maze	0.40	3 years	0.01

In devastated area, 80.70 ha (5.75 %) is recorded as *forested ground.* Forest growing on effected area is often partly or completely damaged which is manifested mainly by deformed tree trunks and their high indicence of drying or rotting. According to Kubíny et al. (1983) such forest gives less timber yield, with wood of lower quality, and its surface results in more difficult lumbering and transportation conditions. Losses from damaged area are 97 mha/year of wood. In estimating looses from damaged forest, it must be borne in mind that recultivation in accessible forest often with muddy surface is difficult. And despite of all the effort, the new wood will not have quality as the one on stable, undamaged land (Fig. 12). It would be a mistake to count losses as production of wood only. Other functions of forest (source of oxygen, water, protection against erosion and deflation, recreational background etc.) have, together, higher value.

The entire *cultivated ground* in devastated area is 72.4 ha (16.0 %). Despite the fact that this area is large, no slope deformation is presently active. Damaged area is henceforward usable for agricultural purposes and losses of harvest yield due to slope movement are minimal. It is probably the result of cultivating the land which positively regulates run off of water. Soils in the investigated area belong among the less productive. Its category is 4–5 (range of this categorization is 1–5). The reason is not more active slope deformation, but the fact that for farming purposes the land used is that with slope dip of less then 7° which are not involved in slope movement.

Fig. 11 Damaged pasture with disturbed grass cover. Photo by M. Fischerová.

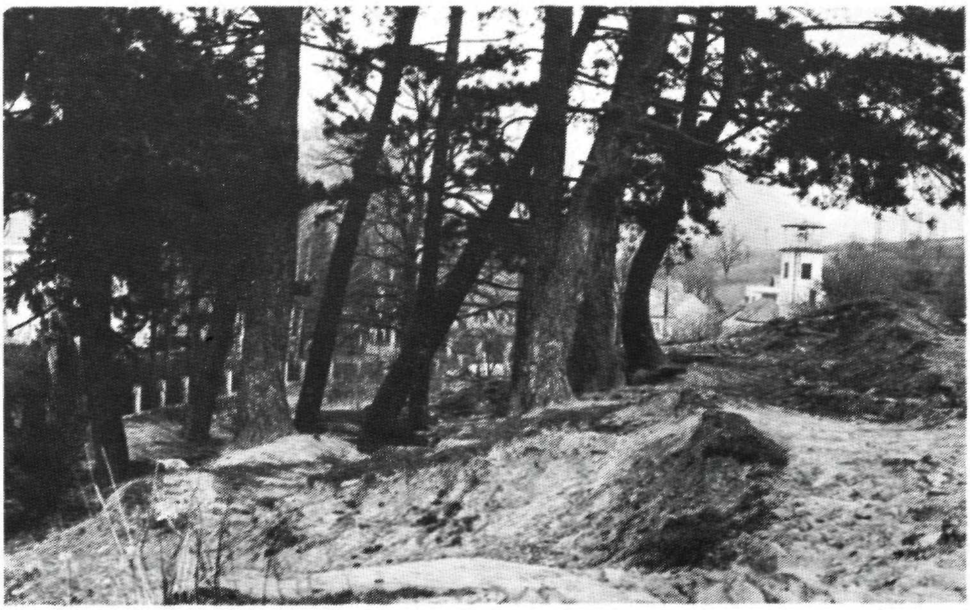

Fig. 12 Forest damaged by landsliding. Locality Krasňany. Photo by M. Fischerová.

As displayed in Table 2, unstable slopes which are *economically unused* cover 125 ha, i. e. 5.8 % of entire unstable area and majority of them are still active. Originally, they were used for various purpose (meadows, pastures etc.). Currently this area has become overgrown with wind-born trees, bushes, acid grass, and devastated by open cracks and typical "wild" topography.

Habilitation of devastated slopes

As we have stated above slope deformations limit the use of land. It involves rather large economically underused areas (for farming, lumbering, recreation). Our effort is in returning the devastated land to its original or other useful function. The way to this is unambiguous – stabilizing and recultivating of affected land.

Judging the effectiveness of revilizating efforts we have to consider the fact that this effort includes:

1. Stabilization of unstable slopes by

a) simple constructions eliminating pressure in foot of the slope (pillar wall, load dikes etc.)

b) deep drainage by use of horizontal draining wells.

2. surface draining of unstable slopes by:

a) "biological" draining through planting of plants with high transpiration ability. This can be used only on not highly saturated land.

b) technical draining which include digging of draining ditches and channels on the surface and placing of draining pipes under ground.

3. Regulation of affected land and revitalization of vegetation. It include planing of uneven surface, filling up of cracks, remove of unsuitable woods, revitalization of soil horizons and original flora, etc.

In evaluation of revitalized unstable slopes dedicated to a farming it is necessary to consider:

a) only small part of unstable land has slopes favourable for plowing. Suitable slopes is less then 7° (Jůva et al., 1984) and only 27.65 ha of devastated land of investigated area has this acceptable slope.

b) entire area devastated by slope deformation (including slopes with dipping over 7°) is 72.4 ha. However typical features of a moving surface were eroded off, and access to fields for agricultural machines is good.

We have reached conclusion that although cultivation can not prevent development of slope deformation, it can significantly reduces its impact, mainly by slowing down the mass movement. The sliding assumes character of creep, and plowing smoother the undulation and other roughness. But this is acceptable only: if suitable machines are used for field works i. e. these do not needlessly damage soil horizons by their high unit weight; if proper method of cultivation is used; and if right type of plants are grown. If these principles are not followed, mass movement can be accelerated.

To practice optimal methods of cultivation for both, slope stability and good crop yield, coordination of experts from both farming and engineering geology is required.

This team should commonly: work up a optimal principles of working with ground threatened or damaged by sliding; guide the follow-up of suggested principles; regularly evaluate effectioness of suggested principles and make new flexible decisious in case of earlier errors. Fundamental condition of their common success is the search for reasonable compromise which will satisfy often almost opposite demands.

It is welcome when both sides of experts agree on common demands in reduction of water and wind areal erosion of soil, needless stripping of soils, etc.

As conclusion, reached experiences and economical analyses, we suggest that unstable slopes as less suitable for any kind of activity. However, their value can be increased by appropriate professional treatment which must include methods for stabilization and revitalization and successive use of land. All these methods, as part of preventions effort, must respect preservation/renewal of ecological balance of the land as a entity.

To return the slide damaged area to its original function and to optimal use, it has been recomended:

a) reduction of erosion, improvement of stability of slopes and increasing the production of meadows and pastures by draining and agrotechnical works,

b) planting of forest on part of unused land, not only for wood but as an environment for field animals and birds,

c) an unstable slopes near town and villages, use the area for building of vacation cottages and gardening,

d) on part of devastated slopes near Žilina town set up a park, serving as recreation green zone for inhabitants of Žilina. Relaxation centers and stadiums, paths with benches should be built up, and suitable kinds of trees planted in this area.

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MÁRIA FISCHEROVÁ – IGOR MODLITBA

Výskyt zosuvných svahov v oblasti Žilinskej kotliny a ich využitie

Resumé

Časť Žilinskej kotliny bola vybraná ako modelové územie na hodnotenie podmienok výskytu svahových deformácií a možnosti rekultivácie devastovaných plôch na pôvodné alebo iné využívanie (obr. 1).

Podľa KAPASNÉHO (1983) sa na území Žilinskej kotliny vyskytuje 201 lokalít úplne alebo čiastočne devastovaných pohybmi. Ich celková plocha je približne 40 km^2, čo predstavuje 9,4 % z celkovej plochy kotliny. Tieto plochy boli v minulosti využívané najmä ako lúky, pasienky, orná pôda, na zástavbu, sady a záhrady a pod. (tab. 2).

Výskyt svahových deformácií typu plošných a prúdových zosunov, frontálnych zosunov, blokových pohybov a rútenia je viazaný na šesť geologických štruktúr (tab. 1). Pri vývoji svahových pohybov sa uplatňujú najmä štruktúry flyšoidných hornín (paleogénne a mezozoické) — t. j. striedanie pieskovcov a ílovcov. Výskyt však bol evidovaný i v horninách kvartéru (ílovité hliny a íly), v mezozoických horninách krížňanského príkrovu a obalu Malej Fatry (ílovce, slieňovce) a výnimočne aj v horninách bazálneho paleogénu — v zlepencoch (skalné rútenie).

Svahové deformácie sa vyskytujú najmä na svahoch so sklonom spádnice v rozsahu 10—15°. Ojedinelý výskyt však bol evidovaný i na svahoch so sklonom okolo 4° a do 25° (KAPASNÝ, 1983). Približne 18,4 % lokalít z celkového počtu sú zosuvy v aktívnom pohybe.

Ako sme uviedli, väčšina devastovaných plôch je síce využívaná, ale extenzívne, prípadne je ponechaná ako úhor. Príčinu zanedbávania zosuvných plôch treba vidieť:

1. V poľnohospodárskej veľkovýrobe, ktorá nemala záujem o využívanie poľnohospodárskych plôch permanentne porušovaných svahovým pohybom a s "divokou" morfológiou povrchu. Takéto pozemky neumožňovali mechanizáciu poľnohospodárskych prác vo veľkom. Ich obrábanie vyžaduje najmä ručnú prácu a neustálu osobitnú starostlivosť o odvodňovanie pozemku, stabilizovanie svahu a povrchovú úpravu terénu.

2. V pomerne značných finančných nákladoch potrebných na sprístupnenie pozemkov s dlhodobou návratnosťou. Veľkovýroba na devastovaných plochách musela byť krytá neúmerne vysokými finančnými nákladmi na zabezpečenie málo efektívnej nemechanizovanej práce pri vtedajšom nedostatku pracovných síl.

Uvedené aspekty sa prejavovali najmä pri snahe rekultivovať lúky a pasienky, a to i napriek tomu, že ich úpravami bolo možné podľa JŮVU et al. (1984) zvýšiť produktivitu rastlinnej výroby o 70 až 120 % a výrazne znížiť efekt plošnej erózie (tab. 3). Menej sa uplatňovali pri ornej pôde, kde permanentné intenzívne obrábanie znižovalo priebežne nepriaznivé prejavy svahových pohybov. V takýchto územiach bol zaznamenaný relatívne pomalší a menej deštruktívny pohyb svahových sedimentov, ktorý mal často charakter až plazivého pohybu (creepu).

V prípade lesných porastov straty na drevnej hmote sa pri aktívnom svahovom pohybe pohybujú okolo 97 m^3/ha/rok prírastku drevnej hmoty a značne sa znižuje tzv. všeužitočná funkcia lesa, ako napr. vodoochrana, protierózna a protideflačná funkcia a pod. Vzhľadom na odľahlosť a neprístupnosť devastovaných pozemkov a spravidla i značné znehodnotenie drevnej hmoty svahovým pohybom (zakrivenie a polámanie kmeňov, vývraty a pod.) lesné podniky nemajú záujem o rekultiváciu a stabilizáciu takýchto plôch, pričom prostriedky vyčlenené na sanáciu svahových deformácií vyčerpajú už pri sanovaní lesných komunikácií poškodených zosúvaním.

Z predbežného hodnotenia vyplýva, že rekultivácie a sanácie zosuvných svahov s poľnohospodárskou a lesnou pôdou by sa mali v prvom rade zamerať na prevenciu účinným odvodňovaním pozemkov. V prípade aktivovania pohybu svahu odporúčame používať jednoduché stavebné konštrukcie na zachytávanie tlakov v päte svahu (kamenné múry, ochranné siete a pod.), hĺbkové a povrchové odvodnenie pomocou rigolov, rýh, studní a pod., ako aj používaním tzv. "biodrenáže" vysádzaním rastlín s vysokou transpiračnou schopnosťou. Dôležité sú terénne úpravy (zasypávanie trhlín, vyrovnanie nerovností terénu a pod.), likvidácia náletových porastov, obnova pôvodného pôdneho horizontu a poľnohospodárskych kultúr i vhodná technológia obrábania pôdy, ktorá by nerušila pôvodné odtokové pomery na pozemku.

Pri navrhovaní úprav a spôsobu využívania devastovaných pozemkov je potrebné zosúladiť požiadavky poľnohospodárov — odborníkov na pestovanie rastlín a inžinierskych geológov, ktorí by mali hľadať vzájomný kompromis pri presadzovaní optimálneho riešenia rekultivácie a stabilizácie svahov.

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MÁRIA KOVÁČIKOVÁ

Landfills in Protected water-resource area Žitný ostrov

(1 figs., slovak summary)

A b s t r a c t. From the economic viewpoint, Žitný ostrov (Rye Island) is a very significant area. Its environmental protection also entails registration of pollution sources including landfills. This contribution deals with the results of registration in the area concerned, characterizes the wastes, landfills and applied registration technique as well as assigns the registered landfills into categories according to selected criteria with regard to their environmental impact.

Introduction

Landfills, as a pollution source, were subjected to virtually no regulations in the previous economic-political system. As a result of this unmanaged "wild" landfills clearly prevail over managed ones. The first step to be taken in resolving this situation is landfill registration.

There are a number of reasons why the Protected water-resource area (PWRA) Žitný ostrov was selected for our landfill registration: it is a centre of intensive farming and related food industry as well as a major water source in a direct contact with the recently constructed water reservoir Gabčíkovo. These, often contradictory characteristics, make Žitný ostrov an ideal place to study relationship between man and the environment.

Any assessment of landfills should be based on
- natural conditions reflecting geological history of the territory,
- past and present-day economic activities in the given territory.

Geological and morphological characteristics of the territory

The studied territory is a part of the lowest morphological level of the Danube Lowland designated by Hromádka (1956) in the Danube Plain.

The surface here is even, generally inclined from the NW to SE. In the centre of the territory there is a longitudinal elevated belt up to 15 km wide in the upper

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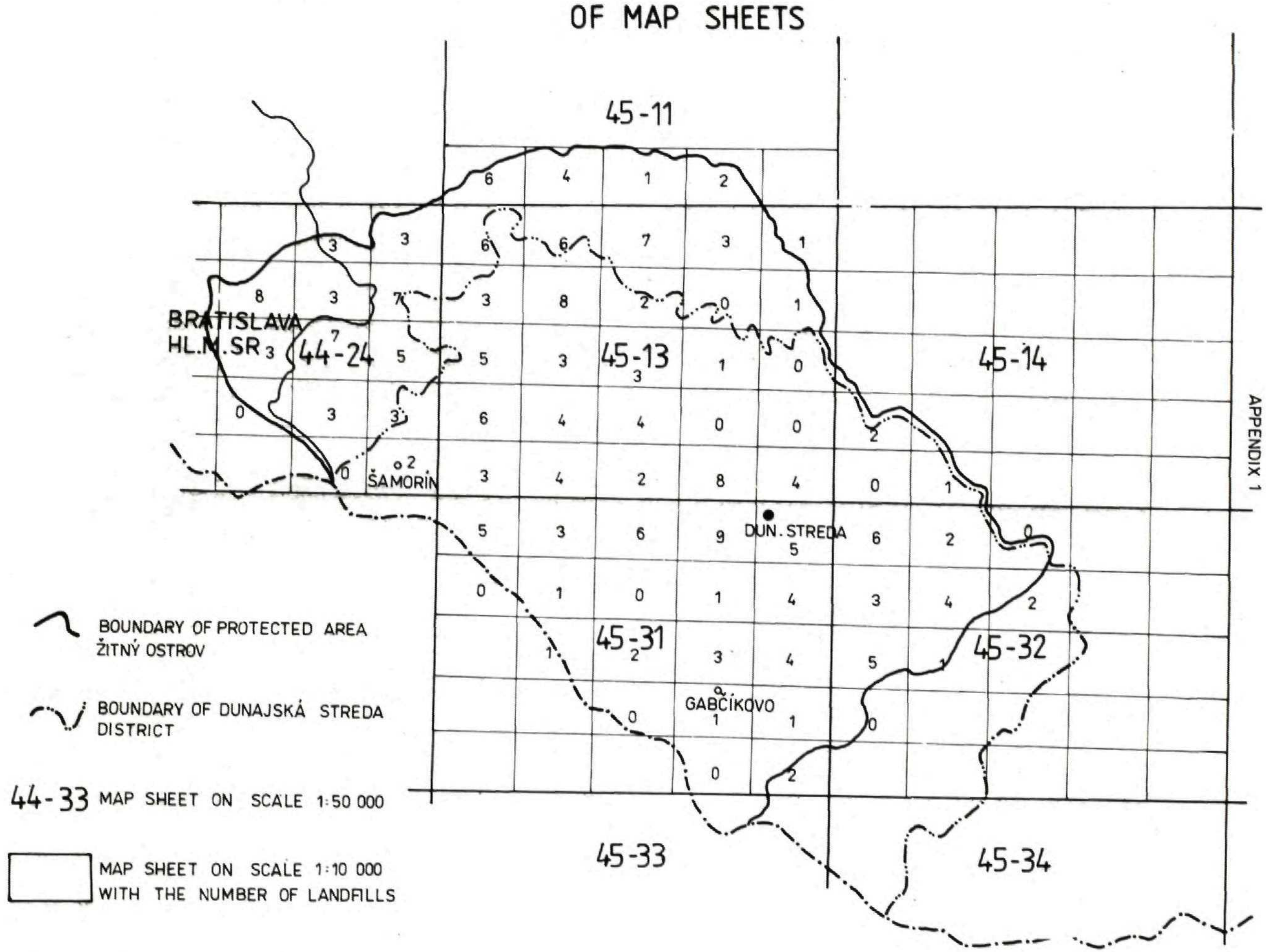

APPENDIX 1

Fig. 1 Location of the investigated territory and distribution of map sheets tract and 6–4–2 km in the lower tract. The elevated belt consists of a Late Pleistocene core composed largely of gravels, sandy gravels and sands topped with loessy soils or Holocene loams and bogs, rarely with wind-blown sands.

On both sides, the elevated belt passes into shallow (2–3 m) depressions parallel with both streams (Danube and Little Danube) fringing Žitný ostrov. The depressions are filled with Holocene bogs, flood-plain loams underlain by sandy gravels. Throughout its periphery, Žitný ostrov is lined with a slightly elevated belt of Late Holocene levees composed of gravels, sands, loamy and other flood-plain deposits.

The whole Žitný ostrov is completely covered with Quaternary sediments without exposures of the underlying Neogene substratum of variegated lithological composition (clays, sands, sandy gravels). The Quaternary sandy gravels cannot be reliably distinguished from the subjacent gravels and sands assigned into the Upper Pliocene (Levantian). These stratigraphically undifferentiated sandy gravels termed *Danube sandy gravels* with minor lenses of gray coal clays are up to 300 m thick (Dunajská Streda area). To the west, towards Bratislava, and to the east their thickness drops to 30–15 m. As far as landfill location and possible spreading of contamination into ground waters are concerned, surface cover plays an important role. The surface cover consists of two facies:

– flood-plain facies

– oxbow lake facies.

The *flood-plain facies* extend throughout the territory, sometimes as a continuous cover, sometimes in the form of patches and locally it is completely absent. In the latter case, the above-mentioned sandy-gravel complex is exposed on the surface. As regards their grainsize composition, the flood-plain facies sediments are mostly composed of loam and/or clay fractions, rarely of sand or small-gravel ones. They are of Holocene age (until the last glacial age). The flood-plain deposits form several generations of flood muds and loams. Their thickness is irregular, generally growing from the N to S central core towards Danube and Little Danube levees. The maximum thicknesses attain 5 m, averaging 1.5–2 m.

The flood muds (and/or sandy gravels) are interlaced with oxbow sediments. They occur either on the surface or are buried. Lithologically, the deposits are loamy, highly humic sediments – silty and clayey loams locally with sand lenses, gravel layers and bogs. Their thickness varies from 2 to 4 m.

Lesser volumes and areas are occupied with fluvial-aeolian sands. All the facies-genetic types are covered with recent soils.

The fluvial sediments are major unconfined aquifers. Their hydrogeologic characteristics reflect grainsize composition, spatial distribution and groundwater recharge. Gravel beds with a low sand content play a dominant role. Filtration parameters decrease with increasing content of the psammitic-pelitic component. In general, it can be said filtration coefficient of the sandy gravels to a depth of 30 m is roughly 10^{-3} m/s.

The aquifer can be divided into two zones:

– near-surface zone to a depth of 15–20 m with intensive water circulation through bank infiltration from the Danube river,

– deeper zone with slower water circulation.

The main source of the groundwaters is the Danube river, in the inner part to a lesser extent also precipitation.

Economic potential of the territory

Thanks to the favourable hydrogeological and geological setting, the resources of potable groundwaters in the studied territory are of European importance. According to Polák et al. (1983), the water sources ISTROCHEM – Vlčie hrdlo, Slovnaft, Kalinovo, Šamorín, Báč, Gabčíkovo, Baka and Lehnice have a combined yield of 19.8 m^3/s. That is why the territory was proclaimed as a protected water-resource area in 1978. A significant economic activity in the area studied is agriculture. The territory has excellent soils and climatic conditions to reach the highest yields of all agricultural products.

The coexistence of these two economic functions brings some problems by the increasing amount of nitrates in groundwater.

Agriculture is not the only significant characteristics of the studied territory. Other ones are is associated with food industry, local workshops, services etc. The construction of industrial facilities and dwelling houses (particularly after the disasterous in the year 1965 flood) requires large amounts of construction materials. The area concerned has enormous resources of high-quality gravels (to a lesser extent also sands) which are extracted from the bottom of the Danube river and (especially for local consumption) a number of small gravel pits have also been excavated in the vicinity of villages and small towns. Such numerous abandoned pits are a characteristic sign of today's Žitný ostrov. They are often used for waste disposals.

Wastes in protected water-resource area Žitný ostrov

With regard to their origin, wastes in the studied area can be divided into:

- household
- agricultural
- industrial.

Household wastes are extremely heterogeneous, and their composition and properties change from one area to another. Household waste in a small-town or village landfill understandably contains less organic matter than that from a large town with concentrated collecting to trash bins and containers. In the former case, the waste management is wiser – organic materials serve as animal feed or compost and consequently the ultimate volume of wastes dumped in the landfill is smaller. Such reduced volumes of relatively organics-poor wastes are dissolved by solar radiation, precipitation and temperature changes, and do not pose a major threat to the environment. The case is quite different in large landfills where waste from several villages or towns or from a single major town is concentrated. Furthermore, municipal wastes differ from rural ones in their considerably higher content of organic matter.

The process of decay is much longer, producing larger volumes of leachate of higher concentration. The leachate hazards to groundwaters are further aggravated by the fact that such landfills are not managed. The landfill substratum is not sealed, there is no drainage to remove percolating water and the waste is not interlayered with an inert material. Assessing the impact of household wastes on the environment, it is necessary to take into consideration that, in addition to organics, the waste here also contains hazardous components such as batteries, fluorescent tubes, refrigerators, used oils and oil-polluted materials, drugs, which are treated separately in developed countries. In Slovakia there, is no separate collection of these hazardous materials and so they are dumped on common landfills.

Agricultural wastes account for a fairly high percentage of wastes because farming is intensive in this area. Once again, we may state that, if dumped in minor amounts, these wastes are not hazardous. However, concentrated collecting gives rise to the processes similar to those described above. A special kind of agricultural wastes is represented by remnants of fertilizers, their wrapping and pesticides which, because of their character, are in fact chemical wastes. Similarly, dung heaps, silage pits etc. represent a special case which was not studied by the author.

Industrial wastes comprise a wide range of wastes controlled by the type of local industries.

Building industry produces large volumes of building wastes (surplus earth, excavations, concrete, panels, asphalt, glass, wood, plastics etc.) particularly in places of extensive construction of dwelling houses (Bratislava, Dunajská Streda). Further, wastes originate from demolished old buildings. The relatively larger number of landfills in the studied area in comparison with other areas can be explained by the disasterous flood in 1965.

As far as their impact on the environment is concerned, building wastes can be regarded inert or having a slight impact on groundwaters.

Food industry produces wastes which, because of their content of organics or technological chemicals, can be dangerous for groundwaters. Wastes from sugar mills are a good example. Food-industry wastes partly serve as animal feed and so the percentage of organics in them is relatively lower.

Petroleum industry and thermal power plants in the Bratislava area produce wastes as well. The oil-refinery Slovnaft has a special place in the PWRA Žitný ostrov. Leakage of oil derivatives into the ground has invalidated the water source at Podunajské Biskupice and threatens the whole Žitný ostrov. A hydraulic barrier on the eastern rim of Slovnaft reduces this danger.

Slovnaft produces chemical, oil and oil-polluted wastes which are disposed of by incineration. Cinder left by the incineration as well as polluted earth are temporarily dumped on the spot. Insufficient separation of the polluted and unpolluted earths and their joint dumping on landfills is a drawback. Sludge deposited from industrial water supplied from the Danube River is dumped on unsuitable places (without a basal liner). There is a justified supposition that the sludge has high contents of heavy metals.

In comparison with other pollution sources Slovnaft is the largest source of contamination in the area concerned. The assessment of its influence on the environment would require a separate article.

A municipal incinerator on the SE rim of Slovnaft produces cinder by the incineration of household waste. The incineration is imperfect, takes place at a temperature of 600 °C and so the cinder contains a high proportion of unburned or insufficiently burned waste. Such a waste can be classified as hazardous. Coal cinder can be seen in landfills throughout the PWRA.

Landfills

Landfills in the PWRA are mostly located in abandoned gravel pits, morphological depressions – oxbow lakes or in other nonproductive sites. Wastes are dumped on the landfills without any basal liner. There is only one landfill, at Čukarska Paka, which could be classified as managed one in the whole investigated area. All other landfills are unmanaged. Some of them, however, are officially classified as managed – are surrounded by a fence, are guarded and their surface is levelled. These landfills were declared legal by local authorities that issued a permission for them but in essence they are nothing more than wild landfills.

To evaluate landfills, several criteria can be applied. As far as their registration is concerned, landfills may be exposed or buried (recultivated). Special attention should be paid to the latter ones, because they were converted to field, meadows, playgrounds, football stadiums, building lots etc. with no surface signs of dumped waste.

Further categories are given in registration forms (Appendix 1), e. g. legal - illegal, managed – unmanaged (wild), above- or below-terrain etc.

Another significant criterion is the environmental impact of the landfill. This criterion is described in more details in the chapter on waste classification.

Technique applied to landfills inventory in the PWRA

The previously applied system of landfill management did not entail a systematic inventory of landfills in maps. Numbers of landfills and/or dumped materials were reported and statistically evaluated. Such data, however, were biased by personal opinions of the reporting authorities as well as by intentional attempts to hide problems and to report the situation better than it really was. Inventory by an impartial organization is therefore a key precondition to the objective knowledge of the real state.

Landfill inventory consists of two successive steps:

– summing up available data on landfills and their surroundings,

– field mapping (verification) of the situation.

Landfill location requires good maps to be studied. Best time-honoured maps for this purpuse are those on scale 1:10 000 covering the whole territory of Slovakia. The map study should identify favourable areas which may serve as landfills. These include mainly abandoned gravel pits, surface depressions – gullies, oxbow lakes and nonproductive areas. Field investigations in such favourable areas reveal mostly buried (recultivated) landfills. It is desirable to study maps dating from different periods – recent ones allow easy orientation while earlier provide us with information on old pits and other surface depressions which have later been levelled.

The preparatory study naturally comprises summing up all data available on landfills in the area concerned (data by the Slovak Statistical Bureau, local authorities and residents) which have to be verified in the field. A good technique to reveal landfills is the study of serial maps. Such maps of the PWRA have been made to assess environmental impacts of the Gabčíkovo water reservoir. Black-and-white photographs were used for landfills identification. The most convenient scale of the serial photos seems to be similar to the scale of topographic maps – 1:10 000. Such magnified photos have less contrast, but could have been studied without any equipment. The aerial photos compared with topographic maps made it possible to identify probable landfill sites. Such aerial landfill identification may sometimes be erroneous because a landfill seen from above resembles an active gravel pit, building yard or a haystack in disorder, a large dung pile etc. All selected sites must be verified in the field. The interpretation of aerial photos made it also possible to identify such landfills which could not be discovered by commonly applied techniques.

Multispectral photos of the PWRA Žitný ostrov are also available. A set of multispectral photos in true and false colours showing the vicinity of Slovnaft and Dunajská Streda were made by the Remote Sensing Centre. The assumption that such photos could reveal negative effects of landfills on the nearest vegetation or discover buried landfills was not confirmed. These photos, however, are much more useful in built up areas. E. g. in the Slovnaft plant, only a colour photo allowed to distinguish landfills (dumps of polluted earth and mud) from other industrial installations (buildings, power lines etc.). The multispectral photos are rather expensive (500–600 Sk/photograph) and therefore can hardly be used for regional investigations. Simple geodetic photos are sufficient for landfill registration.

The field mapping is aimed at the verification and detailed description of identified localities. Each landfill is marked on a topographic map on scale 1:10 000 and described in a registration form which contains basic data on the landfill, its material composition, surroundings and outlines its environmental impact (Appendix 1).

A special task, logically associated with the foregoing stages, is to summarize the registration results and to evaluate environmentl impact of the landfills.

Results of landfill inventory

Our preparatory works for the landfill inventory included:

– elaboration of topographic maps on scale 1:10 000 covering the PWRA,

– interpretation of 81 geodetic photos of the PWRA,

– field verification of some 400 sites in which 219 landfills were described.

Each landfill has its inventory form and is marked on a 1:10 000 map. A review of landfills on scale 1:10 000 is given in Appendix 2 and that on scale 1:50 000 is in the next table:

Map sheet 1:10 000	Number of lanfills
45–11	14
44–24	47
45–13	80
45–14	3
45–31	49
45–32	23
total	216

Waste classification

In general, wastes can be classified for various purposes and according to diverse criteria. Waste classification is directly linked to landfill classification and therefore both these classifications should apply criteria of the same character. In both cases, the impact on the environment – groundwater, soil and atmosphere – is a basic criterion. The impact on these principal elements can consequently affect human beings too. Wastes can be classified as:

– safe, inert, which do not affect groundwater, soil and air quality. These comprise building wastes, surplus (unpolluted) earth from excavations and household wastes with low percentage of organics.

– wastes whose leachates produced by extremely complicated chemical reactions between the dumped material and rain and/or ground waters threaten the environment. These include household, agricultural and industrial wastes.

– hazardous wastes whose toxic, bacteriologic, explosive, combustible and carcinogene properties are dangerous.

Most wastes on the PWRA fall into the first or second group. The third group only includes chemical wastes dumped in Slovnaft and/or cinder left by burning of communal wastes.

Landfill classification

Like the waste classification, the landfill classification is also based on environmental impacts. Wastes are dumped in a certain environment whose characteristics also play a decisive role in an assessment of the landfills environmental effects. Rock environment (earths - in our case) is a space through which leachate percolates until it reaches groundwater. The major factors in assessing environmental impact of a given landfill are:

- waste material
- permeability of the environment
- water table.

Waste material

Landfills mostly contain wastes of more than one kind. Single-component waste landfills are only those in Slovnaft refinery) and very rarely building and agricultural landfills in major towns (e. g. Dunajská Streda). Material dumped on each landfill is marked in its registration form (V – excavation, S – building, B – concrete and panels, D – household etc., see Appendix 1).

Environmental permeability is a hydrogeological characteristics which expresses the rate of groundwater movement in a given rock environment. It amounts roughly to 1.10^{-3} m/s in well-sorted gravels and to 1.10^{-9} m/s in clays. Between these two marginal values (very simplified) there is a wide range of substances – silty earths, sands, loams etc. From the lithological viewpoint, the PWRA is composed of Holocene gravelly deposits. The permeability of these sediments averages some 1.10^{-3} m/s. They are topped with flood deposits composed of sandy loams, loams, clays, silty and bog sediments whose combined thickness varies from 1 to 5 m averaging 1.5–2 m. Assuming that their thickness and composition are sufficient and their areal distribution is uniform, these sediments might act as a temporary barrier controlling spreading of pollution. Unfortunately, the flood-sediment cover is discontinuous and locally is completely absent. Furthermore, its protective function is invalidated by a number of landfills located in abandoned gravel pits where this layer was removed. The extraction proceeded to considerable depths, very frequently as deep as the water table. We may generally conclude that the filtration coefficient in landfills in abandoned pits is on average very high, up to 1.10^{-3} m/s. It is the worst situation as regarde spreading of contamination.

In some cases it is impossible to determine whether the landfill rests on an even terrain or on an old gravel pit.

Water table under individual landfills can be inferred from a map of the maximum groundwater-level contours. In assessing a landfill, it is important, but often also very difficult to determine whether the landfill bottom is in contact with groundwater (with its maximum level).

The criteria selected for the classification of landfills registered in the PWRA are applied in this manner:

- 1st category – landfills whose environmental impact is slight or none,
- 2nd category – potentially hazardous landfills,
- 3rd category – hazardous landfills.

The individual categories are characterized as follows:
1st category:

– landfills of inert wastes,

– landfills of household, agricultural and building wastes of a very limited extent (below 500 m^3, thickness below 2 m^3) in a very permeable environment or in direct contact with groundwaters,

– landfills of household, agricultural and building wastes of a limited extent (below 1 000 m^3, thickness below 2 m, outside surface depressions) underlain by flood loams, clays etc.

2nd category:

– landfills with all kinds of wastes except of hazardous ones, divided into two subcategories according to their size:

2a – landfills of a minor areal extent (up to 6 000 m^2) and small thicknesses (up to some 3 m)

– the water table is not in contact with the dumped material (or the contact is very limited)

2b – landfills of large areal extent and thickness, the dumped material contacts groundwaters

3rd category

– landfills of hazardous wastes (including assumed ones).

Buried, recultivated landfills, where the above mentioned criteria can only hardly be applied, were treated separately. The numbers of landfills assigned into the individual categories follow:

1st category	– 45
2nd a category	– 68
2nd b category	– 53
3rd category	– 1
recultivated, buried	– 52

Conclusion

The presented landfill classification based on environmental impacts illustrates the situation in the whole Protected water-reserve area Žitný ostrov. The area is characterized by a high number (52) of buried – recultivated landfills accounting for 23.7 % of the total number of landfills. Only one landfill was placed into the third category (hazardous landfills), although three landfills assigned into the 2nd b category are very close to the 3rd category. 45 landfills, or 20.54 %, were assigned into the first category. These landfills are safe, causing only aesthetic problems and, because of their small volume, could easily be liquidated.

121 landfills, or 55.25 %, were put into the 2[nd] category. Like the 3[rd] – category landfills, they also require further attention.

Our assignations should be verified by inexpensive techniques, primarily geophysics which could provide further data on the dumped wastes – thickness, material composition as well as the surrounding environment – depth and surface of the substratum, its lithological composition, hydrogeological parameters, direction and distance of pollution spreading etc. Some landfills will require monitoring wells to verify their assumed pollution, and some others will have to be equipped with monitoring systems which will provide us with quantitative and qualitative parameters of the contamination. When summarized, all this information will make it possible to propose further measures aimed to liquidate the numerous unmanaged landfills in the Protected water-resource area Žitný ostrov.

Translated by M. Böhmer

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MÁRIA KOVÁČIKOVÁ

Skládky odpadov na území chránenej vodohospodárskej oblasti Žitný ostrov

Resumé

Uvedená kategorizácia skládok podľa vplyvu na životné prostredie poukazuje na celkovú situáciu CHVO Žitný ostrov. Pre oblasť je charakteristický veľký počet skládok zakrytých — zrekultivovaných — 52, čo je 23,7 % z celkového počtu. Len jedna skládka bola zaradená do III. kategórie — nebezpečné skládky, hoci tri skládky v kategórii IIb sú na rozhraní IIb—III.

45 skládok (20,54 %) je zaradených do I. kategórie. Sú to skládky neškodné, predstavujú len estetickú záťaž prostredia. Ich likvidácia by vzhľadom na malé objemy nemala byť problematická.

121 skládok (55,25 %) je zaradených do II. kategórie a spolu so skládkami III. kategórie vyžadujú ďalšiu pozornosť.

Z hľadiska ďalšieho postupu je potrebné lacnými prieskumnými metódami overiť zaradenie do príslušných kategórií. Odporúča sa využiť najmä geofyzikálne metódy prieskumu, ktoré umožňujú na určitej úrovni upresniť charakteristiku odpadov — mocnosť, materiálové zloženie i charakteristiky prostredia — hĺbku a priebeh podložia, jeho litologické zloženie, hydrogeologické parametre, smer šírenia znečistenia, jeho dosah a pod. Na niektorých skládkach bude nutné vybudovať kontrolno-indikačné vrty na overenie predpokladaného znečistenia, na iných monitorovacie systémy, ktoré umožnia určiť kvantitatívne a kvalitatívne parametre znečistenia. Sumarizáciou všetkých týchto informácií bude možné určiť ďalší postup pri likvidácii veľkého počtu divokých skládok na území CHVO Žitný ostrov.

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MARTIN ONDRÁŠIK

Assessment of environmental geofactors in broader vicinity of Vrícko

(4 figs., slovak summary)

Abstract. Problems related to environment protection require new, up-to-date techniques in technical as well as natural sciences. The contribution of geological sciences to this topic involves study and mapping of geological environmental factors (geological hazards) which are dealt with also in this article.

Geological environmental factors described in this paper have been analysed on a model territory in broader vicinity of Vrícko. Three factors, which are the most important from the viewpoint of anthropogeneous activity, have been mapped and illustrated on analytic multipurpose regional maps of predisposition to slope failures, weathering and erosion.

Introduction

The old days when it was possible to carelessly affect and damage the environment are over. We now face the problem how to relieve the results of our past careless attitude, how to prevent further devastation of the environment and to achieve an optimum harmony between the man and the nature.

To achieve such a harmony, it is necessary to know all environmental aspects of our neighbourhood so that we can adapt ourselves to them and/or cope with them. The only way to achieve this state is a wide cooperation among working teams of diverse geoscientific disciplines. That is why several teams directed by the Dionýz Štúr Institute of Geology in Bratislava prepare an album of maps environmental geofactors on scale 1:50 000.

There are a number of reasons why human activity moves more and more into areas unfavourable from the geological and geomorphological points of view. In such areas, an unsuitable activity may result in various adverse geodynamic and hydrogeological phenomena (e. g. erosion, weathering, slope failures, groundwater contamination, dewatering of rock environment etc.) which devastate the territory as well as threaten the construction of new structures and safe usage of existing ones.

The territories posing geological, geomorphological and engineering problems undoubtedly comprise mountain areas and therefore these should be paid much more

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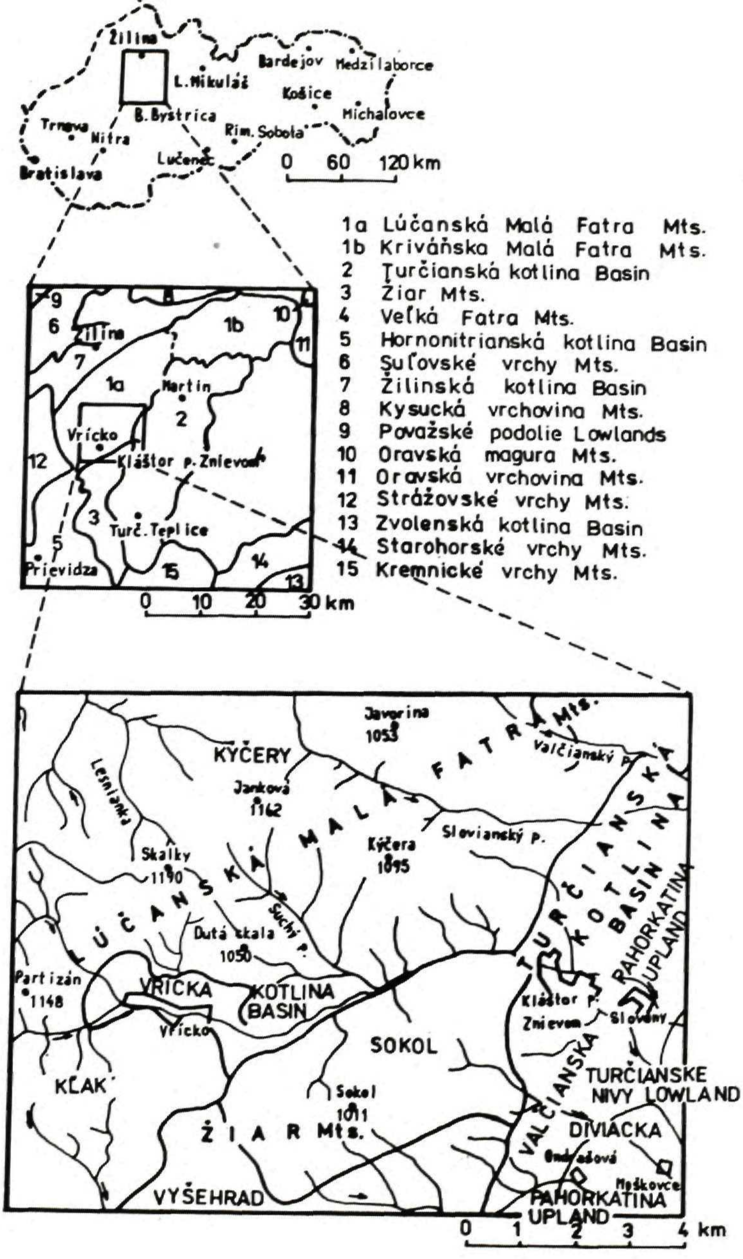


Fig. 1 Schematic location of model territory with limits of geomorphic units (after Atlas of the Slovak Socialist Republic, 1980)

attention than they are at present. That is the reason why we carried out studies on a model territory situated between the Žiar and Lúčanská Malá Fatra Mts. (vicinity of the village of Vrícko, Fig. 1). Our model was aimed at obtaining initial material for a discussion on a wide spectrum of problems invariably associated with each new, emerging idea. The crucial problems are: which theoretical premises should be employed, which phenomena should be studied and how they should be treated as well as how to compile maps of environmental geofactors, what should be included in these maps and how they should be presented to potential users. The above brief review of problems suggests that the spectrum of questions to be answered is really wide.

Methodic procedures applied to solve the task

The available definitions and classifications given in encyclopedic and professional literature (see Regulations on the compilation of engineering-geological maps 1983, Regulation N° 1/1989 on the compilation of engineering-geological maps 1989, MOLDAN, 1983, MATULA–ONDRÁŠIK, 1990, REZNÍČEK–PAŠEK–ZEMAN, 1980, ONDRÁŠIK, 1989, PETRO et al., 1989) clearly indicate that the term "geological environmental factor" does not imply any new phenomenon in our neighbourhood. The assessment of geological factors on a given territory essentially represents a sort of programmed evaluation of known geological phenomena and processes affecting the environment, their comprehensive observation and evaluation in the interaction with human activity. This procedure is aimed at the optimum utilization of the territory concerned, minimizing environmental impact of any kind and creating good harmony between the man and the nature as was mentioned earlier in this article.

The only way to obtain this optimum state is to map the present-day environment and prognose its hypothetical development under diverse conditions. One of the most effective means of expressing the most significant constituents of geological environment in relation to human activity is a geological map. Among various kinds of engineering-geological maps, so called "Maps of geological environmental factors" are increasingly employed to illustrate environmental phenomena. Their contents and character should be simple so that even a nongeologist can easily understand them and at the same time they should supply information for databases of the geographic information system that is currently being prepared.

To achieve this, three maps of environmental geofactors were compiled in the above-mentioned model area near the village of Vrícko as part of ONDRÁŠIK's (1989) diploma work:

Map of predisposition to slope failures (Fig. 2)

Map of predisposition to weathering (Fig. 3)

Map of predisposition to erosion (Fig. 4)

The maps are analytical multipurpuse ones with elements of prognosing, compiled in the form of engineering-geological regions. Such a regional division assessing geological environment of the studied territory with its engineering-geological properties differs from a typologic regional division because the latter evaluates the geological environment regardles of the relief (solely the geological structure). Such a regional division was most clearly reflected in a map of predisposition to erosion in which individual regions were evaluated with respect to their geological structure, engineering-geological properties of rocks, length and energy of slopes. The climatic conditions throughout the investigated territory were classified as uniform.

A crucial precondition to the compilation of these maps was the existence of a geological map on scale 1:25 000 compiled by Rakús et al. (1984) and related report as well as the existence of other works on engineering-geological and hydrogeological situation in the broader vicinity (such as Böhm et al., 1971, Ondrášik–Hyánková, 1981). Further source of information was aerial imagery and materials deposited at Geofond.

The compilation on the maps was preceded by detailed field mapping and recording geodynamic phenomena in the model territory. The field works were performed by Modlitba in 1984 as part of slope-deformation registration project and by the author of this article in 1986 and 1987 as part of his diploma work.

Physical-geographical situation on the territory

The model territory is shown in Fig. 1. Its area totale 114 km^2 and, according to the valid orographic division (Atlas of the Slovak Socialist Republic, 1980), belongs into three orographic units:

1. *Lúčanská Malá Fatra Mts.* – this mountain range is further subdivided into the units Kýčery, Kľak, Vrícka dolina valley. The territory's morphology is dominated by Mt. Partizán (1147.8 m above sea level), Dutá skala (1050 m) and Skalky (1 190.2 m). The relief is mountainous, covered with woods, the lower elevations being occupied by grassy hills. This orographic unit comprises almost the whole northern tract of the territory in question.

2. *Žiar Mts.* – this mountain range is further subdivided into two parts: Sokol and Vyšehrad. It occupies the central and southern parts of the studied territory. This mountainous and wooded area is dominated by Mt. Sokol (1010 m above sea level).

3. *Turčianska kotlina Basin* – this unit occupies the whole eastern tract of the investigated territory. It is further subdivided into the Valčianska pahorkatina Upland, Diviacka pahorkatina Upland and alluvial plains Turčianske nivy.

The geomorphological character of the territory is controlled by the lithology and tectonics. The relief is dominated by Alpine landforms with steep slopes.

The areas underlain by crystalline rocks generally have a fairly smooth relief. In contrast, Mesozoic rocks of the Krížna nappe give rise to a more rugged topography.

Depressed landforms largely occur on soft rocks such as marls, claystones, marly limestones which are abundant in the Cretaceous series (mostly Albian), Carpathian Keuper and Lunz Member.

Elevated landforms evolved on solid rocks such as limestones, dolomites, radiolarites etc. which commonly occur in Triassic and Jurassic series. Layers of solid rocks amidst semirocks frequently form conspicuous steps, e. g. in the Skalka area where Lower Cretaceous marly limestones are intercalated with limestones.

The Šturec nappe is mostly present in the form of outliers giving rise to cliffs (Dutá skala).

The Strážov nappe forming the Sokol massif gave rise to a notable erosion relief with steep slopes developed on the Wetterstein Dolomites characterized by angular disintegration.

The territory concerned is highly dissected, mainly by fault tectonics which, at least in some areas, is directly responsible for landslides (RAKÚS, 1984).

From the hydrographic point of view, the studied territory is part of three drainage areas: those of Turiec, Rajčianka and Nitra River. The watershed leads through the highest peaks of the main ridges of the Lúčanská Malá Fatra and Žiar Mts.

The predominant part of the territory is drained by the Turiec River with its left-hand tributaries Vríca and Valčiansky potok along with its tributary Sloviansky potok (96.4 km^2). 12.2 km^2 are drained by Lesnianka, a right-hand tributary of the Rajčianka River, and a more 5.5 km^2 are drained by left-hand tributaries to the Nitra River.

Geological structure of the territory

The oldest, pre-Mesozoic complexes on this territory occur in the crystalline core of the Lúčanská Malá Fatra Mts. They occupy only an insignificant area near the northern edge of the map sheet. The complexes include medium-metamorphosed psammitic-pelitic series, biotite paragneisses with indistinct schistose structure and medium-grained massive biotite granodiorites with quartz phenocrysts visible by unarmed eye.

The Tatric envelope series are nowhere exposed on the surface. Their absence can be explained by the existence of Valča fault as well as by the fact that the Tatric envelope is overlain by the Krížna nappe.

The territory concerned is dominated by Mesozoic series, mainly by the Krížna nappe (covers 69 % of the area) here represented by the Zliechov development. Its oldest members are thick-bedded Ladinian limestones overlain by dolomite, limestone, marlstone, marly-limestone, claystone, radiolarian-limestone, radiolarite and sandstone series of diverse thicknesses continuing uninterrupted until the Middle Cretaceous.

These complexes are in turn overlain by outliers of Šturec nappe composed of limestones, dolomites and a thin claystone intercalation (Lunz Member). The rocks range from the Anissian to Norian. In the southern, tectonically sunken tract of the territory, this nappe makes up a relatively significant percentage of the Žiar Mts.

Owing to tectonic downthrowing of this block, the Strážov nappe was preserved above the Šturec nappe in the Sokol massif. The former consists of Middle Triassic limestones and dolomites, largely the Wetterstein Limestones characterized by their noticeable angular decomposition.

No Inner Carpathian Paleogene sediments occur on the studied territory but there is no doubt that they covered at least a part of it (RAKÚS et al., 1984).

The Turčianska kotlina Basin is largely filled with Neogene sediments (whole eastern tract of the territory concerned) which have been assigned into the Pannonian. These clastic rocks (clays, claystones, gravels, sandy gravels, sandstones, conglomerates) are dominated by pelitic rocks which account for more than 50 % of the filling. The sandy gravels are unsorted, the average size of the pebbles is 2–3 cm, exceptionally 7 cm. The gravels and conglomerates consist mainly of limestone pebbles.

Apart from the bedrock composition, the deposition of the Quaternary sediments is closely associated with the neotectonic and geomorphological evolution of the territory whose central part is occupied by the Turčianska kotlina Basin. This process persisted from the Badenian till the present day, i. e. it has been going on for some 15 million years (Ondrášik, 1988, Ondrášik–Rybář, 1991).

Minor landforms were shaped by selective erosion, largely along faults. Neogene erosion is suggested by the presence of mainly gravel accumulations in the adjacent part of the Turčianska kotlina. Following an onset of cold climate in the Quaternary, alternating cold and warm periods were dominated by deep erosion and slope erosion, respectively. The earliest stream terraces above the present-day Turiec River indicate that the depth of the Quaternary erosion reached about 40 m (Halouzka in Rakús et al., 1984), i. e. on average some 0.05 mm per year.

The products of Neogene and Quaternary weathering moved downslope mainly as a result of run-off, volume changes due to intermittent freezing and thawing, solifluction, intermittent streams and downslope movement. In the lower altitudes, the weathering products accumulated in the form of deluvia, largely on the periphery of the mountain range. The deluvium is mostly loamy-stony, on steep slopes stony.

Part of the deluvial material reaches streams which, in the upper portions, flow through steeply inclined valleys and therefore are able to transport fairly large fragments, particularly at increased water levels. When the streams reach the flat basin, the stream gradients abruptly drop and their load is laid down in the form of fluvial sediments.

Hydrogeological setting

From the hydrogeological point of view, the studied territory can be divided into four units:

1. Hydrogeological unit of the Malá Fatra crystalline. It is positioned at the northeastern edge of the studied territory (NE of the Valčianska dolina valley) and is composed of granitoid rocks. From the hydrogeological viewpoint, the rocks are of little importance as they are unsuitable for large groundwater accumulations feeding significant springs. The observed springs have low yields (max. 0.5 l/s, mostly 0.1 to 0.2 l/s). In spite of the absence of significant springs, the valley drained by Trebostovský potok brook has a relatively high specific run-off which indicates that the rocks here are highly fractured and/or faulted and the Quaternary sediments are considerably permeable.

2. Hydrogeological unit of Mesozoic rocks. Three basic, hydrologically distinctive rock groups can be established within this lithologically variegated unit:

– Werfenian, Lunz, Keuper, Jurassic and Cretaceous formations composed of shales, marls and sandstones. Hydrogeologically, these rocks make up a slightly permeable to almost impermeable complex acting as an aquiclude above and below aquifers, mostly Middle Triassic limestones and dolomites.

– a variegated group of marly limestones, Cretaceous limestones, cherty limestones and spongolite limestones ranging from the Triassic to Neocomian. In these formations, fissure permeability mostly prevails over karst one. Clayey, marly and sandy admixtures in the limestones reduce or even completely supress their permeability.

– Middle Triassic limestones and dolomites. In the limestones, karst permeability prevails over fissure one. In addition to large and concentrated springs, the limestones are characterized by karst relief with its typical vegetation and scarce surface streams. Such important hydrogeological structures occur in Valčianska and Slovianska dolina valleys where karst springs have a yield as much as 40–58 l/s and 53–94 l/s, respectively (Kullman in Rakús et al., 1984) and in the Žiar Mts.

Vast areas in the Žiar Mts. Mesozoic complex are covered by the Šturec unit and Strážov unit dolomites. They are drained by a number of springs situated on the periphery or in the centre of the mountain range above impermeable rocks of the Krížna unit. Their abundance depends on the prevailing rock type (limestones or dolomites). The northern tract is drained by Vrícky potok brook, either directly or through minor springs scattered in the Predvrícko area. More concentrated springs occur in the SW part of the mountain range dominated by limestones.

3. Hydrogeological unit of Neogene rocks is composed of impermeable clay layers as well as permeable gravel, sand, conglomerate and sandstone beds. These nearly horizontal alternating permeable and impermeable layers are a precondition to the formation of confined pressure aquifers filled directly with groundwaters from the mountain range, particularly in places of their tectonic contact with Triassic carbonates.

The groundwater level is fairly deep (below the range of common excavations). Only in spring and in depressions can the groundwaters approach the surface.

The Neogene sediments are exposed directly on the surface or are covered with alluvial deposits thus forming a single aquifer with an alluvial regimen (Kláštor pod Znievom area).

4. Hydrogeological unit of Quaternary rocks is characterized, from the hydrogeological point of view, mainly by marginal conditions controlling the depth of the groundwater level and its regime. It allowed to distinguish the following types (Böhm et al., 1971):

a) Flood-plain sediments with their groundwater regine controlled by the amount of water in the stream.

b) Alluvial fans whose groundwater regimens are intermittently controlled by the surface streams and rainfall.

c) Deluvial-eluvial sediments of little hydrogeological importance.

A fairly significant hydrogeological unit is the alluvial fan of Vríca brook. Its detailed hydrogeological characteristics, however, are only available for a combined complex of Quaternary and Neogene gravels. The yields of individual drilled wells in these gravels very from 3.8 to 14.6 l/s at groundwater level lowering of 1.5–2 m (Bujalka, 1973).

Modern geodynamic phenomena

The present-day relative stability of earth-crust verical movements in the Turčianska kotlina area has been proved by accurate geodetic measurements put forward by Vyskočil (in Böhm et al., 1971). Nevertheless, some geomorphic phenomena attest to minor contemporary differentiated movements along individual faults. The recent movements are indicated, for instance, by some conspicuous steps and gullies in soft rocks of the Turčianska kotlina Neogene filling as well as by Paleogene sandstones thrust onto several-tens-of-cm-thick alluvial gravels as was noted by Záruba (in Ondrášik–Rybář, 1991) in the excavations for the Krpeľany dam. They also disturbed Quaternary sediments in an alluvial fan below Kláštor pod Znievom and affected the morphology of the present-day Turiec river bed (Böhm et al., 1971).

Geological structures most likely to cause slope failures occur in the valleys of Valča, Sloviansky potok, Suchý potok and Vríca, which is also suggested by a number of landslides at these localities. Elsewhere throughout the studied territory there are virtually no slope failures.

These geological structures include (Modlitba in Rakús et al., 1984):

a) slope loams of loamy to loamy-stony character on poorly permeable substratum or with loamy-clayey layers (surface landslides),

b) formation of solid rocks and semirocks of claystone-marlstone character intercalated with claystone-, dolomite- or sandstone-type solid rocks (creep movement in deeper zones),

c) highly fractured limestone- and dolomite-type solid rocks forming cliffs of rugged relief (blocks rolling downslope).

Another ongoing process is karst. However, only scarce quantitative data on the subject are so far available. Its presence is suggested by large karst springs in Slovianska dolina, rare small caves formed on fold-fault structures (Dutá skala) and minor karst manifestations on rock outcrops, such as karren and limestone karstification along fissures. No significant karst phenomena have been noted on the territory of the map sheet concerned.

Serious problems arise from recent disintegration (weathering) of dolomites on the erosional relief and in artificial excavations in the rock environment. The dolomite breaks into angular fragments (angular disintegration of the Wetterstein Dolomites) which are often subsequently transported downslope by solifluction to form extensive deluvia at foothills.

The contemporaneous processes are caused not only by the natural environment but also by human activity. These anthropogeneous processes considerably affect the shaping of the relief. Deforestation, which has been going on since historic times till the present day, triggered areal erosion that in turn is responsible for increased load in local streams.

The studied territory falls into seismicity categories 7–8 MCS and 8 MSK-64 (Czechoslovak standard 73 0036). Since 1400, no earthquake epicentre was situated on the territory concerned. The nearest noted earthquake epicentres were on Mt. Šturec and near the village of Necpali in the Veľká Fatra Mts., near the town of Martin in the Turčianska kotlina and close to the town of Rajec in the Rajecká kotlina Basin (Schenková–Kárnik–Schenk, 1984).

Analysis of environmental geofactors

The mapped territory is dominated by Alpine relief composed of Mesozoic rocks. Only insignificant area in the northeastern part consists of crystalline rocks which gave rise to a relatively gentler mountain relief, and the eastern part with its hilly topography is composed of Neogene sediments.

The whole territory is covered with young Quaternary sediments of variable thicknesses. They exceed one-meter thickness only in places favourable for their accumulation: flood plains, surface depressions, on readily weathering substratum, on tectonically fractured rocks, in places of slope failures and on foothills.

Thanks to its gentle, smooth morphology, the eastern part of the territory is fairly thickly populated (with residential, production as well as linear structures) and intensively farmed on.

The central and western parts of the territory serve as a rich source of wood, pastures as well as recreational resort (State Natural Reserve Kľak). The only noteworthy man-made structures are the village Vrícko in the Vrícka kotlina Basin and recreational facilities in Valčianska dolina valley. The area is an important groundwater reservoir, in Valčianska and Slovianska dolina valleys there are artificial groundwater springs.

Residential buildings concentrate on foothills, i. e. in places of the largest deluvial accumulations which, when resting on a poorly permeable or impermeable substratum, form an ideal landslide structure. The landslide hazards increase, if the foot of the slope is carelessly removed. That is why it is desireable to identify in time places of potential slope failurews. Possible hazards are illustrated with the example of the construction of an up-to-date assembled two-storey charity house in the village of Vrícko. Excavations here removed the foot of the slope which was replaced only by an insufficient, shallow unanchored support wall. The slope foot is composed of loamy to loamy-stony water-bearing deposits of a recent landslide and therefore, if not properly dewatered, the renewal of slope movements is only a question of time.

Similarly, construction of forest roads (and their maintenance) necessary for mechanized logging as well as the logging itself imply a number of problems. Roadcuts excavated in steep slopes at unfavourable places, without proper drainage of surface waters, trigger new or resume pre-existing slope failures. Such phenomena took place in Sloviansky potok valley, on the southern slope of Holica and in Suchý potok valley where a forest road was completely destructed. The landslide here also obliterated trees on an area of 100 by 150 m.

The cost of road maintenance depends upon the rate of rock weathering and debris falling from the walls of unprotected roadcuts. This process is particularly intensive in spring when water in fissures intermittently freezes and thaws. Some roadcuts are gradually obliterated and the ultimate slope gradient depends upon the internal-friction angle of the slope material which is subsequently covered with vegetation. Roadcuts made in solid rocks are stable even if their height is considerable but the road is permanently or at least temporarily endangered by debris falling from the walls, the process controlled by the fracturing of the rock massif, mainly its near-surface horizons. The most serious problems are associated with roadcuts made in dolomite-type rocks characterized by intensive angular disintegration (e. g. Wetterstein Dolomites in the Sokol area). These readily disintegrating rocks constantly add new fine dolomitic deatritus and so new vegetation is unable to start growing on it. Furthermore, the pre-existing vegetation above the roadcuts moves downslope and ultimately falls onto the road. That is why roadcuts in such rocks require regular maintenance.

Deforestation leads to increased kinetic energy of surface waters and to increased vulnerability of rocks by erosion. Deep wheeltracks made on the forest roads by heavy machinery are suitable routes of concentrated run-off. Gullies are thus frequently eroded, especially in rocks sensitive to the presence of water, such as Carpathian Keuper variegated shales, Middle Cretaceous marly shales as well consolidated and unconsolidated loams with a low filtration coefficient.

On the territory concerned there occur karst waters (in Middle Triassic limestones of Valčianska dolina, Sloviansky potok and Sokol massif) which are most sensitive to contamination. Groundwaters, however, must be protected throughout the territory concerned, and this can only be done by identifying current and potential contaminators, infiltration areas, thorough analysis of the geological setting and its reactions with contaminations etc.

Fortunately, sources of contamination on this territory are much more limited than those in other industrial areas. The worst contamination on this territory is associated with farming: usage of artificial fertilizers, leakage of liquid fertilizers and wastes (dung water), intentional disposing of liquid wastes to abandoned gravel pits. Such contaminations, along with problems associated with residential areas and infiltration of contaminated waters from the Turiec River into alluvial deposits, concentrate in the low-lying sections of the territory.

The mountainous areas are contaminated by seasonal cattle raising, logging machines in bad technical condition, casual carelessness of humans and acid rain.

The spreading rate of contaminants is controlled by the properties of the rock environment and groundwater regime. The areas most vulnerable to contamination are those composed of Mesozoic rocks with karst and fissure-karst permeability. Groundwaters rapidly flow through these systems with a minimum absorbtion. Permeability of this kind prevails in Middle Triassic limestones (Sloviansky potok and Valčianska dolina valleys, Sokol massif). In other Mesozoic units, karst permeability occurs only locally (limestones of Šturec nappe outliers, Krížna nappe limestones ranging in age from the Upper Triassic to Lower Cretaceous). Such karst-permeability aquifers are relatively thin (up to 30 m) and are situated amidst impermeable beds, and therefore their waters are isolated.

The most widespread type of permeability is fissure one typical of all unkarstified limestones, dolomites, sandstones, crystalline rocks etc. Their sorbtion properties depend upon the thickness of fissures and rock type.

Pore permeability occurs in all loams, regardless of their degree of compaction. These include cover Quaternary units and Neogene sediments of the Turčianska kotlina. They often irregularly alternate with impermeable loams. Contamination in them spreads at the lowest rate controlled by their filtration coefficient and sorbtion properties which are here several times better than in solid rocks and semirocks.

Cover formations (together with relief energy) significantly influence infiltration of surface waters. They are the first to contact these waters (with their contaminants) and affect their chemistry.

Serious problems are related to structures built in areas of unsuitable engineering-geological properties or in places threatened by floods. Such cases are mostly confined to valleys of the mountainous areas and in the Turčianska kotlina where all human structures are concentrated and where high groundwater levels (southeastern tract of the territory) as well as loams susceptible to freezing and volume changes occur.

It is also necessary to take into consideration a high degree of seismicity (7 - 8 MCS according to Czechoslovak standard 73 00360 as well as the proximitz of neotectonic Valča fault and other faults whose origin and activity are associated with the neotectonic history of the territory.

The submitted geofactor analysis clearly suggests that slope failures, weathering and erosion are the most significant engineering-geological phenomena in the studied area. Their dynamics and resulting effect control the environment of the model territory. That is why these three geodynamic phenomena as the crucial environmental geofactors were analysed by us in detail, the results being shown in enclosed maps and tables (Figs. 2 - 4 and Tabs. 1 - 3).

Regional division of the territory from the viewpoint of the key environmental geofactors

1. *Slope failures*

According to its predisposition to slope failures, the territory was divided into three principal regions. The individual regions are further divided, according to their geological and structural properties and activity of movements, into several subregions (Fig. 2, Tab. 1).

The region predisposed to slope failures includes active as well as dormant slope failures which can be morphologically recognized in the field and, provided that some conditions are met, they can again become active as rapid slope failures. This region also comprises areas with rock-fall hazards.

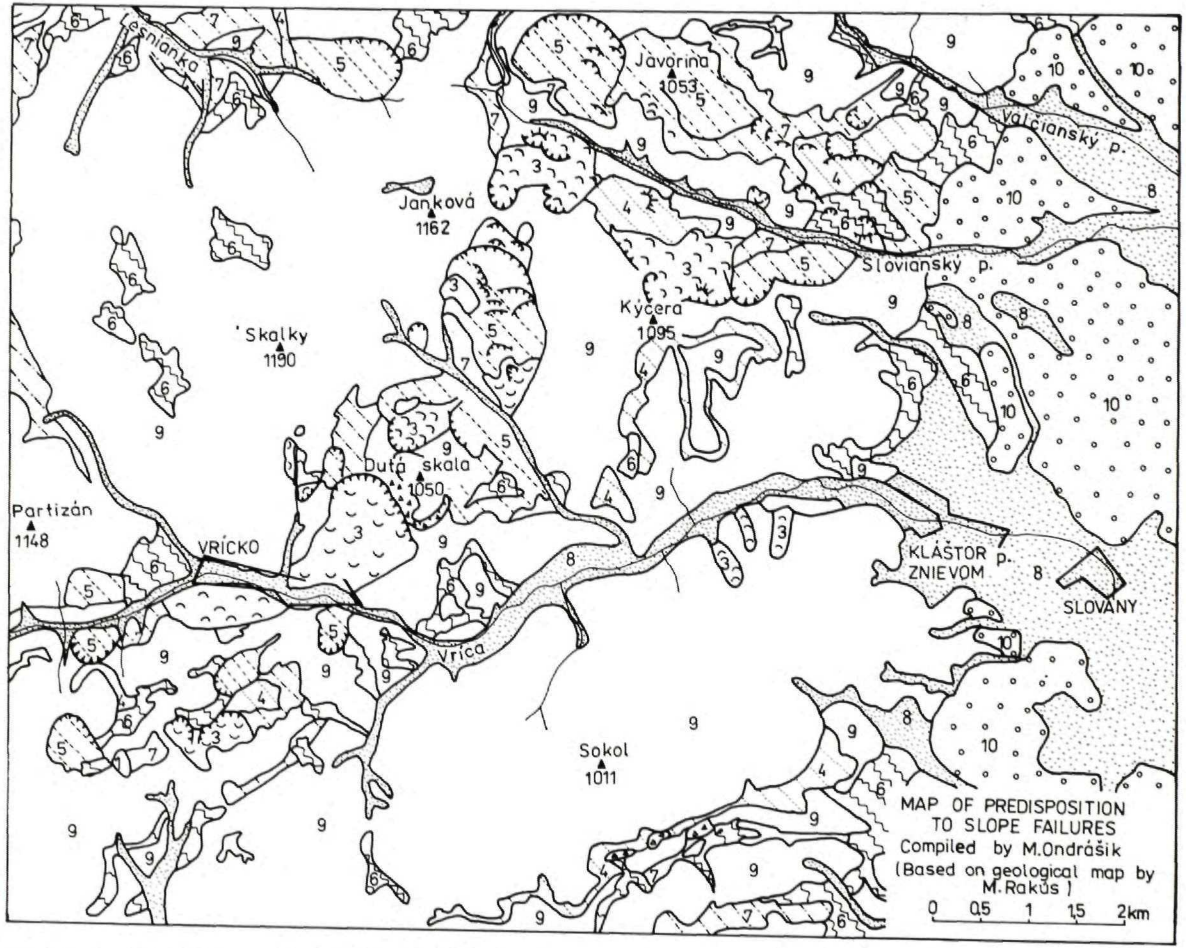
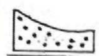


Fig. 2 Map of predisposition to slope failures. Compiled by M. ONDRÁŠIK (based on geological map by M. RAKÚS et al., 1984). For explanations see Tab. 1.

Table 1 Explanations to Map of predisposition to slope failures

Region	Subregion	Schematized Section	Symbol	Geological Setting	Morphological Setting	Hydrogeological Setting	Character of movement and shear plane	Assessment for constructional purposes
Area relatively predisposed to slope failures	recent active landslides		1	slope loams of loamy-stony character above impermeable claystone and marlstone substratum	distinct landslide relief, concave--convex valley bottom	swamps, intermittent springs, hightly water-bearing, infiltration of ground and surface waters into cover layers	planar and combined shear planes, rapid movement even solifluction	any construction impossible
	areas threatened by falling rocks		2	triassic limestones	rock walls and cliffs, talus accumulations, seas opf rock	in rock walls fissure water, high pore permeability in talus accumulations	rolling	unsuitable for construction (possible with special measures)
	stabilized old potential landslides		3	slope loams: loamy--stony, clayey on impermeable marlstone and claystone substratum, locally with carbonate layers of fissure permeability	rock slopes, relief levelled by areal erosion, indistinct limits of preexisting landslides	intermittent springs, swampy depressions	creep movements in shear zones	marginally suitable (with respect to slope energy, deluvium thickness, site and extent of planned construction) stabilization precautions necessary
Area predisposed to slope failures	blocky crevices and fields		4	rock talus and blocks of highly fractured limestones	rock steps, undrained depressions, steep cliffs, hilly relief	fissure water in blocks on impermeable substratum	movements in creep zones	marginally suitable. increased horizontal stresses occur in block foregrounds
	blocks of solid rocks and semirocks on plastic substratum		5	highly fractured carbonates on claystone and marlstone substratum	high planes of division (15 m walls) inclined at 35 – 40°, undrained depressions	intermittent springs and swamps, groundwater regime complicated by movements along shear planes	landslides along rotation shear planes and simultaneous movement in creep zones	marginally suitable (suitable for light structures – chalets forest roads), exploration necessary
	undisturbed slopes predisposed to landslides		6	slope loams of loamy-stony character on semipermeable substratum	slopes without distinct morphological forms (only erosional), straighline or slightly concave--convex valley bottoms	dry slopes, locally swamps and intermittent springs	possible movements in creep zones	marginally suitable (depends on water occurrences, slope energy, thickness of cover unit, extent and site of planned construction)

Table 1 — continuation

Region	Subregion	Schematized Section	Symbol	Geological Setting	Morphological Setting	Hydrogeological Setting	Character of Movement and Shear Plane	Assessment for Constructional Purposes
Stable area	undisturbed slopes composed of semi-rocks sensitive to water		7	slopes composed of claystones and marlstones, unstable in water and impermeable	steep slopes with plant cover, without distinct morphological forms, only erosional gullies, straightline valley bottoms	abundant springs and swamps at base of overlying beds	creep movements controlled by rainfall and freezing depth, weathering degree etc.	marginally suitable (ground and surface water must be drained away)
	alluvial fans and flood plains		8	poorly rounded and angular pebbles with loam	flood plain	pore permeability, groundwater infiltrates from surrounding slopes and streams	no movement	suitable
	steep slopes and ridges in fresh solid rocks		9	solid unfractured limestones and dolomites alternating with marlstones and claystones	steep high slopes	fissure and karst waters, stratal springs, stable hydrogeological regime	no movement	suitable
	hills and plains composed of Neogene sediments		10	mostly dolomitic poorly rounded gravels, locally sand and clay layers	upland gradually passing into plain, gently slopes	pore permeability, continuous water table, possible occurrence of artesian waters	no movement	suitable

The region is unsuitable for construction or, with respect to the concrete site and construction project, activity and characteristics of the slope failure, it can be viewed as marginally suitable. Any construction in this region requires detailed exploration, extensive precaution measures, and permanent monitoring and maintenance once the structure was erected.

The region relatively predisposed to slope failures comprises slopes with creep deformations, blocky fields and crevices as well as undisturbed slopes with a thick loamy-deluvial cover.

Unwise activity in this region may trigger slope failures on a previously stable slope or resumption of blocky-field-type deformations. That is why such areas should be classified as marginally suitable. The construction conditions must be individually assessed in each single place with respect to the projected construction site, extent of the construction on the concrete geological structure.

The stable region includes slopes made up of fresh, resistant rocks of considerable stability degree, hilly areas underlain by Neogene gravels and alluvial plains. Such areas in their natural form display no signs of slope failures. Minor landslides may locally occur only in excavated foundation pits (even in plains) and in deep cuts made in susceptible rocks (KRIPPEL, 1988).

Although the territory may be regarded as suitable for construction, the proposed construction site should be assessed individually with respect to its concrete engineering-geological situation (material inhomogeneity, high relief energy, complicated tectonic structure etc.).

2. *Weathering*

The whole territory was divided into four regions on the basis of its predisposition to weathering. The individual regions are further divided, according to their geological structure, into several subregions (Fig. 3, Tab. 2).

The region of rocks predisposed to weathering includes thick layers of marlstone- and claystone-type rocks interbedded with thin layers of more resistant rocks (limestones, dolomites, sandstones etc.) and tectonically fractured dolomites with intensive angular disintegration.

In their natural state, the rocks are not subjected to intensive weathering as they are protected by plant cover and weathering products. If this natural shield is removed, however, they undergo rapid weathering. Marly and clayey rocks change their volume in response to the water content. Dolomites of angular disintegration are also decisively influenced by the presence of water. Alternating drying up and watering, freezing and thawing cause intensive weathering advancing depthward into the massif. If the weathered material is eroded away or is removed in any other way, the process continues at a steady rate. If the weathered material remains in place, the process slows down or even completely stops provided that the protective layer (new weathering crust and plant cover) is sufficient.

The region of rocks relatively predisposed to weathering comprises variegated formations composed of readily-weathering rocks (marlstones, claystones) alternating

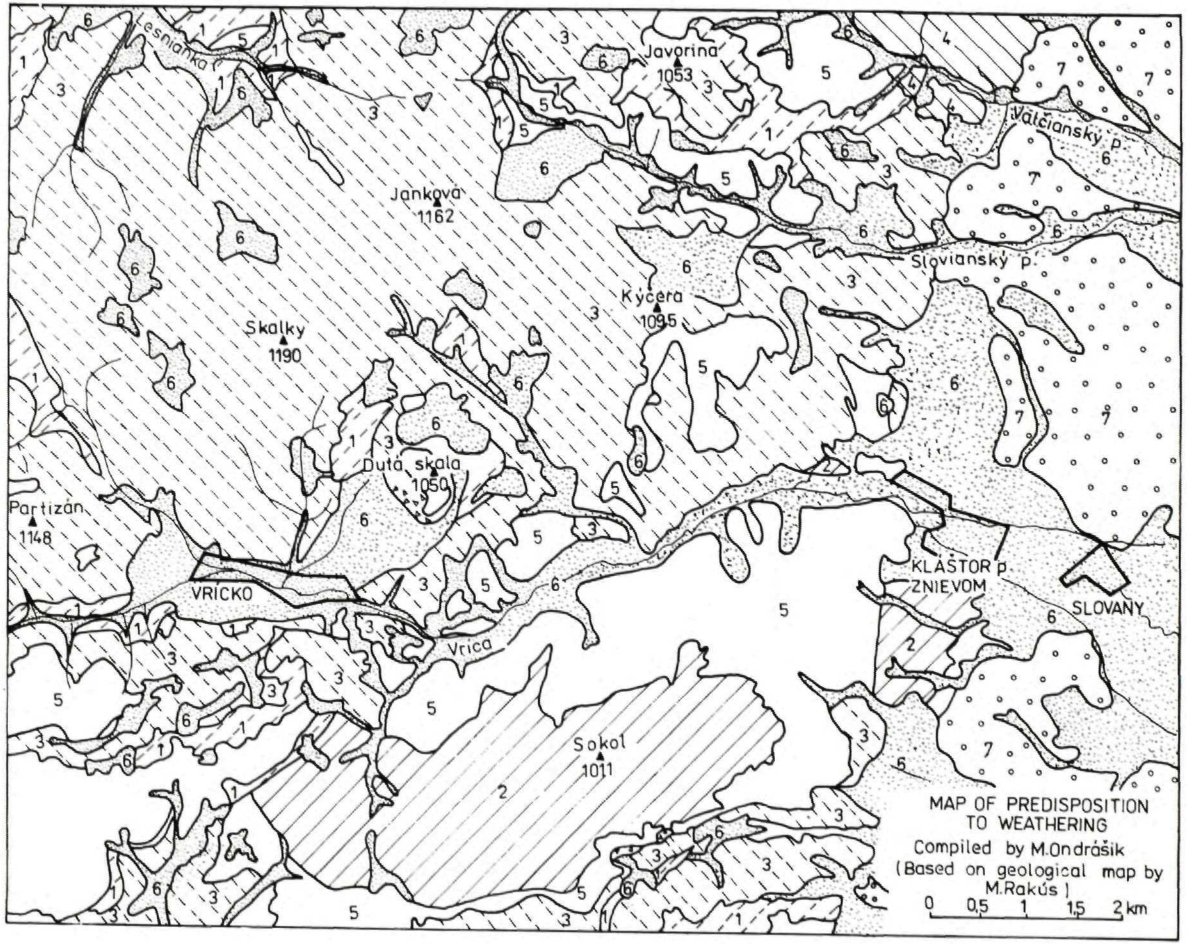


Fig. 3 Mpa of predisposition to weathering. Compiled by M. Ondrášik (based on geological map by M. Rakús et al., 1984). For explanations see Tab. 2

Table 2 Explanation to Map of predisposition to weathering

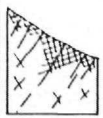
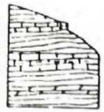
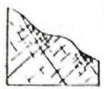
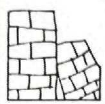
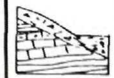
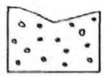
Region	Subregion	Schematic Section	Symbol	Geological Setting	Morphological Setting	Hydrogeological Setting	Processes and changes caused by Water	Character of Weathering	Behaviour in open Construction Pits and Cuts
Area composed of rocks relatively predisposed to weathering	thick marlstone and claystone layers		1	Carpathian Keuper (varie-gated claystones, dolomites sand-stones), marl-stones of Mid-dle Cretaceous	steep slopes (unfractured Keuper), flat ridges, gentle slopes, negative landforms, gul-lies, landslide relief	impermeable material, abun-dant springs of small yield at contact with overlying rocks, swamps	unstable volume swelling, free-zing, increa-sing viscosity, decreasing ϕ	mostly intensive disintegration, compact delu-vium is formed	in dry state even steep slopes hold, only small frag-ments are mechani-cally loosened, weathering does not proceed depthward; in wet state it swells, its visco-sity increases, small landslides may oc-cur, weathering pro-ceeds to depth, up to 30 cm of weathe-ring crust may be formed annually
	dolomites of in-tensive angular disintegration		2	dolomites of int. angular dis-integration into dolomite rubble	high steep slopes narrow ridges, deep narrow V-shaped valleys, distinct erosion-al relief	fissure perme-ability, springs of small yield, shallow ground-water circula-tion	water-resistant large accumula-tions of dolo-mitic talus may cause loam-stone flows after heavy rains	mostly very in-tensive disinte-gration, uncon-solidated delu-vium is formed	in dry state frag-ments intensively break off the walls, disintegration pro-ceeds deep into the walls thus under-cutting the slope and destructing plant cover above the cut, in wet state the process in-tensifies especially by alternating freez-ing and thawing, due to erosion, dis-integration process in cuts and pits proceeds mainly la-terally

Table 2 — continuation

Region	Subregion	Schematic Section	Symbol	Geological Setting	Morphological Setting	Hydrogeological Setting	Processes and changes caused by Water	Character of Weathering	Behaviour in open Construction Pits and Cuts
Area composed of rocks predisposed to weathering	variegated formations		3	alternating layers of solid rocks and semirocks limestones, dolomites) marlstones, claystones etc.), frequently thick deluvia	steep or gentle slopes, flat wide ridges, locally landslide relief, fresh solid rocks locally form rock steeps	alternating aquifers and aquicludes (fissure and fissure-karst permeability), abundant springs of small yield, intermittent swamps, shallow groundwater circulation	marlstones and claystones swell when wet, their viscosity increases, ϕ decreases; limestones and dolomites are water-resistant	slight disintegration and decomposition, consolidated deluvium is mostly formed	in dry state even steep walls hold, only small fragments break off mechanically, in wet state this process intensifies due to increased viscosity of unstable-volume members, water pressure etc., solid rocks make up a framework preventing fast weathering
	massive solid rocks, intensively tectonically fractured		4	intensively tectonically fractured solid rocks granodiorite, biotite paragneiss)	high rounded slopes, deep and wide valleys, wide ridges	fissure permeability, shallow groundwater circulation, abundant intermittent springs of small yield	chemical weathering intensifies	slight disintegration and decomposition, unconsolidated deluvium is mostly formed	in dry state rock fragments only exceptionally break off the walls, in wet state due to torrential rains and particularly repeated freezing and thawing the weathering process intensifies, particularly along dense discontinuity planes
Area composed of rocks resistant to weathering	massive solid rocks		5	limestones, dolomites	rock walls, steeps table mountains, high steep slopes	fissure-karst permeability, exceptional springs of high yield/karst springs	water-resistant	very slight decomposition and disintegration, unconsolidated deluvium is formed	in dry and wet state forms safe vertical walls, fragments and large blocks casually break off due to quarrying and blasting. Natural weathering visible after decades

Region	Subregion	Schematic Section	Sym-bol	Geological Setting	Morphological Setting	Hydrogeological Setting	Processes and changes caused by Water	Character of Weathering	Behaviour in open Construction Pits and Cuts
Area composed of redeposited weathered material	alluvial and deluvial soils		6	clayey, loamy and loamy-stony soils, in alluvia — loamy gravels	gentle deluvium--covered slopes, landslide relief, flood plains	highly aniso-tropic perme-ability – poorly permeable along beds, imperme-able across beds	unstable volume swelling, free-zing, their vis-cosity increases, ϕ decreases	volume changes, consolidated deluvium, un-consolidated gravels	in dry state even steep walls hold, fragments break off only mechanically, in wet state the process intensifies, construction pits may suffer from sliding and soliflucion
	gravels		7	mosly molasse Neogene gravels	hills, flood plain	pore permeabili-ty, free ground-water table, pos-sible occurrenc-es of confined groundwater level	water-resistant	slow decomposi-tion, unconsoli-dated	in dry state gravels hold even in vertical walls, only casually break off mechani-cally, in wet state disintegration inten-sifies due to water pressure, maximum disintegration takes place in spring and autumn
	talus		8	accumulations of rock frag-ments to blocks of carbonate	talus fans, seas of rock	very good pore permeability	water-resistant	slight decompo-sition, unconso-lidated	in dry and wet state cannot support steep walls, in wet state the process in-tensifies due to water flow pressure

with layers of more resistant rocks (marly limestones, radiolarian limestones, sandstones, limestones, dolomites etc.). The region also includes tectonically fractured crystalline rocks (granodiorite, biotite paragneiss). In open construction excavations their weathering continues fairly quickly. The weathering proceeds under conditions similar to those described in the foregoing region, but here the rapid weathering of some constituents is slowed down by the presence of more resistant rocks. Members resistant to weathering sometimes weather out selectively, with regard to their fracturing, and shield the little resistant rocks from the direct influence of water and exogene agents.

The region of rocks resistant to weathering consists of massive compact rocks which are not fractured and faulted (limestones, dolomites). Occasional disintegration and falling of rock fragments from the walls are caused by prolonged exposure to alternating freezing and thawing of water in natural (tectonics, bedding etc.) or man-made fissures (blasting, quarrying).

The region of redeposited weathered material includes all redeposited and weathered materials whose thickness exceeds 1 m, i. e. Quaternary and Neogene sediments. Weathering can possibly affect only gravels (chemical weathering), but its effects are insignificant. That is why we may state that the region's rocks are resistant to weathering, because they already underwent this process and adapted themselves to the new physico-mechanic and chemical conditions.

3. *Erosion*

The territory is divided into three principal regions according to their predisposition to erosion. The regions are further divided into subregions with regard to erosional manifestations after the natural conditions were artifically changed (assessed were geological structure, engineering-geological properties of rocks and relief energy), (Fig. 4, Tab. 3).

The region predisposed to erosion is composed of thick claystone and marlstone formations (Carpathian Keuper, Middle Cretaceous), loamy and loamy-stony deluvial material, dolomites with intensive angular disintegration and Neogene gravels. The whole region has a high relief energy and is divided into two subregions: 1. area with significant erosional manifestations and 2. area with significant erosional manifestations due to human activity which disturbed the natural state. In the first case the territory contains crevices and gullies eroded on tectonically pre-weakened zones, slides of fractured rocks, areas disturbed by logging and grazing as well as intensive run-off. In the second case, the engineering-geological properties of rocks and relief energy are favourable for erosion which, however, did not take place yet. Devastating erosion may be started by removing the plant cover or damaging the surface by heavy machines. Erosion is supported mainly by intensive weathering of this material and its vulnerability to water. The stream load ranges from particles hundredths of millimeter in size to centimeter-large fragments.

The region relatively predisposed to erosion includes tectonically fractured and weathered compact rocks (granodiorite, biotite paragneiss) as well as variegated

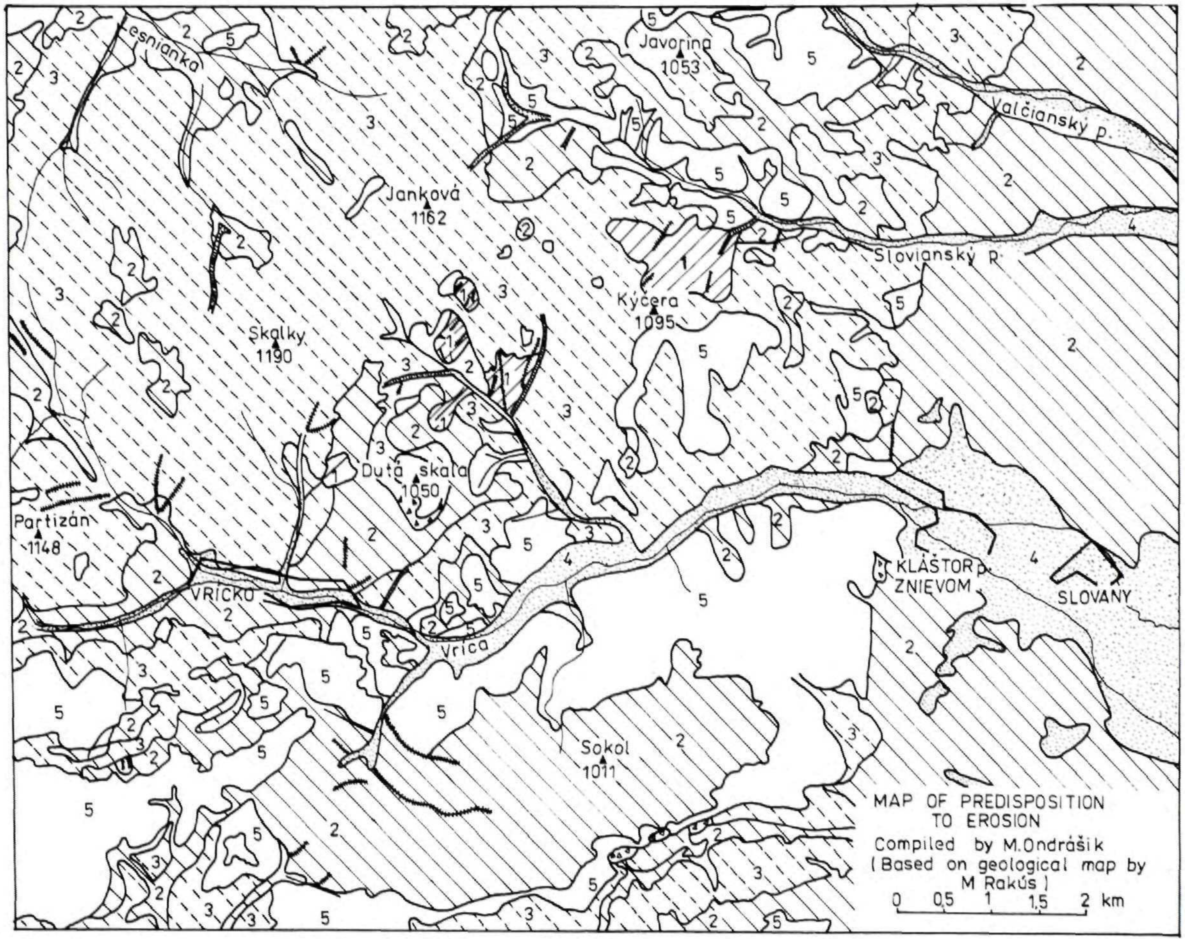


Fig. 4 Map of predisposition to erosion. Compiled by M. ONDRÁŠIK (based on geological map by M. RAKÚS et al., 1984). For explanations see Tab. 3

Table 3 Explanations to Map of predisposition to erosion

Region	Subregion	Symbol	Geological Setting	Morphological Setting	Size of transported Particles	Erosion Character
Area predisposed to erosion	area with significant manifestations of erosion	1	loamy and loamy-stony deluvium, thick mostly claystone and marlstone formations disturbed by logging, slope failures etc.	active erosional gullies and scours, landslide rugged relief	from clay particles to tens of centimeters large solid rock fragments	distinct gully to scour erosion in tectonically pre-weakened zones, areas of recent logging, in places of strong water influx
	area with significant manifestations of erosion caused by human activity	2	1. dolomite of intensive angular disintegration 2. Neogene gravels 3. mostly claystone and marlstone rocks — undisturbed (slope failures due to excessive water influx etc.), deluvial-eluvial sediments	1. high steep slopes, deep narrow V-shaped valleys, distinct erosional relief 2. hilly country with gentle slopes 3. broad flat ridges, gentle slopes	1. mostly angular dolomite fragments several mm to 3 cm large 2. gravels 2 – 3 cm exceptionally 7 cm in diameter 3. clay particles to fragments of undecomposed claystones several mm large	strong erosion after removal of plant cover, erosion advances rapidly due to intensive weathering of dolomites, marlstones and claystones, and loose Neogene gravels
Area relatively predisposed to erosion	area with slight manifestations of erosion caused by human activity	3	1. tectonically fractured and weathered solid rocks (granodiorite, biotite paragneiss) 2. variegated formations or solid rocks and semirocks (limestones, dolomites, marly limestones, marlstones, claystones)	1. high steep slopes, deep valleys, broad ridges 2. high slopes, rock steeps composed of rocks weathering out selectively, locally landslide relief	1. stony deluvium of several mm to tens of cm-large fragments 2. clay particles to 5 cm fragments, exceptionally tens of cm large	after removal of plant cover weathered and loosened material is eroded away, further advance of erosion depends on rate of decay of the massif, more resistant and fresh members protect less resistant ones from erosion
	area with local manifestations of erosion caused by human activity	4	aaluvial sediments (loams and loamy gravels), deluvial-eluvial sediments (loamy and loamy-stony soils), Neogene gravels	flood plain, lowland	from clay particles to 3 cm large gravel pebbles, exceptionally larger pebbles	erosion only in walls of construction pits, intensity depends on time during which the pit is open, in flood plains – lateral stream erosion
Area resistant to erosion	area without erosion even due to human activity	5	seas of rock with boulders exceptionally 3—5 m large, rock talus with fragments 2—6 cm large	seas of rock, rock talus	no erosion	erosion improbable because material devoid of loam has high pore permeability
	area with very slight manifestations of erosion due to human activity	6	massive solid rocks (limestones, dolomites)	rock walls, steps, table mountains, high steep slopes	fragments several tens of cm large	erosion takes place by torrential rains, only aterial loosened by quarrying is eroded

formations of compact rocks and semirocks (limestones, dolomites, marly limestones, marlstones etc.). In this region with a high-energy relief, only slight manifestations of erosion should be expected following an artificial intrusion as the erosion here is limited by the degree of disintegration and weathering rate of compact rocks resistant to water. Similarly, like in the region relatively predisposed to weathering, also here more resistant rocks protect less resistant ones from intensive erosion. E. g., these resistant rocks form minor waterfalls and steps in gullies. The stream load varies from a fraction of a millimeter to ten-centimeter fragments.

The region resistant to erosion comprises massive, fresh, compact rocks, seas of rocks (also on high-energy relief), deluvial sediments, deluvial-eluvial sediments and Neogene gravels alid down on a low-energy relief. In this region, erosion is very unlikely to take place even if the natural state is disturbed by human activity. Erosion in compact rocks may only be caused by extreme torrential rains in places affected by quarrying. The size of transported fragments varies from several cm to tens of cm.

In plains, erosion can only locally take place in little resistant rocks - in construction excavations and therefore while excavations are being made this possibility must always be born in mind, particularly if they remain open for long. The size of transported material varies from clay particles to gravel pebbles several cm large. Flood plains are affected by lateral stream erosion as well.

Conclusion

The compilation of the three environmental geofactors maps (Maps of predisposition to slope failures – Fig. 2, Map of predisposition to weathering – Fig. 3, Map of predisposition to erosion – Fig. 4) of a model Alpine territory was aimed at providing concrete fundamental data for a comprehensive assessment of environmental geofactors from the engineering-geological point of view. Practical experience obtained by the compilation of these maps should make it possible to identify problems which will arise during mapping and thus anticipate and direct the controversial initial purely theoretical discussion on environmental geofactors.

We have taken advantage of all available rapid and inexpensive techniques including a study of aerial imagery, literature and archives as well as detailed field mapping.

The compilation of maps was based on the principle of engineering-geological regional division (see Slovak Bureau of Geology regulation No. 1/1989 for the compilation of engineering-geological maps). Regional division for maps of slope failures was put forward long ago (Malgot, 1973). The regional divisions for maps of predisposition to weathering and to erosion were worked out by the author of this article.

The geological structure of the territory was taken over from a geological map on scale 1.25 000 with an enclosed report compiled by Rakús et al. (1984).

The maps themselves were compiled as prognostic analytical multipurpose maps analysing the present-day state of geodynamic phenomena as environmental geofactors and prognosing possible aftermath of artificial intrusion into the geological environment.

Experience obtained during the compilation of the environmental-geofactor maps on the model territory in the vicinity of Vrícko as well as the compilations of similar maps of the Turčianska kotlina Basin (Kováčik et al., 1991) indicates that the study of geodynamic phenomena as environmental geofactors should view individual phenomena as the phenomena of the geological setting composing this territory rather than territorial phenomena. These geological phenomena should be assessed by objective analytical and quantitative methods, and the geodynamic phenomena should be areally illustrated on separate maps and briefly characterized in easy-to-review tables employing a simple three-class classification (each class represents one level of potential activity).

The geological-setting phenomena will be converted to territorial phenomena by correlation relationships defining the intensity of the influence of the individual factors on a given geodynamic phenomenon (e. g. in assessing a territory's predisposition to erosion, these factors will include resistivity of geological environment to erosion, intensity and amount of rainfall, length and gradient of slope etc.).

The maps of environmental geofactors compiled in this manner will allow flexible and versatile treatment of obtained field data as well as their simple digitalization and storing in a database of the currently prepared geographic information system. Similarly, gradually obtained, more complete and accurate correlation relationships will make it possible to evaluate environmental geofactors in more detail without a need to rework the basic field data.

The materials of this kind are so simple and easy-to-understand that they can be read by broad nongeological public, which could prevent numerous risky intrusions into geological environment. Such materials are particularly useful in territorial plannning and in working out various projects which can affect the geological setting and/or environment. The projecting engineers can thus readily and at low cost evaluate the present-day state of the territory, to select the best locality for the projected object and to foretell the territory's reaction to the planned activity. In addition to the evaluation of the actual state of the territory concerned, it is also possible to stress likely hazards and to propose the most efficient way of its improvement and protection.

The submitted article also suggests that the outlined topic requires close cooperation of all geoscience disciplines, because the project of environmental protection put forward by us is unthinkable without professional approach of all involved parties.

Translated by Ľ. Böhmer

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MARTIN ONDRÁŠIK

Hodnotenie geofaktorov životného prostredia širšieho okolia Vrícka

Resumé

Zámerom zostavenia troch máp geofaktorov životného prostredia (mapa náchylnosti na svahové deformácie, obr. 2, mapa náchylnosti na zvetrávanie, obr. 3, mapa náchylnosti na eróziu, obr. 4) v modelovom území horského typu bolo získanie konkrétneho podkladového materiálu na súborné spracovanie geofaktorov životného prostredia z hľadiska inžinierskej geológie. Na základe praktických skúseností získaných pri zostavovaní týchto máp sa mal identifikovať okruh problémov, ktoré sa prejavia až pri mapovaní, a tým posunúť a usmerniť rozpačitú, čisto teoretickú úvodnú diskusiu o geofaktoroch životného prostredia do nového svetla.

Pri mapovacích prácach boli použité všetky dostupné, časovo a ekonomicky nenáročné prostriedky, t. j. štúdium leteckých snímok, dostupnej literatúry, archívov a detailné terénne mapovanie.

Samotné zostavenie máp bolo realizované na princípe inžinierskogeologickej rajonizácie (pozri Smernicu SGÚ č. 1/1989 na zostavovanie inžinierskogeologických máp). Rajonizácia pre mapu svahových deformácií bola vypracovaná už dávnejšie (MALGOT, 1973). Rajonizácia pre mapy náchylnosti na zvetrávanie a náchylnosti na eróziu sú pôvodným autorovým riešením.

Ako hlavný podklad geologickej stavby územia slúžila geologická mapa v mierke 1:25 000 so sprievodnou správou zostavenou RAKÚSOM et al. (1984).

Samotné mapy sú zostavené ako prognózne analytické viacúčelové mapy analyzujúce súčasný stav geodynamických javov ako geofaktorov životného prostredia a prognozujúce možné následky po umelom zásahu do geologického prostredia.

Zo skúseností, získaných vypracovaním máp geofaktorov životného prostredia na modelovom území okolia Vrícka, ako i zostavovaním súboru obdobných máp z Turčianskej kotliny (KOVÁČIK et al., 1991), sme dospeli k záveru, že pri štúdiu geodynamických javov ako geofaktorov životného prostredia by sme sa mali sústrediť na jednotlivé javy nie ako na fenomény územia, ale ako na fenomény geologického prostredia tvoriace toto územie, objektívnymi analytickými a kvantitatívnymi metódami ich zhodnotiť a pomocou jednoduchej trojstupňovej klasifikácie (každý klasifikačný stupeň predstavuje úroveň potenciálnej aktivity) geodynamické javy plošne znázorniť na samostatných mapách a stručne slovne charakterizovať v prehľadných tabuľkách.

Ich transformácia z fenoménov geologického prostredia na fenomény územia bude zabezpečená pomocou korelačných vzťahov definujúcich intenzitu vplyvu jednotlivých faktorov na daný geodynamický jav (napr. pri hodnotení náchylnosti územia na eróziu sú takýmito faktormi odolnosť geologického prostredia voči erózii, intenzita a množstvo zrážok, dĺžka a sklon svahu a pod.).

V takomto zmysle zostavené mapy geofaktorov životného prostredia umožnia pružné a všestranné narábanie so získanými terénnymi údajmi a ich jednoduchú digitalizáciu a uloženie do databanky pripravovaného geografického informačného systému. Rovnako, postupným dopĺňaním a upresňovaním korelačných vzťahov v budúcnosti bude možné relatívne presnejšie hodnotenie geofaktorov životného prostredia bez prerábania základných terénnych údajov.

Využitím materiálov tohto druhu širokou verejnosťou a vďaka jeho jednoznačnej a ľahkej čitateľnosti aj verejnosťou laickou, sa v praxi dá predísť neuváženým a často i nebezpečným zásahom do geologického prostredia. Vhodný je najmä pri územnom plánovaní a pri vypracovávaní rôznych projektov, ktoré rôznym spôsobom ovplyvnia geologické, respektíve životné prostredie. Projektantom umožnia rýchlo a lacno zhodnotiť súčasný stav územia, vybrať najvhodnejšiu lokalitu pre projektovaný zámer a predvídať reakciu územia na plánovaný zásah. Súčasne zhodnotením reálneho stavu, v ktorom sa územie nachádza, je možné upozorniť na jeho prípadné ohrozenie a navrhnúť najvhodnejší spôsob nápravy a ochrany.

Z predloženého materiálu taktiež vyplýva, že načrtnutá problematika nevyhnutne potrebuje tesnú spoluprácu všetkých geovedných disciplín, pretože takto navrhovaný projekt ochrany životného prostredia vyžaduje profesionálny prístup zo strany riešiteľov.

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František Baliak–Jozef Malgot–Vlasta Jánová

Slope failures in the western tract of the Liptov Basin

(25 figs., slovak summary)

A b s t r a c t. The article deals with the results of investigations of slope failures, mainly landslides, in the western Liptov Basin. It describes in detail the conditions and factors controlling the formation of slope failures, their types, principles governing their evolution and areal distribution, economic impacts as well as engineering-geological assessment of the territory in question. These data can essentially reduce hazards and costs of planned constructions and contribute to environmental protection.

Introduction

Like in many other basins in Slovakia, slope morphology in the Liptov Basin is also significantly shaped by slope failures. Their formation and evolution result from favourable natural conditions.

Landslides and other slope failures are a geodynamic process which influenced construction activity and farming in the Liptov region since the earliest times. In the last decades, the intensive construction activity converted many previously potential landslides into active ones.

The investigation of slope failures in the Liptov Basin was necessary because of problems related to the construction of the water reservoir Liptovská Mara and damaged buildings in the village of Potok.

Project definition and applied techniques

Because of the above-mentioned problems, the Slovak Bureau of Geology ordered engineering-geological investigation of the Liptov Basin which was performed in 1978–1984. The investigations concentrated on two separate areas: a) Slope failures in the western Liptov Basin (carried out by the Department of Geotechnics, Faculty of Civil Engineering Slovak Technical University) and b) Slope failures in the vicinity of the village Potok (state company IGHP = Engineering-Geological and

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Hydrogeological Survey, division Žilina). The IGHP company is currently investigating slope failures in the eastern tract of the Liptov Basin which, however, are not dealt with in this contribution.

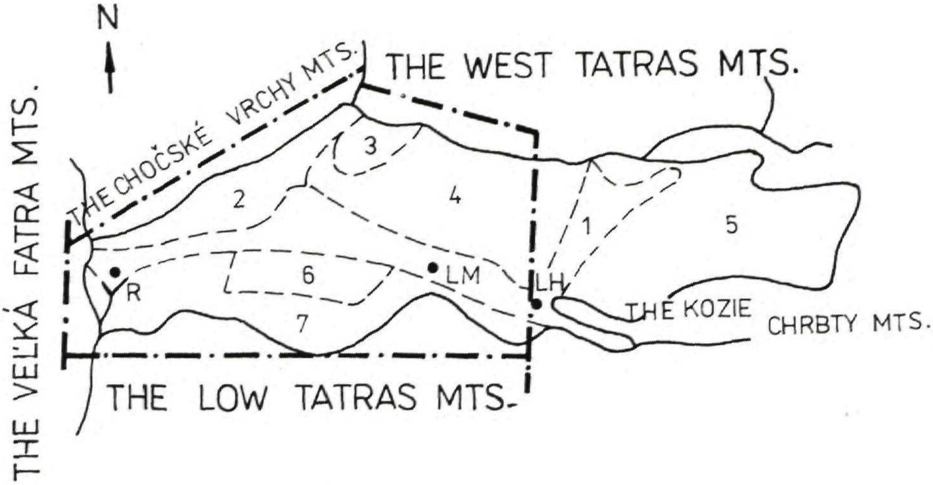


Fig. 1 Geographic division of the investigated territory (after Atlas of the Slovak Republic)
Division of Liptov Basin: 1 — Liptov flood plains, 2 — Choč Mts., 3 — Matiašovce groves, 4 — Smrečany hills, 5 — Hybe hills, 6 — Galovany groves, 7 — Ľubela hills

The investigated area, 380 km^2 in size, comprises the western part of the Liptov Basin and foothills of the adjacent mountain ranges in the stretch between Ružomberok and Liptovský Hrádok.

According to the Atlas of the Slovak Socialist Republic, the Liptov Basin is divided into: 1. Liptov flood plains, 2. Choč Mts., 3. Matiašovce groves, 4. Smrečany hills, 5. Hybe hills (outside the mapped area), 6. Galovany groves and Ľubela hills.

From the geomorphological viewpoint, the Liptov Basin is an extensive depression of irregular shape. The investigated area is 32 km long and up to 19 km wide.

The surface and ground waters are drained by the Váh River which forms a hydrographic axis of the studied territory. Side streams and their valleys alternating with N–S ridges further subdivide the basin which thus has the character of a typical basinal rolling country.

The hydrological conditions in the Liptov Basin were significantly influenced by the construction of the water reservoirs Liptovská Mara and Bešeňová. Changes took place not only in the hydrological, but also in the hydrogeological and climatic conditions which in turn influence some contemporary geodynamic processes.

The investigation programme also includes an analytic map of slope failures in the western Liptov Basin on scale 1:25 000 as well as a related map of engineering-geological regions and a reference map. The western end of the Liptov Basin was mapped by us on scale 1:10 000 on three map sheets. Selected localities were mapped in more detail, on scales 1:5000 (Konská) or 1:2000 (Háje, Lisková, Potok). In the course of the mapping, we noted a total of 898 slope failures, for which record forms were elaborated. In addition to mapping, 57 vertical cored holes (1524 m) and 6 horizontal holes (900 m) were drilled. 236 soils samples and 43 water samples were collected for hydrochemical investigations. Apart from the drilling, detailed study of the localities also included geophysics, special field measurements, monitoring of groundwater levels, geodetic monitoring of landslide movements using a grid of stable and monitored points, radionuclide measurements, measurements of shear-plane indications and landslide activity. The stability of landslides at the individual localities was assessed and remedial action was proposed. Aside from the employees of the company IGHP Žilina and Slovak Technical University, the works were also performed by the Mining University at Ostrava and D. Štúr Institute of Geology, Bratislava.

The engineering-geological maps of slope failures are supplemented with sections. These are based on mapping and exploration drilling carried out within this (Mahr et al., 1984) or earlier exploration projects.

The above works allowed us to compile a detailed study on the present-day state of slope stability in the western Liptov Basin, principles of slope-failure formation and areal distribution, natural factors and causes which give rise to slope failures.

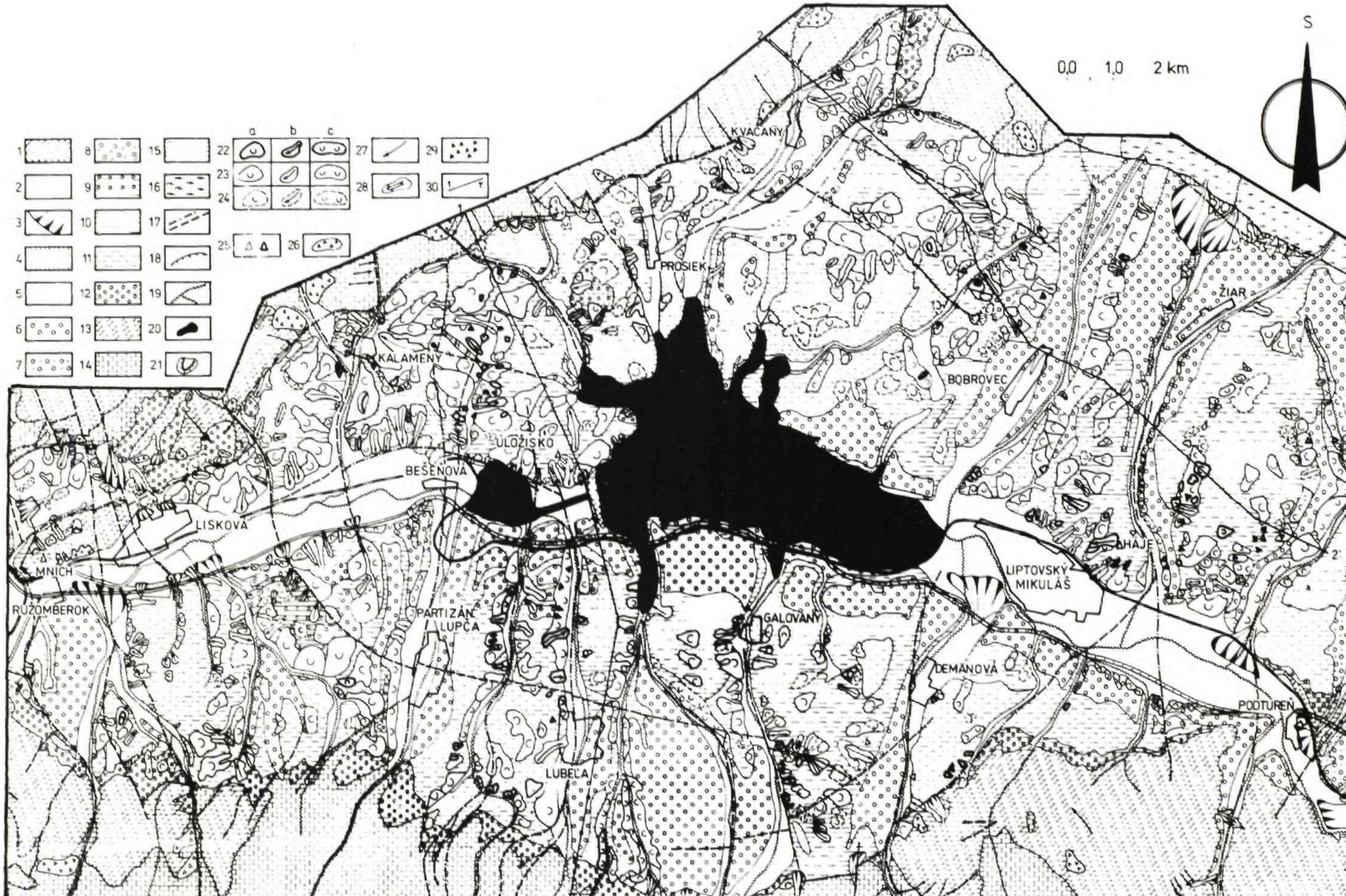
Review of investigations

Geologically, the Liptov Basin is fairly well explored. Most works have so far dealt with geological, tectonic, stratigraphic and paleontological problems. The earliest of them date back to the early 19th century. Although the works often concentrated only on partial problems and the validity of their results is now limited, they still brought valuable information. All earlier works in the area concerned were listed and briefly assessed by Gross–Köhler et al. (1980).

Out of the immense number of geological reports, we mention only a few ones dealing with slope failures, e. g. Matějka (1927, 1935), Volek Starohorský (1932), Koutek (1935) who mapped landslides in the Choč Mts. and Liptov Basin, Sladký (1938) who compiled a map of the Ružomberok area, Andrusov–Kuthan (1944), and fairly recent maps on scale 1:200 000 plus related explanations to the sheet Banská Bystrica (Maheľ et al., 1964) etc.

Latest detailed and systematic research of the Liptov Basin sediments was performed by Gross–Köhler et al. (1980) who studied the area since 1968. In addition to the geological map (published on scale 1:50 000), they also studied fauna, petrology, lithology, rock chemistry, hydrogeology, hydrochemistry and geophysical properties. This map served us as a basis for the compilation of the map of slope failures.

From the hydrogeological viewpoint, the territory was investigated very irregularly. Most projects focused only on very limited areas in compliance with the investor's instructions. Regional investigations were performed by Bujalka (1960), Šuba (1966), Cibulka (1972), Kullman–Zakovič (1974), Hanzel (1971–1976), Franko (1975, 1978) but mainly Tužinský et al. (1971), (in Gross–Köhler et al., 1980).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Similarly, engineering-geological investigations have so far been carried out on very small areas. They mostly assessed the properties of foundation soils for large structures, particularly on alluvial deposits of the Váh River and its tributaries.

Slope-failure investigations concentrated on the largest failures in relation to the construction of roads, railways, water reservoir Liptovská Mara, etc. These include e. g. landslide at Okoličné described by Nemčok (1966) and Fussgänger–Jadroň (1977); landslides in motorway cuts around the water reservoir Liptovská Mara investigated by Mencl–Gromm–Kuchár–Repka (1975) and Jadroň–Fussgänger (1974) on the slopes of Čebraď; landslides near the water reservoir Liptovská Mara studied by Mach (1968) and Ingr–Fekeč (1973), and roads near L. Michal (Š. Kuchár, 1976).

Regional slope-failure researches in the territory concerned started with their registration in 1960–1963.

Landslides in the Liptov Basin were studied by a team directed by Nemčok. The systematic regional investigations by the Department of Geotechnics, Faculty of Civil Engineering Slovak Technical University continued also in the following years. The region of the Liptov–Poprad Basin was characterized by Nemčok–Malgot–Baliak (1970). Crystalline units adjacent to the basin were investigated by Mahr (1976) and Mesozoic ones by Baliak (1978). The latest knowledge of slope failures and remedial actions in the area concerned is presented in A. Nemčok's monography (1982).

Conditions and factors of slope-failure origin

Slope failures are extremely widely distributed in the Liptov Basin. The reasons include conditions and factors favourable for their origin evolved during the geological-geomorphological history, favourable physical-mechanical properties of loams and rocks in the Liptov Basin as well as favourable climatic and hydrogeological conditions. The modern geodynamic processes and intensive anthropogeneous factors also significantly influence the contemporary evolution of landslides.

Fig. 2 Map of slope failures in western Liptov Basin
1 — anthropogeneous sediments, 2 — alluvial deposits, 3 — alluvial fans — proluvial sediments, 4 — travertines, 5 — loamy-stony landslides, 6 — terrace fluvial sediments, 7 — glaciofluvial sediments (1 — 7 Quaternary), 8 — fluviolacustrine sediments (Neogene), 9 — nonflysch sandstone-conglomerate facies, 10 — flysch luthofacies, 11 — claystone lithofacies, 12 — basal transgressive lithofacies (9 — 12 Paleogene), 13 — Hronicum—Choč nappe, 14 — Fatricum—Krížna nappe, 15 — Mesozoic, undifferentiated (13—15 Mesozoic), 16 — crystalline units (Paleozoic), 17 — faults (proved, assumed), 18 — thrust lines, 19 — water courses, 20 — lakes, 21 — blocky deformations, 22 — landslides, active, 23 — landslides, potential, 24 — landslides, stabilized (a — sheet, b — flow, c — frontal), 25 — small landslides (potential, active), 26 — rockslides, 27 — stony-loamy flows (mures), 28 — earth flows, 29 — talus accumulations, 30 — geological sections (compiled after Gross (1979) map).

Geologic-tectonic structure of the territory

The Liptov Basin is composed of Quaternary cover units and Inner-Carpathian Paleogene formations underlain by the Mesozoic Choč and Krížna nappes which are exposed on the slopes on the nearby mountains. In the SE part of the mapped territory there rise southern slopes of the Západné Tatry Mts. composed of the Paleozoic Gneiss series which is not described in this article because of its limited areal distribution.

a) *Mesozoic*

The Mesozoic rocks continuously fringe and underlie the Paleogene basinal filling.

The map (Fig. 2) shows that the adjacent slopes are dominated by the Choč nappe except for the central Choč Mts. and the Nízke Tatry Mts. between Sliač and Demänová valleys where the Krížna nappe prevails.

The Choč nappe here consists of the Biely Váh series. The mapped territory largely contains thick layers of Middle Triassic limestones and dolomites with less abundant dark shales and sandstones (Lunz Member) and light limestones of Norian age.

The Krížna nappe is made up of the Zliechov (Iľanovo) series. Prevailing rocks comprise relatively plastic Cretaceous marlstones and marly limestones (Hauterivian) and shales intercalated with schistose limestones (Middle Albian).

Drillholes at Bešeňová and Vlachy revealed that the Eocene basinal filling is underlain by Mesozoic rocks at a depth of as much as 1200 m (Fig. 3), (Chmelík, 1963).

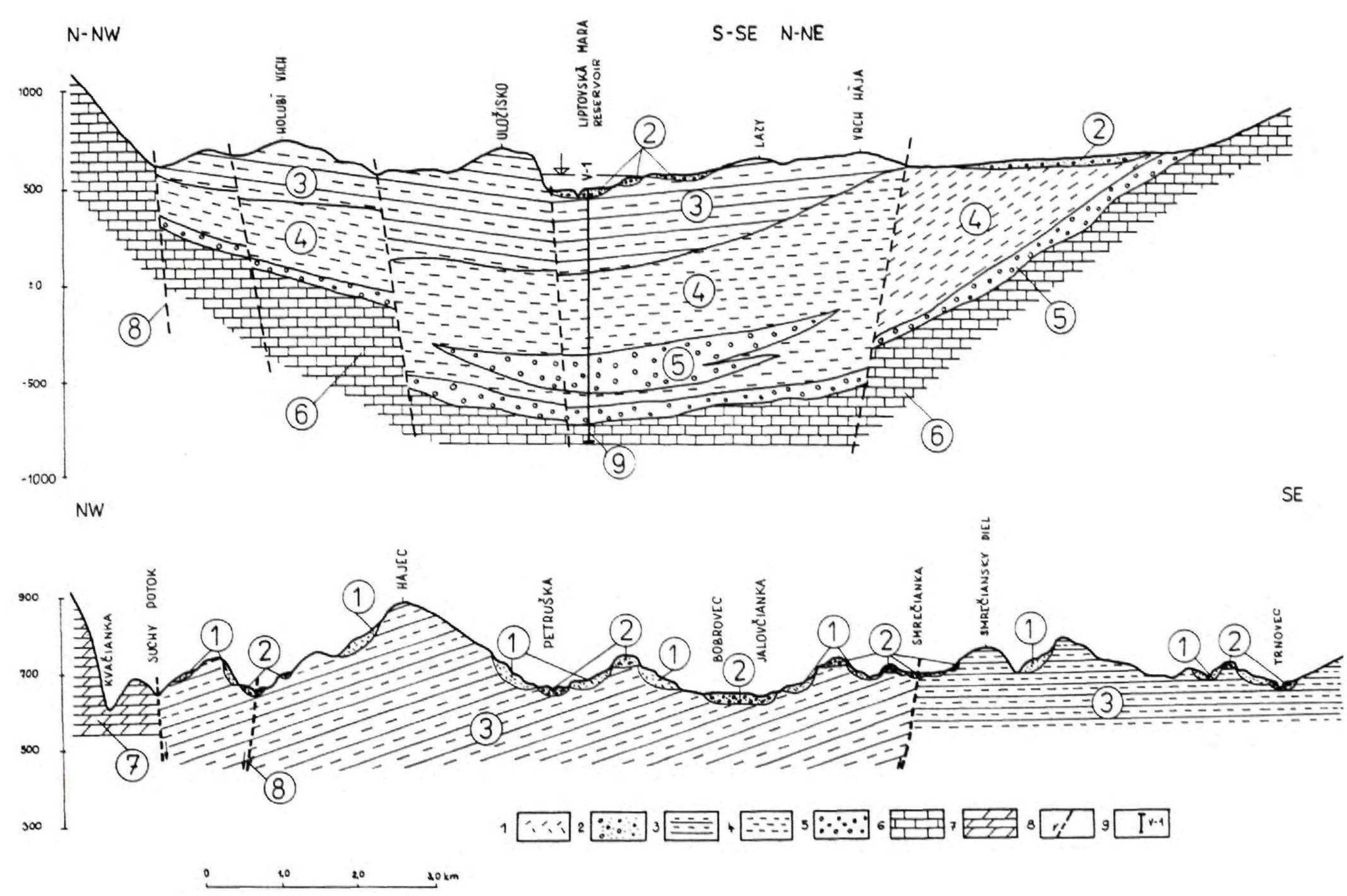
b) *Paleogene (Middle to Upper Eocene)*

Detailed geological investigations allowed Gross et al. (1980) to divide the Inner Carpathian Paleogene of the Liptov region into the following formations:

1. Basal transgressive lithofacies (Upper Lutetian)
2. Claystone lithofacies (Upper Lutetian–Priabonian)
3. Flysch lithofacies
4. Nonflysch sandstone-conglomerate development (Priabonian–Lower Oligocene).

Basal lithofacies

The Nízke Tatry Mts. are more or less regularly fringed with basal deposits (Fig. 2). Near the northern margin of the basin, the sediments sank along the Choč-Subtatric fault system (Fig. 3). In this formation of variable thickness, Gross et al. (1980) have identified breccias and conglomerates, detrital dolomite or limestone sandstones and sandy limestones, organodetrital and organogenic limestones (nummulite, locally reef limestones).



Figs. 3, 4 Geological sections 1—1' and 2—2'

1 — loamy-stony landslides, 2 — alluvial deposits (1—2 Quaternary), 3 — flysch lithofacies, 4 — claystone lithofacies, 5 — basal transgressive lithofacies (3—5 Paleogene), 6 — marly limestones — Neocomian — Krížna nappe, 7 — Middle Triassic limestones and dolomites — Choč nappe (6—7 Mesozoic). 8 — proved faults, 9 — drillhole

Claystone facies attains great thicknesses and spreads on a vast area in the western and central tracts of the basin.

Its lowermost formation consists of locally developed nummulite-type claystones. These non-calcareous claystones are composed of siliceous-clayey cryptocrystalline matter. The claystones are overlain by a thick and monotonous formation dominated by calcareous claystones clearly prevailing over thin sandstone beds.

If unweathered, the claystones are massive, gray to gray-yellow or green-blue. In contrast, weathering results in their schistose, leaf-like or sometimes even conchoidal disintegration. The completely weathered rock is converted into highly plastic clayey loams. The formation contains thin intercalations of siltstones which are 10–20 cm thick, fine-grained sandstones, fine- to medium-grained conglomerates and organodetrital sandy limestones. The thickness of the claystone lithofacies verified by drilling attains 600–800 m (Chmelík et al., 1962, Franko, 1978). It was assigned into the Middle Priabonian.

Flysch lithofacies is characterized by multiple hemicyclic rhytms (Andrusov, 1965) composed of layers of different grainsize. Sandstone beds alternating with aleuritic to pelitic siltstone and claystone layers are typical (Fig. 4).

The flysch in the mapped territory is characterized by the prevalence of claystones over sandstones. The sandstone beds are commonly 2 to 30 cm thick, exceptionally in the coarse-rhythmical development even 400 cm. The claystones are calcareous, of schistose or leaf-like disintegration. In addition to layers of pure claystones, sandy and silty claystones occur as well.

Non-flysch sandstone-conglomerate development

Near the villages of Sliač and Bukoviny there occur sandstone-conglomerate formations probably deposited as submarine alluvial fans. Because of their great variability, abrupt pinching out and the presence of multiple irregular beds, they have the character of a chaotic facies. Their areal extent is small.

c) *Neogene*

The Pliocene fluvio-lacustrine sediments have only a limited distribution in the investigated basin. They form erosional remnants resting on the partly eroded Paleogene surface between the villages of Nižný Sliač and Partizánska Ľupča. In the northern tract, they top flat hills between the villages of Bobrovček and Bobrovec. Lithologically, the sediments are sandy, strongly loamy, considerably weathered gravels up to 30 m thick.

d) *Quaternary cover units*

are extremely significant for the formation of landslides. These sediments involve several genetic types.

Freshwater limestones were deposited from mineral springs. They have different forms – from unconsolidated (sandy) brittle calcareous tufas, strongly cavernous bioclastic limestone to massive solid bedded travertines.

Eluvia have only limited distribution on flat ridges and passes. Their thicknesses vary from 1 to 3 m. Their grainsize is very variable, controlled by the properties of the parent rocks.

A strange feature of the Liptov Basin is eluvia resting on Quaternary units, mainly Early Pleistocene fluvial sediments and alluvial fans (Gross et al., 1980).

Deluvial sediments are the most widespread of all units. Owing to the effects of diverse slope-modelling processes (creep, solifluction, slope-wash, landslides etc.) and different properties of parent rocks, their lithological composition is very variable. The sediments locally have the character of loess loams, sometimes resemble loams to clayey loams. They frequently contain fragments of sandstones, limestones and shales or pebbles. These sediments are as much as 4–25 m thick.

Deluvial-fluvial sediments fill the bottoms of undrained bathtub-like erosional valleys. These up to 2 m thick sediments owe their origin to torrential rains.

Fluvial sediments laid down by the Váh River and its tributaries belong among the most significant Quaternary units in the Liptov Basin.

The fluvial sediments mostly form compound terraces composed of the eroded substratum (erosional terrace) and depositional surface. In general, with respect to their relation to valley bottoms, Vaškovský (in Gross et al., 1980) distinguishes four groups of terraces: flood plains, low, middle and high terraces.

Alluvial fans are genetically closely associated with the river terraces. They lie on the foothills fringing the Liptov Basin. Like the river terraces, the fans form several levels overlying each other, and gradually pass into the river terraces. Their evolution temporally coincides with that of the terraces. Three kinds of fans have been noted: low, middle and high. The fans were preserved to a different degree, with the middle and low fans being better preserved than the high ones. The alluvial fans are composed of poorly rounded fragments of variable size and a loamy-sandy admixture.

The Liptov Basin is a vast E-W-trending tectonic depression confined by the largest West Carpathian megaanticlinal belts – Nízke Tatry and Západné Tatry passing into the Choč and Veľká Fatra Mts.

In the western and central tracts of the basin, Gross et al. (1980) have distinguished two basic fault systems: 1. earlier faults whose strike is parallel with the basin's longitudinal axis, 2. younger faults, roughly perpendicular to the earlier ones.

Earlier faults. The most important of them is the Choč-Subtatric fault which confines the basin in the north. It has a normal-fault character (Fig. 3, 4) and dips steeply to the south (Gross, 1980).

The *younger faults* are transversal. They extend into the basin either from the north (Choč, Západné Tatry) or from the south (Nízke Tatry) and considerably disrupt the originally linear course of the earlier E–W faults.

The intersections of the transversal faults with the Choč – Subtatric ones gave rise to numerous springs of gas-free or gaseous mineral waters as well as emanation of dry gases (Dovina et al., 1980).

Many of the described faults were formed prior to the Paleogene, while others became active in the Paleogene or soon afterwards. During and after the Helvetian disturbances, repeated movements took place along these faults irrespective of their previous sequence of formation.

Geomorphological history

The geomorphological setting of the Liptov Basin and nearby mountain ranges was significantly controlled by the geological history of the territory in the Pliocene but mainly in the Quaternary.

Its geological-tectonic history, rock properties and exogene agents shaped the characteristic relief of the studied territory composed of piedmont foothills and hilly landscape formed on the surface of the tectonically confined sunken morphostructure (megastructure with a tectonic-basin morphostructure).

In the area of this basin lined with normal faults, diverse kinds of relief can be distinguished according to the presence of erosional or depositional exogene agents during the Quaternary.

The erosional-depositional activity of streams was of prime importance. The water courses shaped various landforms.

The morphologically significant *depositional landforms* include flood plains, and low, middle as well as high terraces and proluvial rolling plains.

Depositional-erosional relief is represented by landforms such as proluvial-fluvial rolling country and proluvial-fluvial eroded rolling country. The relief of this kind dominates the basin.

Erosional-denudational relief was formed at the basin's margins characterized by relatively smaller subsidence. It is a piedmont relief eroded by streams.

Aside from the erosional-depositional activity of streams, the basin microrelief was also shaped by slope failures. In the Pleistocene, when the basin was situated in a periglacial area, freezing of surface layers and solifluction played a major role. During interglacials, massive landslides were triggered largely by climatic factors. Because of the degradation of rocks filling the basin, landslides became one of the most important processes shaping slopes in the Pleistocene and recent.

The last stage in the morphological history of the basin was significantly influenced by human activity which is so intensive that the relief frequently has an anthropogeneous character, particularly in the vicinity of major towns such as Ružomberok, Liptovský Mikuláš and Liptovský Hrádok. Considerable changes were caused by the modifications of farmland and water courses, by the construction of water reservoirs Liptovská Mara and Bešeňová etc.

The relief of the sourrounding mountain ranges (Chočské vrchy, Západné Tatry, Nízke Tatry and Veľká Fatra) is characterized by the morphostructure of core-mountain tectonic elevations separated from the basin by active fault systems. The closely adjoining slopes are therefore morhologically conspicuous, evolved on tectonic dislocations.

The principal exogene agents here were water courses and their predominantly erosional activity which shaped the relief to form a highland eroded by streams.

Climatic and hydrogeological conditions

From the climatic viewpoint, the area in question comprises a wide range of climatic areas falling into individual types and subtypes. According to the division of climatic regions (Climatic Atlas of the Czechoslovak Socialist Republic, 1958; Climatic Tables of the Czechoslovak Socialist Republic, 1961), the area concerned belongs into a moderately warm area, district B_7, which is characterized as moderately warm, humid with cold or moderately cold winters. Only some small marginal portions of the basin adjoining the surrounding core mountains are classified as cold, district C_1 (moderately cold). Thanks to the great differences between the altitudes in valleys and summits there are also considerable differences in climate over fairly short distances. Aside from the general circulation and solar radiation, which are the main characteristics of climate in a given area, the altitude and exposition also play a major role.

In assessing the effects of climatic conditions on slope stability in a given territory, it is necessary to pay attention mainly to the amount of rain- and snowfall.

The precipitation in the area concerned depends on the overall circulation in Central Europe. Precipitation comes almost exclusively as the so called western situations which bring moisture from the Atlantic Ocean. Precipitation within the air masses is also considerable, particularly in summer (local storms). Maximum rainfall comes in summer (July), while February is the dryist month. The distribution of the annual precipitation is very variable. Long-term measurements in the Liptov Basin indicate that the most abundant precipitation occurs in the western and eastern tracts of the basin, e. g. in the vicinity of Ružomberok which receives 762 mm/yr, whereas the central tract is relatively drier. The precipitation grows with the increasing altitude and the highest values have been recorded on the western windward slopes. The studied area is covered with snow from mid-December to April.

The slope stability is influenced cheifly by prolonged rains in spring and autumn as well as by summer torrential rains.

As far as the temperature is concerned, the mean annual temperature varies from 5 to 7 °C, with 32 warm and 160 frost days per year. The warmest month is July (16 °C) and the coldest one is January (-5.3 °C).

Western and north-western winds prevail, their speed being mostly 2–4 °C.

One of the fundamental factors controlling the character of hydrogeological situation in the investigated territory is the geological structure. With respect to the geology, we can distinguish several hydrogeological units characterized by different hydrophysical properties of the rock setting, regime as well as chemistry of groundwaters.

The Mesozoic rocks of the Krížna nappe can be classified as hydrogeologically very slightly favourable or unfavourable with insignificant accumulation capacity. This unit acts as an aquiclude below carbonatic erosional remnants of the Choč nappe. The course of the Krížna/Choč-nappe contact controls the groundwater circulation. This fact is extremely important for the formation and activation of block-type failures. The Choč nappe Mesozoic is very valuable from the hydrogeological viewpoint, but its presence on the studied territory is confined to a few erosional remnants.

Very favourable conditions for groundwater circulation and accumulation are in Triassic carbonates which make up a single aquifer with carbonatic breccias, conglomerates and organogenic limestones of the basal Paleogene lithofacies. The complex has fissure to fissure-karst permeability and the springs here are mostly barrier ones with a very high discharge (GROSS–KÖHLER et al., 1980).

The above-described circulation of groundwaters is reflected in their chemistry. The groundwaters are of calcium-magnesium and calcium-magnesium-bicarbonate type and their T. D. S. varies from 514.9 to 98.0 mg/l (GAZDA in ZAKOVIČ–HANZEL et al., 1976).

Because of their lithological composition, the separate Paleogene sediments are very poor in groundwaters. The best hydrogeological conditions occur in carbonatic sediments of the basal transgressive lithofacies with fissure to fissure-karst permeability. The springs here have only a limited discharge and are concentrated in valleys, either at the contact with the claystone lithofacies or on small joints. From the chemical viewpoint, the waters are of HCO_3-Ca-Mg (calcium-magnesium-hydrocarbonate) type, their T. D. S. ranging from 0.3 to 0.6 g/l. The sandstone-conglomerate sediments mostly have fissure to fissure-pore permeability. The springs have stratal character and are located on the contact between the sandstone-conglomerate sediments and the underlying claystone lithofacies. The scattered springs give rise to extensive swamps. Their discharge is insignificant – around a mere 0.1 l/s. The waters here are of HCO_3-Ca-Mg type and their T. D. S. amounts to 0.4–0.5 g/l.

Groundwater circulation in the flysch lithofacies is bound to sandstone beds with pore-fissure permeability. The springs are stratal ones, mostly located in sandstone talus, both in landslide and landslide-free areas. The springs are either concentrated or dispersed, the latter causing fairly extensive swamps. The spring discharges amount to tenths of l/s. The waters are of HCO_3-Ca-Mg type with an insignificant shift to HCO_3-Na type (GAZDA, 1975).

In the claystone lithofacies, the only aquifers are rare sandstone layers with pore-fissure permeability. Like in the flysch lithofacies, small amounts of water are bound to the zone of weathering. The spring discharge is below 0.1 l/s. The specific groundwater recharge in this lithofacies has been estimated by A. Tužinský at 0.8–1.04 l/s km^2. The waters are of HCO_3-Ca-Mg type and their T. D. S. varies from 0.2 to 0.8 g/l.

Major aquifers in the studied territory include Quaternary deposits, primarily fluvial sediments of the Váh River and its tributaries as well as glacial and glacio-fluvial deposits at the foothills of the Západné Tatry Mts.

The waters in fluvial deposits in different stretches of the Váh River have different hydrogeological parameters. Their filtration coefficient has been estimated by TUŽINSKÝ (1971) at 10^{-3} to 10^{-4} m/s. Similar filtration coefficients have also been recorded in the deposits of the Váh tributaries where they amount to 10^{-3}–10^{-5} m/s and the water table is 0.5 to 2.0 m below the surface. The waters are of calcium-(magnesium)-bicarbonate type and their T. D. S. varies from 200.5 to 2492.0 mg/l averaging 555.7 mg/l (GAZDA in ZAKOVIČ, 1976).

Glaciofluvial deposits in the NE tract of the basin are also fairly permeable as their filtration coefficient varies from 10^{-4} to 10^{-2} m/s, but still higher permeability coefficients (even around 10^{0} m/s) have been noted in glacial deposits.

The other Quaternary genetic types, such as proluvial and loamy-stony deluvial sediments, are littrle significant for the accumulation of groundwaters because of their high loam content.

As regards the formation of slope failures, the hydrogeologically little valuable subjacent rocks play a significant role. Their Quaternary cover, largely Pleistocene terraces and glaciofluvial deposits, is a good aquifer, its ground waters being concentrated at its base, i. e. at the contact with the subjacent flysch. The direction of the groundwater circulation is controlled by the relief and dip direction of this contact. Landslides occur in places where the contact between the cover and subjacent units, whose dip is favourable for groundwater circulation, is exposed on a slope. Such places include underground depressions of inverse relief reached by erosion, underground depressions exposed in the upper ends of side valleys or on their slopes. In such places, a flysch slope below a spring line is permanently water-logged. These soaked slopes are destructed much more quickly than those where the Quaternary/Paleogene contact is well drained or dry, i. e. where the contact dips downslope or forms a subsurface ridge. Abundant rainfall results in an increased infux of groundwater and consequently also in the reactivation and enlarging of existing landslides.

Rock impermeability, particularly that of claystone lithofacies, is also a phenomenon favourable for the formation of scour erosion caused by torrential rains which may seriously threaten stability of an impermeable territory.

Rock properties

As far as the formation and evolution of slope failures in the Liptov Basin are concerned, rocks of the Central Carpathian Paleogene and Quaternary sediments are of prime importance. The vast majority of slip planes and zones occur in deluvial sediments and weathered claystones.

Sandstones, conglomerates and breccias mostly occur as a passive member in block-type failures. These rocks increase shear strength of earths and thus influence properties of landslide deluvia.

The only Paleogene rocks which, owing to their properties, can influence the character of landslides are claystones and siltstones. These rocks, however, are multiply intercalated within the Paleogene formation and cannot be assessed separately. The claystones contain abundant silt particles. In some layers, silt even prevails and claystones are thus converted to siltstones. That is why these two rock types are described under the joint name of claystones. The properties of Paleogene *claystone* are controlled by the degree of weathering. Their average values are given in Tab. 1.

To study slope stability, it is necessary to know physical as well as mechanical properties of deluvial landslide earths.

Tab. 1 Average physical-mechanical properties of claystones and landslide deluvium in western Liptov Basin

Properties / Rock	γ_n g.cm^{-3}	n %	Ip %	I_c	γ' o	c' kPa	γ_r o	c_r kPa	E MPa
fresh claystones	-	-	-	-	43	90	-	-	255
partly weathered claystones	2.23	29.8	27.6	1.40	31.0	30	-	-	-
weathered claystones	2.09	34.0	23.0	1.18	23.6	13	16.6	0.0	-
decomposed claystones	2.06	36.9	23.5	1.02	22.4	10	17	0.0	-
landslide deluvium	2.00	40.9	25.0	0.91	20.5	9.3	15.7	0.0	-

Landslide deluvia display fairly confused patterns even within a single landslide. The landslides mostly involve loams and clayey loams with rock fragments. If the percentage of sandstones in the parent rocks is high, fragments are more plentiful and the landslide acquires the character of a stony-loamy talus. The heterogeneity of the landslide deluvia is responsible for the fact that their mechanic and physical properties vary greatly. The average values can be seen in Tab. 1.

Natural factors of slope stability

Processes taking place in the Liptov Basin area include mainly deep stream erosion, slope modelling, weathering as well as rainfall and temperature anomalies.

Deep stream erosion cyclically repeated throughout the Quaternary and gave rise to the described river terraces. Each erosional cycle undercut existing slopes modelled in periods of climatic and tectonic quiescence dominated by deposition.

The deep cyclical erosion also triggers cyclical landslides. The increasing height and angle of slopes during erosional cycles is therefore one of the major factors controlling landslide formation. That is why landslides in the basin are likely to be activated during interglacials. Their stabilization during glacials is disrupted by another major phenomenon – deep freezing which gives rise to numerous shallow landslides and solifluction.

Weathering processes are of progressive character in the recent. They cause gradual degrading of rocks forming slopes, reduce their long-term strength and bring them to an unstable state.

Processes of slope modelling

Transformation media often carry material into depressions above the foothills and bottoms of valleys. Transversal depressions filled with deposited material are thus formed on the slopes and give rise to the majority of landslides in the basin.

Deluvia tend to accumulate in such transversal depressions mainly in periods of tectonic quiescence or in glacial periods characterized by the accumulation evolutionary cycle. They cause permanent instability in the next erosional cycle.

Rainfall and temperature anomalies are the most frequent immediate causes which activate pre-existing landslides whose stability is close to balanced.

Abundant rainfall supplies enormous volumes of water into the landslides which increase the water level, buoyancy and significantly reduce slope stability. In waterlogged slopes, properties of rocks are degraded, their specific gravities increase and hydrodynamic effects of groundwaters grow. With some delay, the recharged water triggers slope failures which are mostly activated during spring snow thawing.

The majority of potential landslides in the Liptov Basin are activated as a result of anomalous precipitation but this activation is preceeded by a long period of slow creep.

The role of precipitation in landslide activation has been demonstrated in a number of landslides in the Liptov Basin. Detailed data on the subject were provided by groundwater-level monitoring in model landslides near Lisková, Konská, Háje and Potok (Mahr et al., 1984).

Effect of anthropogeneous factors

Recently, slope stability is significantly affected by human activity. Landslide slopes are vulnerable places particularly sensitive to any human intrusion. This is the case in the vicinity of towns and villages scattered virtually throughout the basin where new objects, communication routes, pipelines, dams etc. are being built. Human activity takes place in the fairly densely populated and economically exploited Liptov Basin as an especially intensive factor which frequently has adverse effects on slope stability. The most commonly encountered practices are:

1. *Wrong soil recultivation*, unwise areal agricultural dewatering and irrigation which may cause extensive infiltration of rain and surface waters into landslide bodies. Prolonged humus removal and unwise farming practices promote scour erosion, speed up weathering, freezing and increase groundwater buoyancy.

2. *Undercutting disturbed slopes* changes the ratio of forces affecting a given slope in favor of active ones.

Slopes are commonly undercut by house construction in villages gradually expanding into little stable areas. Particularly dangerous situation is in the vicinity of villages surrounding by landslides, mainly Turík, Medočany, Lúčky, Potok, Prosiek, Vlašky, Ižipovce, Liptovský Trnovec, Bobrovček, Trstené, Liptovská Ondrášová, Konské, Liptovský Ondrej and Beňadiková. Villages expanding into dangerous terrains in the southern tract of the basin include Ludrová, Liptovská Štiavnica, Sliače, Malatiny, Dúbrava, Galovany, Liptovský Kríž and Závažná Poruba.

Landslides triggered by slope undercutting in Ružomberok occurred in 1943 below Čabraď and in 1949 below Mních (Fig. 5). A dangerous landslide activated by widening a railway line near Okoličné (Fussgänger et al., 1977) is also well-known. Undercut slopes in a local farming cooperative in the village of Ludrová were also disturbed by landslides.

A multitude of problems related to securing stability of excavations also occured by the construction of the Liptov motorway, left-bank 2nd-category road bypassing the water reservoir Liptovská Mara near the villages of Liptovský Michal, Malatiny, Ľubela and Liptovský Kríž as well as a right-bank road near Potok (Fig. 6).

Numerous minor landslides in the Liptov Basin were triggered by excavations for various pipelines.

3. *Removing material from landslide accumulations* is a hazardous if the slide surface is rotational. Landslides of this kind were triggered by the construction of a playground near Závažná Poruba and in a clay pit near Liptovská Ondrášová.

4. *Additional loading of active parts of existing landslides* mostly takes place by road constructions in elevated portions of slopes. Such a landslide caused by the construction of a road between Ružomberok and Likavka destroyed three dwelling

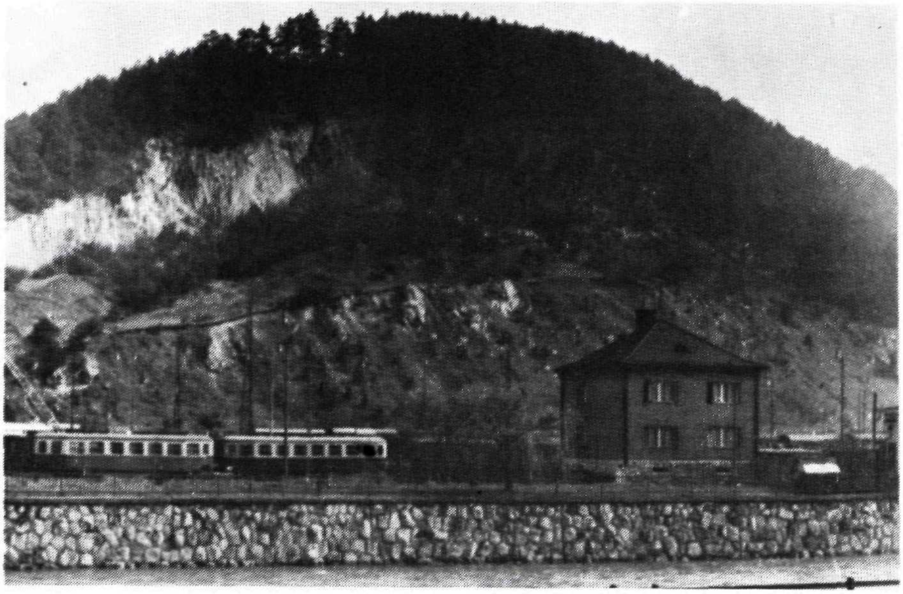


Fig. 5 Rockslide on the southern slope of Mt. Mních triggered by enlarging a railway station at Ružomberok in 1949

Fig. 6 Failure plane of an active slide near the village of Potok

Fig. 7 A road near the village of Veterná Poruba disturbed by an active landslide

Fig. 8 Agricultural objects near the village of Konská threatened by a potential landslide

houses. A road bank erected near Veterná Poruba also activated landslides (Fig. 7). Road banks in the vicinity of Galovany required expensive stabilization. A slope can also be loaded by the construction of various objects which can activate slope failures, as was the case near Konské (Fig. 8) and north of the flooded village of Liptovská Mara.

5. *Dynamic tremours* due to heavy traffic can speed up landslides (Okoličné and elsewhere).

Blasting in stone quarries activated landslides on the slopes of Mních II near the village of Martinček.

6. *Construction of water reservoirs* Liptovská Mara and Bešeňová affected slope stability on the banks. Stabilization of the so called Mara landslide (Fig. 9) is well-known.

A higher number of preexisting landslides reactivated by human activity in the Liptov Basin is alarming. Given the ever-increasing construction and the existence of numerous landslides, this trend is likely to continue in the years next.

Fig. 9 Construction of a stabilizing berm to stabilize the potential Mara slide

Types of slope failures

The above analyses indicate that extensive slopes in the studied territory offer conditions suitable for the formation of regular slope failures. In many, there evolved a typical slope deformation structure defined by NEMČOK (1966). The structure is mostly composed of Quaternary (and/or Neogene) terrace gravels atop flat ridges resting on weathered claystone and/or flysch-like Paleogene or the structure is developed in places where transversal valleys of the Váh tributaries cut through fronts of Paleogene sandstones and shales. The third type of the deformational structure occurs in places where Quaternary travertines overlie Paleogene substratum. The last structure is characterized by special kinds of deformations in Mesozoic rocks where solid limestones and dolomites of the Choč nappe rest, in an advanced position, on the relatively plastic Neocomian of the Krížna nappe composed of marly claystones and clayey marls.

As a result of natural and anthropogeneous factors, slopes of the geological structures in the Liptov Basin are largely modelled by gravity rock movement – creep, rolling, flow and mainly rockslides. In accordance with NEMČOK–PAŠEK–RYBÁŘ's (1974) classification, we have distinguished the following kinds of slope fauilures (Fig. 2):

1. Block-type failures
2. Landslides
3. Stone-loam flows (mures)
4. Rock falls.

1. Block-type slope failures

evolved in places where

a) Middle Triassic limestones and dolomites of the Choč nappe rest on the Krížna nappe Neocomian,

b) Quaternary travertines overlie weathered claystone and flyschlike Paleogene,

c) Enormous beds of proluvial cones or Quaternary terraces rest on the same substratum as in b).

The process of the block-failure evolution starts with the formation of *blocky crevices* (blocks subside vertically in situ) which create *crevice fields.* Their dimensions and areal distribution are controlled mainly by tectonics. Breaking down of the crevice fields starts at the toe of the slope. The blocks move horizontally, subside and become separated from each other, and a characteristic *blocky field* is thus formed in space.

Individual blocks form morphologically conspicuous elevations as much as 100 x 200 m in size which move downslope.

2. L a n d s l i d e s

Landslides disturb many mild slopes in the Liptov Basin. Sheet, flow and frontal landslides have been distinguished with respect to the shape of their surface and their relationship to relevant factors.

Sheet landslides occupy extensive areas. They were mostly caused by areal factors, such as precipitation anomalies, rock weathering etc. Such landslides, as much as 500 x 1200 m in size, occur on the mildest slopes. Their surface is largely water-logged with a number of springs. The sheet landslides often are not associated with the current stream erosion, and their accumulations "hang" on the slope well above the valley bottom.

Flow landslides are formed in partial depressions on slopes. They are up to 200–1400 m long and 50–450 m wide. These landslides occur in places of deluvial accumulations in transversal depressions with concentrated linear groundwater flows. In most cases, their accumulations stretch as far as the valley bottoms. They generally appear younger and more active than the sheet landslides. Their surface is intensively reshaped by landsliding. Groundwater occurrences here are abundant.

Frontal landslides were caused by lateral stream erosion. These 100–400 m long landslides almost continuously fringe slopes of tributaries to the Váh River. Frontal landslides are largely caused by activation of pre-existing flow and sheet landslides. In many areas, they are the most active landslide form, most sensitive to human intrusions.

With regard to their activity and sensitivity to relevant factors and therefore partly also their temporary stability acquired after the completion of the sliding stage, three principal types of landslides have been distinguished on the slope-failure maps: stabilized, potential and active.

Stabilized landslides represent the oldest type characterized by a high degree of stability. They were formed by the action of extreme climatic factors, most probably in the latest Pleistocene, and currently are so stable that their activation by the present-day climatic factors is unlikely. They can only be activated by intensive lateral stream erosion or unwise activity of man.

The surface of the stabilized landslides is almost even, without major signs of landslide microrelief. Their failure plane, accumulatrions as well as lateral borders are indistinct and therefore only a fairly experienced geologist can recognize them.

Potential landslides are most abundant and most extensive. They were caused by modern factors and their current stability is rather low, so low that any factor may activate a part of these landslides. The surface has a clear landslide microrelief. The limits, failure surfaces and accumulations of these landslides are clearly visible. Their surface is often water-logged and scarred by minor active landslides. Such areas are mostly used as poor pastures.

Active landslides are recent landslides bearing clear signs of activity – surface with fresh scars. disturbed grass, damaged man-made objects, etc. Their rate of movement is so great that landslide landforms cannot be removed by areal run-off and other surface-shaping agents.

Landslides identified in the Liptov Basin form extensive *landslide areas* which are defined as slopes composed of a set of landslides of different ages, shapes and activity. Only an experienced geologist can determine correct typologic and genetic forms of landslides in this variegated setting. Division of a given landslide area into individual types is a fundamental step in detailed stability analyses and in projecting remedial stabilization actions in landslide areas. A special kind, so called *rockslides*, was identified by us in areas composed of Mesozoic rocks. The rockslides are commonly accompanied by block deformations which occur under similar conditions.

3. Stony-loamy flows (mures)

These flows occur in transversal valleys in the mountains surrounding the basin (Chočské vrchy, Západné Tatry, Nízke Tatry). Studies of aerial photos allowed us to plot them into the slope-failure maps. We have distinguished reception areas of mures and their alluvial cones. Thanks to fairly small differences in altitudes in the adjacent fold moutains and because of their forest cover, mures are of limited practical importance.

4. Rock falls

Rock falls in the studied territory are mostly dump-type ones taking place on steep rock bluffs composed of Mesozoic rocks. Their practical significance is small.

Principles governing the evolution and areal distribution of slope failures

One of the objectives of our slope-failure researches in the Liptov Basin was to clear up principles governing the evolution and areal distribution of slope failures, the most important of which are landslides. That is why special attention was paid to detailed field investigations and mapping of landslides.

The way in which the mapped landslides were classified is described in the foregoing section. The limits (failure plane, lateral limits and front accumulation) of each classified landslide were plotted on the map. If the map scale was sufficient, partial failure surfaces were also plotted. With regard to the scale, all major hydrogeologic manifestations (springs, swamps, undrained depressions) were recorded as well.

Each identified landslide was described in detail using "Record forms" prescribed by Geofond.

Aside from their informative character, the record forms served us as a basic material for statistic landslide-data treatment.

Our studies in the Liptov Basin made it possible to distinguish several typologically regionally different kinds of slope failures:

– slope failures on slopes of the adjacent core mountains

– landslides on the periphery of accumulation terraces
– landslides on the periphery of travertine piles
– landslides on slopes composed exclusively of Paleogene rocks.

In the following text, we shall statistically investigate the set of landslides in the Liptov Basin.

The distribution of Pleistocene river deposits influences certain principles of geomorphological history involving also landslide evolution.

On the right-hand (northern) side of the basin, the evolution of the Váh terrain is clearly delayed upstream. Terrace deposits in its western tract were completely eroded and the relief is considerably dissected, whereas in the eastern tract terrace remnants are extensive and the topography is generally flatter.

On the left (southern) side, this phenomenon has not been noted. Terrace remnants are regularly distributed and erosion is generally less deep.

These differences suggest that the Quaternary uplift was more intensive on the right-hand side of the basin and therefore also depositional landforms were eroded more swiftly. That is why landslides on the periphery of gravel terraces in the northern tract of the basin occur exclusively in the Smrečany Upland.

In that upland, landslides clearly disturb gravel deposits on the periphery of a Pliocene erosional remnant between Bobrovec and Bobrovček. Landslides of this kind make up a continuous landslide area some 8 km long on the left bank of the Bobrovec brook and about 8.5 km long on the left bank of Smrečianka. Notable landslides of this type are on the slopes of Trnovec brook, near Konské and from Liptovský Ondrej as far as Beňadiková.

Landslides bound to gravel deposits near left-hand tributaries to the Váh River are evident at a water divide between Sliačanka and Ľupčianka, in the upper tract of the brook Dúbravka and in the vicinity of village Dúbrava.

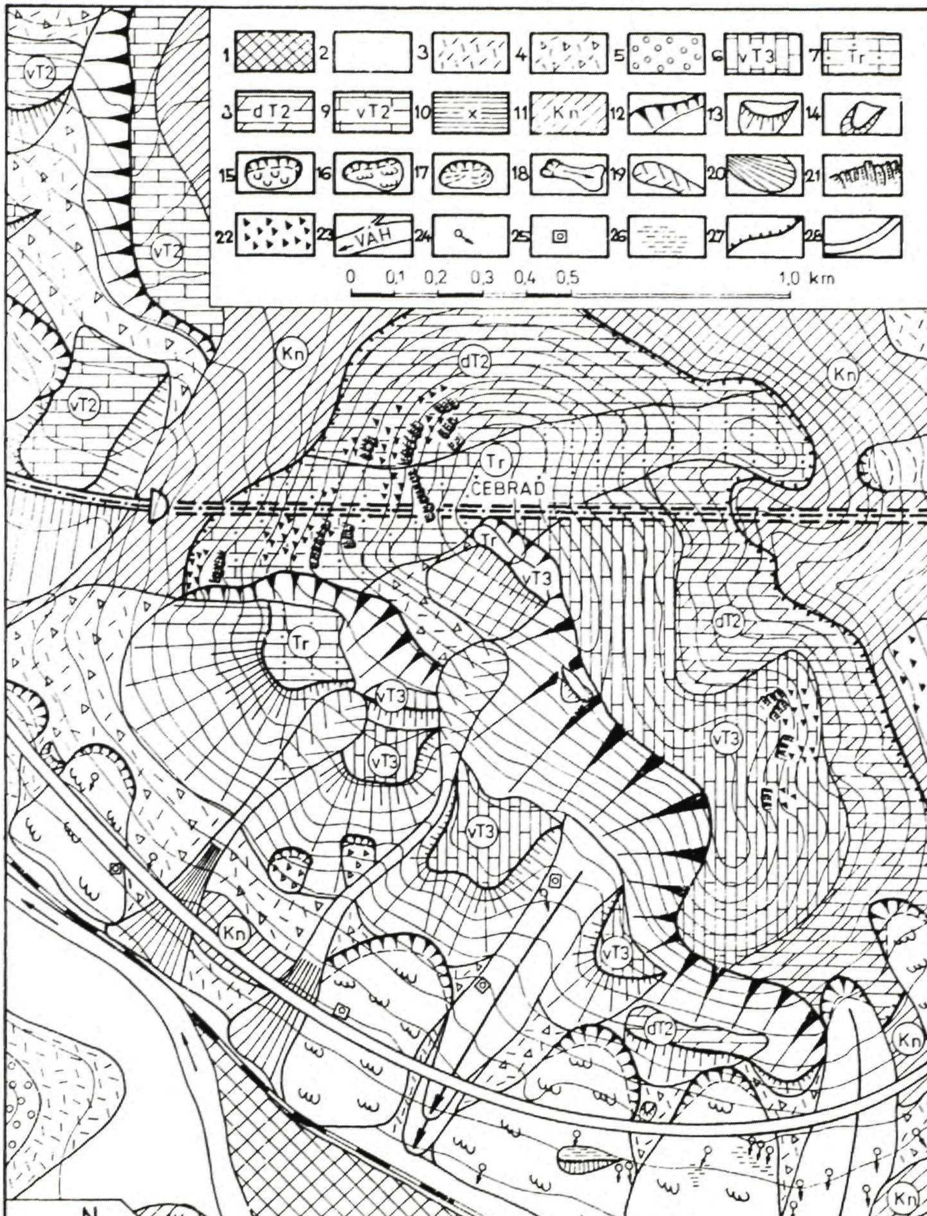
A partly discontinuous belt of frontal landslides also disturbs middle left-bank terraces of the Váh River between the villages of Štiavnička and Liptovský Michal and near Závažná Poruba.

1. Slope failures fringing core mountains

The mountain ranges closely surrounding the Liptov Basin are disturbed by block fissures, rockslides, rockfalls and mudflows. The most disturbed place is Mt. Čebraď situated a short distance NW of Ružomberok.

The slope-failure map (Fig. 10) shows that Mt. Čebraď (1054 m above sea level) is intensively dissected by enormous block fissures in a moderately advanced stage of development (Fig. 11).

The block dislocations evolved in a site where Choč-nappe limestones and dolomites rest on Krížna nappe marls of Neocomian age. On Mt. Čebraď, a 30 m-high rock bluff was formed along which a block of Choč-nappe limestones up to 200 m – thick subsided and was displaced horizontally. On the southern slopes of Čebraď there are systems of such subsided blocks separated from each other by



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undrained depressions which are partly or completely filled with material fallen from the fronts of higher blocks.

In the foreground of the block deformations there are sheet and flow landslides threatening suburb Rybárpole, a railway line and cause problems in projecting a motorway (JADROŇ et al., 1974).

Further minor block deformations occur north of the village Martinček on the slopes of Chočské vrchy in places whose geological setting is similar to that at Čebrať.

Rockslides in the described geological structure were formed on the rims of erosional outlier Mních north of Ružomberok. A well-known landslide in this structure was triggered by undercutting the southern toe of Mních in 1949 when a railway station at Ružomberok was being enlarged (Fig. 5).

Rockslides bound to the Choč/Krížna-nappe contact also occur north of Lúčky, near Liptovská Anna and Matiašovce. They have been noted south of the village Ludrová in the Nízke Tatry as well (Mt. Kundrák and Gregorov vrch).

2. Landslides on the rims of depositional terraces

Landslides on the slopes whose upper parts contain remnants of proluvial cones and terrace accumulations were formed under special conditions. The sandy-gravelly accumulations of cones and Pleistocene terraces, irrespective of their relative altitude above the valley bottom, significantly influenced the evolution of lanuslides on slopes.

Gravelly material is highly permeable. Such layers 10–30 m thick contain large volumes of groundwaters which give rise to stratal springs on the periphery in the source areas of landslides. The sliding material is thus permanently saturated with water streaming from the gravels. The landslides contain permeable gravel layers separated from each other in the upper parts and therefore groundwater pressure is considerable. That is why landslides in this structure represent a separate regional type, homogeneous and suitable for statistical analyses.

Another criterion which can be applied for a more detailed differentiation of this regional type is the character of the Paleogene substratum. Even a brief glance at the

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Fig. 10 Map of slope failures on the southwestern slope of Mt. Čebrať near Ružomberok
1 — anthropogeneous sediments, 2 — fluvial sediments of alluvia and low terraces, 3 — deluvial sediments, 4 — stony-loamy block slides, 5 — terrace fluvial sediments (1—5 Quaternary), 6 — light limestones (Norian), 7 — nodular limestones (Upper Ladinian), 8 — dolomites (Ladinian), 9 — limestones (Anissian), 6—9 Choč nappe — Hronicum, 10 — shales and schistose limestones (Barremian—Middle Albian), 11 — marlstones and marly limestones (Berriasian—Hauterivian), 10—11 Krížna nappe—Tatricum, (6—11 Mesozoic), 12 — failure planes of block fields, 13 — blocks in a block field, 14 — blocks in landslides, 15 — active sheet slides, 16 — potential sheet slides, 17 — stabilized sheet slides, 18 — potential flow slides, 19 — reception area of mure flows, 20 — mure-alluvial fans, 21 — failure planes of rockfalls, 22 — faults, 23 — streams, 24 — springs, 25 — exploited springs, 26 — water-logged areas, 27 — nappe thrust planes, 28 — alternative motorway routes

Fig. 11 Block slides on the southwestern slope of Mt. Čebraď near Ružomberok

map (Fig. 2) reveals differences in the development of landslides on the rims of gravel deposits overlying:

a) claystone-dominated Paleogene
b) typical flysch-like Paleogene
c) non-flysch Paleogene.

3. Landslides on the rims of travertine bodies

The conditions of their formation resemble those of the foregoing type. Springs of aggressive mineral waters here, however, speeded up chemical weathering of the surrounding Paleogene rocks, degraded their physical-mechanical properties and created special conditions for the formation of landslides.

Travertines occur in the western tract of the basin. Landslides on the rims of travertine piles near the village of Ludrová were activated by minor excavations for the construction of objects of a local farming cooperative on a 6° slope. Similar highly sensitive landslides also occurred by the villages of Liptovská Štiavnica and

Vyšný Sliač. Vaškovský and Ložek (1977) described travertine piles here disturbed by block deformations.

Dangerous landslides on the periphery of travertine piles were also formed at the village of Lúčky and near Bešeňová. Landslides in the valley of the village Potok may have partly been caused by inflows of aggressive artesian mineral waters.

4. Landslides on the slopes composed of Paleogene rocks

Landslides in the Liptov Basin largely occur on the slopes composed exclusively of Paleogene rocks. Their evolution depends primarily on the properties and composition of the subjacent Paleogene rocks as well as slope geomorphology and its history.

a) *Landslides on sandstone-conglomerate slopes*

These landslides occur in a geological structure similar to the preceding ones.

The sandstone-conglomerate Paleogene in the basin locally forms flat hills and ridges, the slopes of which are composed either of claystone of flyschoid rocks. Once again, structures predisposed for the formation of landslides but also block deformations occur here.

A flat ridge above the village of Nižný Sliač is strongly deformed in this manner. The whole periphery of this structure is continuously disturbed by potential and active landslides as well as block deformations.

A strongly disturbed structure of this type occurs on the periphery of Mt. Mníchov vrch SW of Prosiek and NW of the village Liptovský Trnovec.

Only 15 landslides have been noted on this rock type, which is an insufficient number for statistical treatment. Potential, fairly large landslides prevail.

b) *Landslides on claystone Paleogene*

The claystone Paleogene dominates the western and southern tracts of the basin. The claystones gave rise to a relatively flat, finely-shaped relief, the slopes of which are controlled by the physical-mechanical properties of the substratum and deluvium, and are in long-term equilibrium with strength characteristics.

Landslides on the claystone Paleogene, totalling 205 in the western Liptov Basin, are mostly areal and considerably reshaped. Stabilized types prevail, but still they are very sensitive to human-caused changes in the current stability regime. The average landslide area is 0.08 km^2 and average angle of slope is 9.26° (Fig. 12). The size of the landslides mostly amounts to 0.02–0.05 km^2 (Fig. 13).

Landslides on the claystone Paleogene are fairly inhomogeneous due to different properties of the subjacent rock or rocks forming the slope.

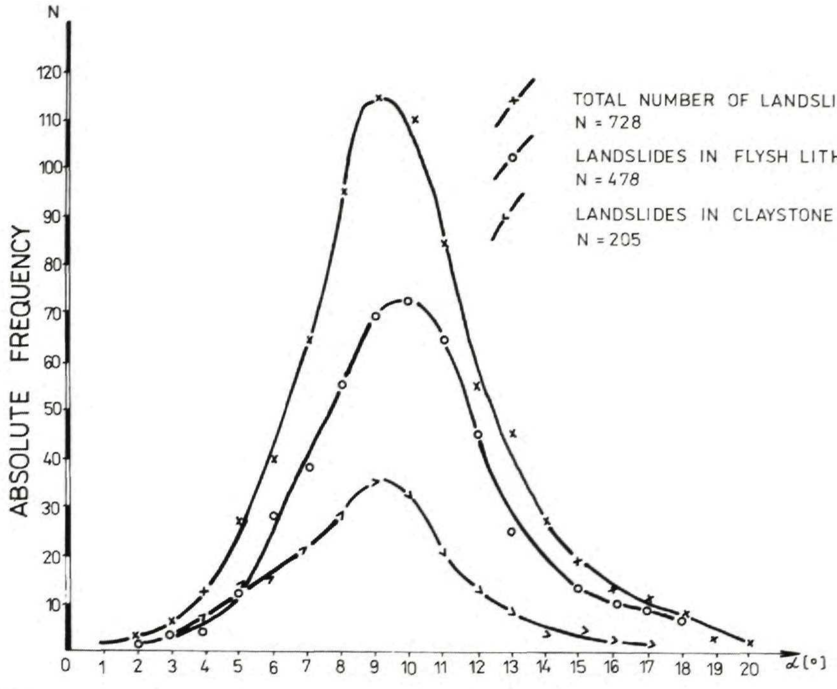

Fig. 12 Curves showing frequencies of landslide slope angles

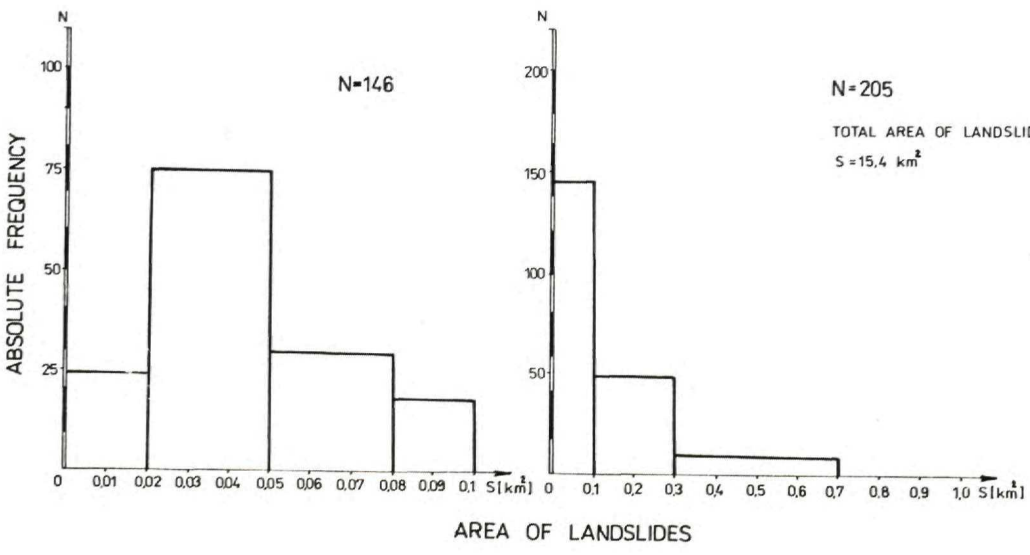

Fig. 13 Histograms of landslide occurrences on Paleogene claystone substratum

Out of this group of landslides, we have studied in detail the one near the village of Lisková (Fig. 14). At this locality we have made slope-failure maps on scale 1:2000 (Fig. 15). This voluminous landslide, whose failure plane is up to 37 m deep (Fig. 16) and dimensions of the main flow are 910 x 420 m, was studied because it intersects the proposed motorway D-1. Aside from drilling and laboratory tests, which allowed us to make a slope-stability analysis, the investigations also included geophysical and radionuclide methods aimed at finding out the depth of failure planes, geodetic measurements in a grid of 9 fixed and 17 monitored points to observe landslide movements as well as regime monitoring of groundwater levels in drillholes.

The investigations have shown that the degree of stability of the main landslide flow is very low – the landslide can be classified as transient between a stabilized and active type. The stabilization of this landslide would be extremely expensive and therefore we have proposed to locate the motorway to the south than originally planned, although in this case it would partly lead above the surrounding terrain (Jánová, 1982, Mahr et al., 1984).

Fig. 14 Landslide area near the village of Lisková

Geologický ústav Dionýza Štúra
INFORMAČNÉ STREDISKO
Bratislava

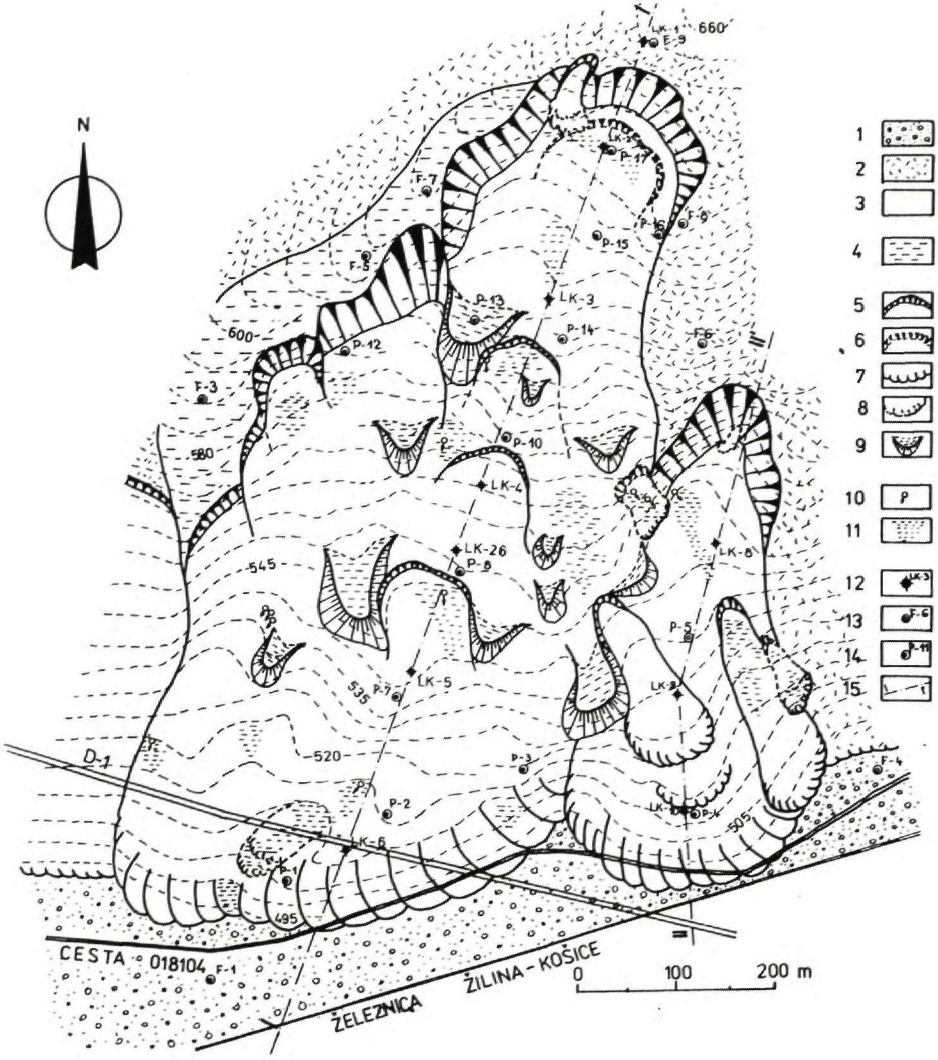

Fig. 15 Map of slope failures near the village of Lisková
1 — alluvial deposits, 2 — deluvial loams, 3 — loamy-stony landslides (1—3 Quaternary), 4 — claystone lithofacies (Paleogene—Upper Eocene), 5 — failure planes of potential landslides, 6 — failure planes of active landslides, 7 — accumulation ramparts of potential landslides, 8 — accumulation ramparts of active landslides, 9 — block dislocations, 10 — springs, 11 — water-logged areas, 12 — cored drillholes, 13 — fixed points of geodetic grid, 14 — monitoring points of geodetic grid, 15 — sections

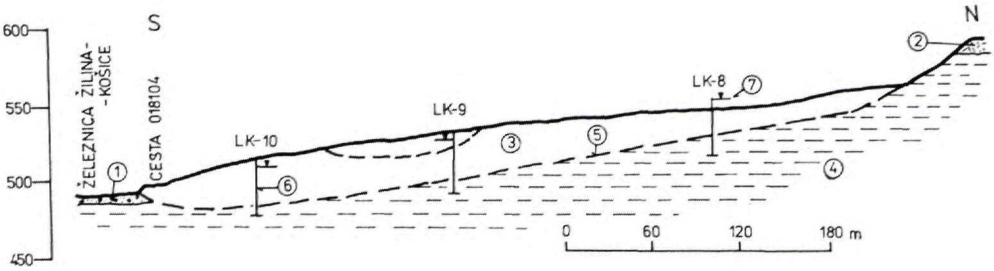

Fig. 16 Section of landslide Lisková 11—11'
1—4 same as in Fig. 15, 5 — failure planes of landslides, 6 — cored drillholes, 7 — groundwater pressure level

c) *Landslides on flysch substratum*

They make up the most severely disturbed areas in the northern part of the basin (Matiašovce Grooves, Smrečany Upland and Choč Mts.).

The relief in the flyschoid tract of the basin is rolling, with greater differences in altitude than in areas underlain by claystones. The landslides totalling 478 are controlled by the properties of their substratum and groundwater occurrences.

Flow-type, both active and potential landslides, prevail. The slopes are largely steeper (10.5° – Fig. 12) than in the two foregoing groups. The landslides mostly occupy an area of 0.02–0.05 km², but many of them (110) exceed 0.1 km². The number of small landslides (60) is not insignificant as well (Fig. 17).

The flysch landslides make up a fairly homogeneous statistical set. It seems that landslides on flysch rocks are not influenced by the rock properties to such a high degree than landslides on Paleogene claystones (Vesel, 1987).

This group of landslides is exemplified by those below hill Háje near Liptovský Mikuláš (Mahr et al., 1984). The hill's northern slopes are disturbed by a huge landslide whose central active part damaged a monument and an access road (Fig. 19). Investigations similar to those at Lisková have shown that also here the degree of stability in a section 1–1' (Fig. 20) is very low (according to Pettersson's method F = 0.96, according to Janba's method F = 1.03), which means that the landslide will continue to be active, particularly in the central and southern parts of the slope.

We have proposed measures to stabilize the slope (Baliak–Malgot, 1987) including measures to stop lateral erosion of a brook which undercut the slope, and drilling horizontal dewatering holes into the landslide body to reduce groundwater buoyancy.

Landslides on the Paleogene substratum which do not fall into the three above-described sets (sandstone-conglomerate, claystone and flysch) are so rare that they could not have been statistically treated because the results thus obtained would be unreliable.

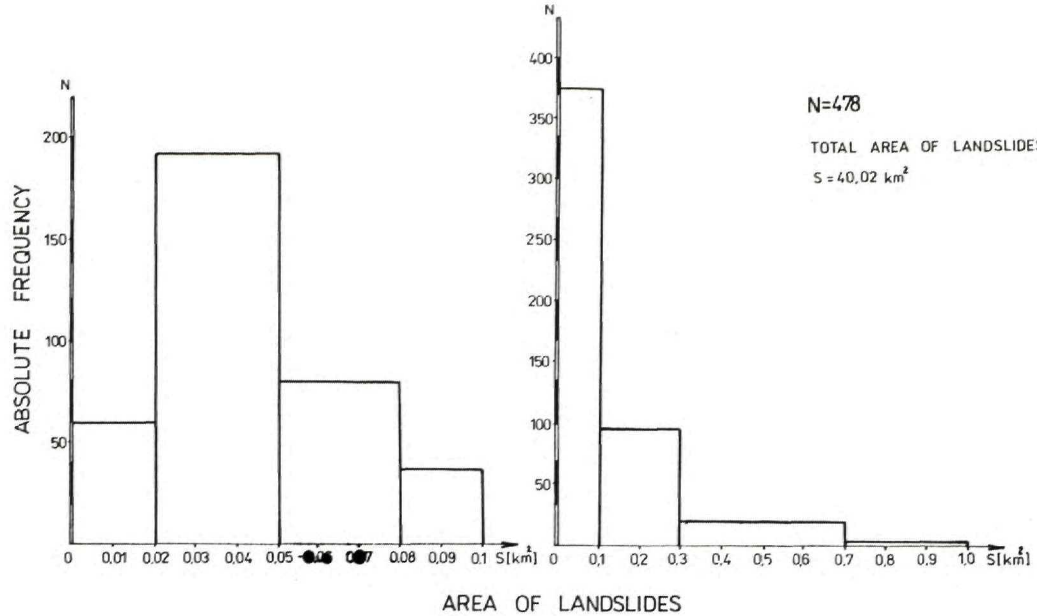

Fig. 17 Histogram of landslide occurrences on Paleogene flysch substratum

Economic impacts of slope failures

Slope failures in the Liptov Basin pose a significant economic problem. Mapping in the western tract of the basin revealed 898 slope failures, 728 of which were landslides. The landslides occupy 58.24 km_2 accounting for 15.3 % of the whole mapped area.

Slope failures here have serious economic consequences. They partly or totally degrade the disturbed areas and pose a direct or potential threat to existing and projected objects. They have a major negative impact on the land's economic value and environment.

1. Impact of slope failures on agricultural land

Farmland is frequently degraded by slope failures. In the Liptov Basin, farmland disturbed by slope failures is mostly used as meadows or, on steep slopes, as pastures. Stabilized landslides were sometimes converted to arable land. In contrast, active landslides marked by red colour on the slope-failure map cannot be used for agricultural purposes.

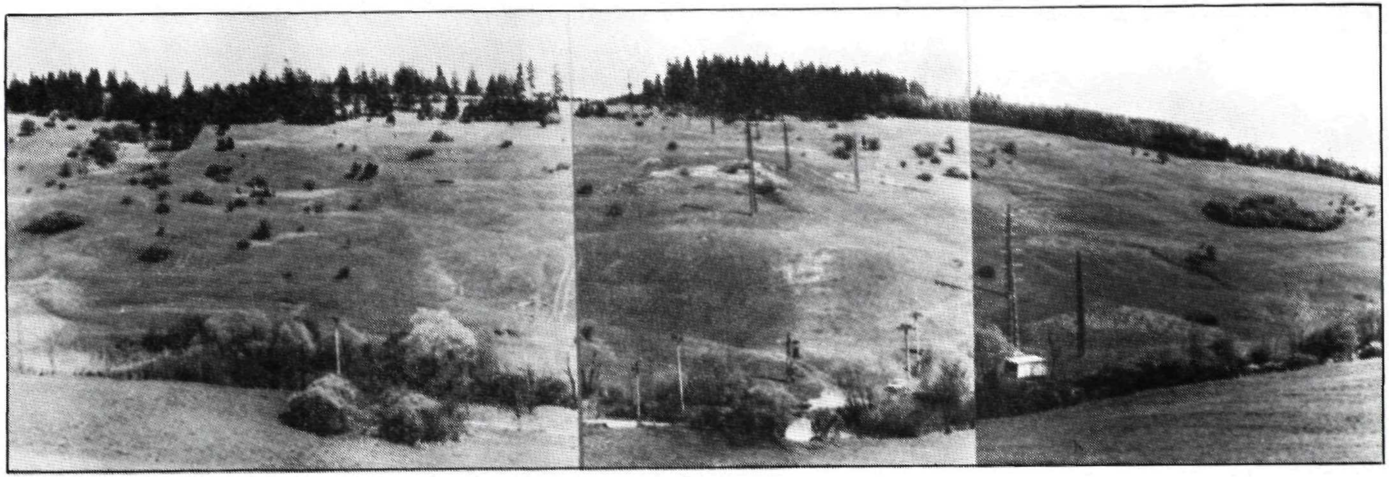

Fig. 18 Active landslide area on the western slope of hill Háje near L. Mikuláš

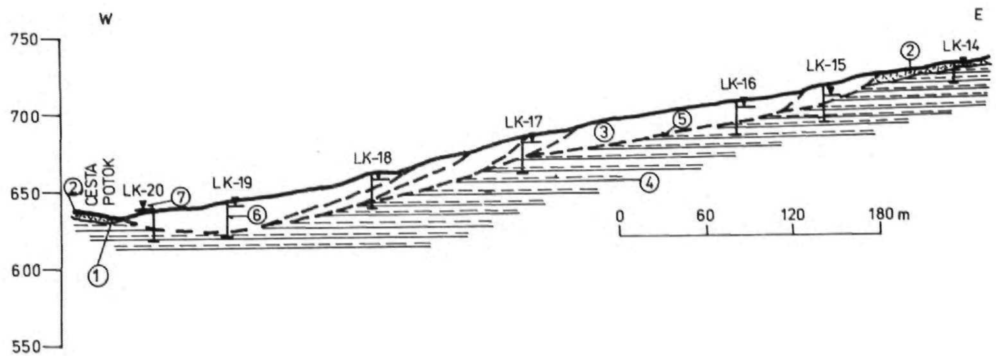

Fig. 20 Section of landslide Háje 1—1'
1 — alluvial deposits, 2 — deluvial loams, 3 — loamy-stony landslides (1—3 Quaternary), 4 — claystones and sandstones of flysch lithofacies (Paleogene—Lower Oligocene), 5 — landslide failure planes, 6 — cored drillholes, 7 — groundwater pressure level

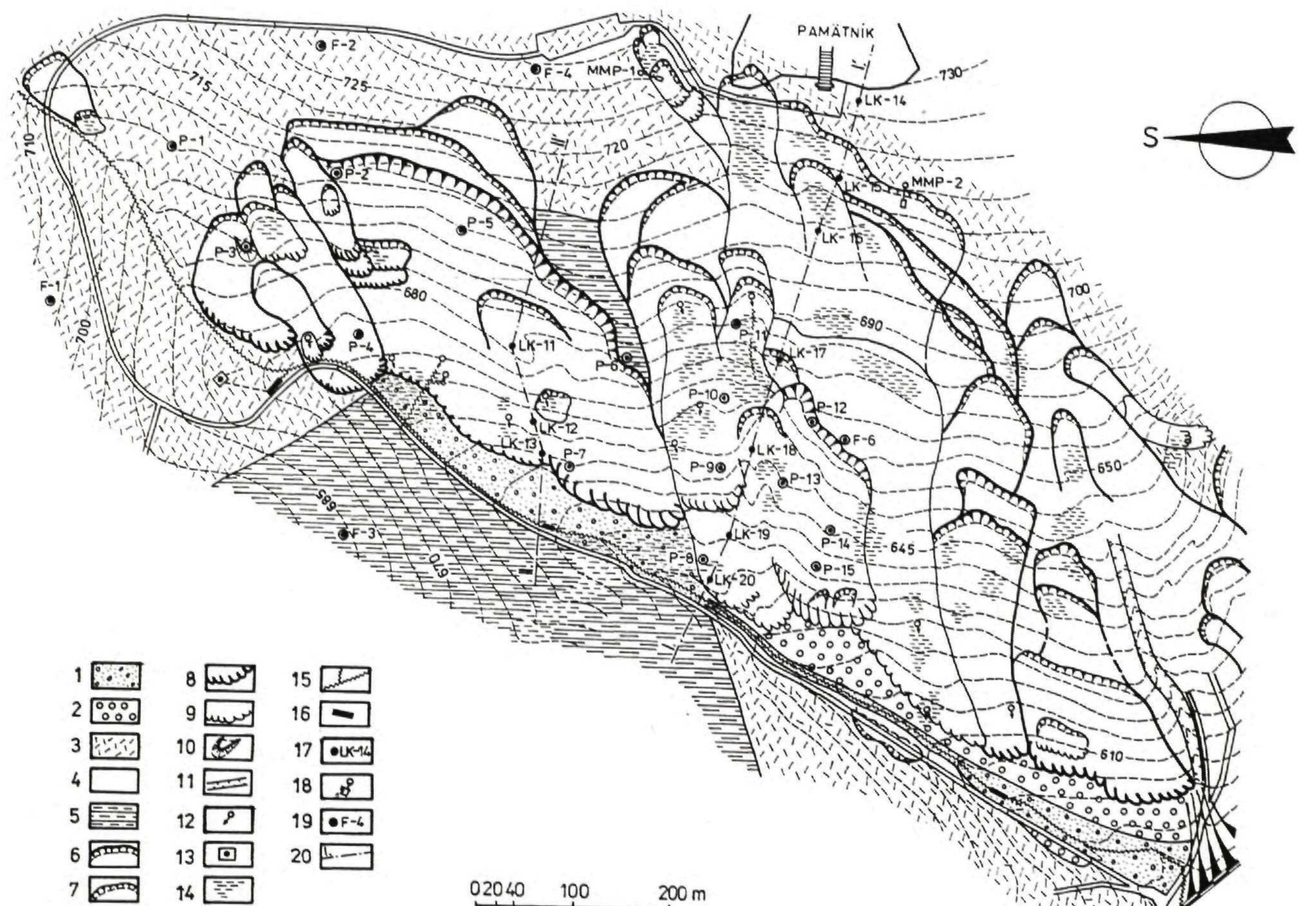

Fig. 19 Map of slope failures below hill Háje near L. Mikuláš

1 — alluvial deposits, 2 — terrace sediments, 3 — deluvial loams, 4 — loamy-stony landslides (1—4 Quaternary), 5 — flysch lithofacies (Paleogene—Lower Oligocene), 5 — flysch planes of potential landslides, 7 — failure planes of active löandslides, 8 — accumulation ramparts of potential landslides, 9 — accumulation ramparts of active landslides, 10 — blocks in landslides, 11 — gullies, 12 — springs, 13 — exploited springs, 14 — water-logged areas, 15 — brooks, 16 — pools and watering places, 17 — cored drillholes, 18 — strainmeters MMP-120, 19 — fixed (F) and monitored (P) points in geodetic grid, 20 — sections

The surface of active landslides is very uneven and water-logged and is therefore inaccessible for agricultural machines.

An extensive landslide area near the village of Potok is a good example. The 3.0 km^2-large landslide is largely a meadow, with 20 % of the area being pastureland (Fig. 21).

2. Impact of slope failures on industrial objects

Slope failures endanger or damage settlements as well as industrial plants.

Our mapping has revealed that 30 villages and settlements lie on or are threatened by landslide slopes.

Here are some of the most endangered ones:

– virtually the whole village of Konská is situated on landslide slopes. Walls of dwelling houses are fractured, and unwise human activity may activate partly stabilized landslides to such an extent that dwelling houses may be totally destructed (see Fig. 22).

– the southern part of the village Potok is threatened by an active partial landslide which regularly damages 5 dwelling houses.

– other villages whose objects are threatened by slope failures include: Lúčky, Turík, Kalameny, Madočany, Bobrovček, Pavlova Ves, Liptovský Kríž, Krmeš, Nižné Malatiny, Nižný Sliač, Dúbrava etc.

Endangered industrial objects comprise Benzinol at Ružomberok and a brick-plant at Ondrašová (Fussgänger–Smolka–Hric, 1983).

3. Effects of slope failures on communication routes and engineering installations

Our slope-failure mapping in the western Liptov Basin has revealed 48 places where roads lead through a landslide area.

Such places include a bypass of state road No. 18 which leads through numerous landslides between Stredné Malatiny and Galovany. The road construction here also implied landslide stabilization, which sharply increased constructon costs (Malý–Janovič, 1976).

Road No. 18 and a railway bypass near the village of L. Michal required excavations in a landslide slope (Fig. 23). Furthermore, roads leading across landslides near Potok, to Veterná Poruba and near Sliače deserve to be mentioned.

Another major problem is the projected motorway in the Liptov Basin. Its construction has so far encountered no significant problems related to slope failures because it leads in an area devoid of major landslides.

However, the projected motorway tract between Hrboltová and Likavka will either lead through a tunnel beneath Mt. Čebraď or the mountain will be bypassed in the south. The surface alternative would intersect several stabilized landslides. The

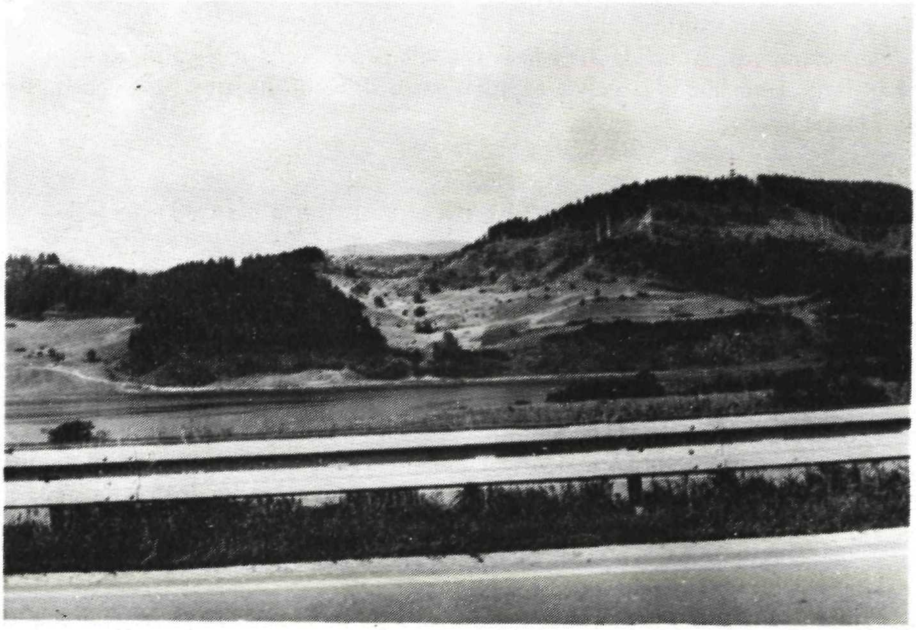

Fig. 21 Active part of sheet landslide near the village of Potok

Fig. 22 A disturbed dwelling house situated on the accumulation part of a landslide in the village of Konská.

Fig. 23 A landslide treating a state road and railway line near Liptovský Michal. It was stabilized by removing part of its

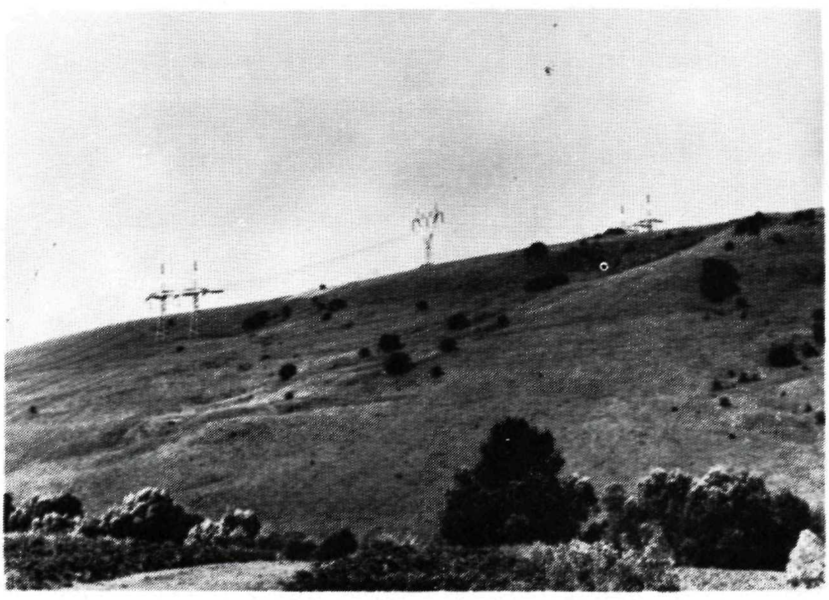

Fig. 24 High-voltage power lines threatened by a landslide near the village of Galovany

underground alternative would lead beneath an extensive blocky deformation on the slopes of Čebraď (Fig. 10, 11).

The tract between Likavka and Lisková will lead across several landslides, the most extensive of which, above the village of Lisková, was described in the previous chapter (Fig. 14, 15, 16).

The railway line from Žilina to Košice is endangered by landslides (in western Liptov Basin) in these places: railway station at Ružomberok – rockslide on the SE slopes of Mních (Fig. 5), Rybárpole – landslide beneath Čebraď (Fig. 10, 11), Liptovský Michal – sheet landslide (Fig. 23) – all of which have already been discussed in this article and a landslide near Okoličné (FUSSGÄNGER–JADROŇ, 1976).

Aside from the communication routes, slope failures also threaten power lines, the poles of which frequently rest on landslides, particularly if the landslides are so extensive that it is impossible to avoid them by erecting the poles on stable ridges. Landslides near the villages of Potok, Konská, Lúčky, Ľubela, Galovany (Fig. 24) etc. are good examples.

4. Effects of slope failures on the construction of water reservoirs

Slope stability is a fundamental engineering-geological problem in the construction of water reservoirs. In some cases, slope stability is a decisive factor controlling the location of a given water reservoir.

Slope failures, primarily so called Large Mara landslide and Small Vlachy Landslide, also complicated the construction of the water reservoir Liptovská Mara in the Liptov Basin.

The former landslide is 900 m long, 500 m wide and its maximum thickness in the accumulation area attains 40 m (INGR–FEKEČ, 1973). To prevent landslide activation by waters of the reservoir, the front of the landslide was reinforced by a massive gravel stabilizing berm reaching the height of the maximum water level (Fig. 9). It is one of the largest stabilizing berms in the whole country. It is 620 m long, 230 m wide, 6–7 m thick and its volume totals 700 000 m^3. Another stabilizing element is underground dewatering by horizontal drillholes and surface ditches on the periphery of the landslide.

The small Vlachy landslide measures 300 by 150 m and the thickness of its landslide deluvia is 5–12 m (Fig. 25). In 1974, as a result of extreme precipitation and partial undercutting, the landslide became active. It moved some 40 m downslope at a rate of 1 m in two months, and was eventually stopped by a gravel stabilizing berm (STOLEČŇAN–LITVA, 1974).

Engineering-geological assessment of the area

The engineering-geological phenomena in the area concerned were areally evaluated on maps of engineering-geological regions on scales 1:10 000 and 1:25 000. The

Fig. 25 A landslide near the village of Vlašky, below dam Liptovská Mara

principal criterion applied in this assessment is slope stability and therefore the maps are analytic ones, although they pay attention to other engineering-geological phenomena as well. These, however, are of minor importance.

The analytic maps of engineering-geological regions are useful in some areas in resolving special problems where certain geological phenomena may play a decisive role. The very unstable slopes in the western Liptov Basin justify our approach in which slope stability is a key criterion.

With respect to slope failures, their types as well as geological, morphological and hydrogeological settings, we have distinguished three basic regions composed of eleven districts on scale 1:25 000 (Appendices 1–2 in Mahr et al., 1984).

Region I – Unstable areas

District: 1. Active landslides
2. Dormant landslides
3. Stabilized landslides
4. Areas threatened by falling rock fragments and rockslides
5. Loamy-stony flows – mures

Region II – Relatively stable areas

District: 6. Slopes predisposed to landslides
7. Slopes of sensitive stability
8. Blocky-field areas

Region III – Stable areas

District: 9. Alluvial deposits, terraces and alluvial fans
10. Flat and mild slopes
11. Steep slopes in solid rocks

The areas were assigned into individual regions and districts so that, when engineering-geological criteria are met, individual districts had roughly equal conditions for the construction of engineering objects. Each civil engineer regards a map of regions more understandable than that of engineering-geological conditions.

By the map compilation, with regard to its purpose, the map was simplified because of its scale and rather strict criteria were employed in assigning the territory into individual districts.

The map's contents depend on its scale. At larger scales, e. g. 1:10 000, we could have distinguished detailed taxonomic units with a detailed description of engineering-geological conditions and a higher degree of their homogeneity (Appendix 2-2 in Mahr et al., 1984).

The maps contain an easy-to-review table which describes basic preconditions to the formation of slope failures (geologic, geomorphologic and hydrogeologic), character and activity of the movements, forecast of their evolution and brief characteristics for building purposes in each district.

Despite its small scale and resulting simplifications, this map of regions may serve us as a basic material in early stages of projecting construction in the western Liptov Basin.

In an easily understandable form it illustrates dangers of disturbing slope stability by construction and emphasizes the need to investigate slope stability by a detailed engineering-geological survey.

Individual regions are marked by traffic-light colours. Hazardous landslide areas of unstable regions are marked by red and individual districts are shaded with red and gray strips.

Conclusion

Slope failures are the most widely distributed geodynamic processes which control engineering-geological conditions in the Liptov Basin. Slope failures in the studied territory have caused extensive damage to various man-made structures. Previously dormant or stabilized landslides reactivated by unwise human activity are particularly harmful.

Our project also included compilation of a special analytic engineering-geological slope-failure map of the western Liptov Basin on scale 1:25 000 (380 km^2). This map is a good basis for detailed engineering-geological investigations preceding construction in a given area.

This map was used to compile a map of engineering-geological region composed of taxonomic units reflecting slope stability. Construction conditions are roughly equal throughout each region. Such a map of regions can easily be understood by a wide spectrum of specialists. In a territory densely dotted with unstable areas, e. g. in the Liptov Basin, this map may be a basis for planning urban construction.

In the western end of the Liptov Basin, several major investments are planned. That is why we have compiled a relatively detailed analytic engineering-geological map of slope failures in this are on scale 1:10 000. This map was supplemented with a map of engineering-geological regions.

These basic maps may considerably increase safety and reduce construction costs.

Aside from their practical value, the maps are also valuable from a theoretical viewpoint because they allow to define basic structural types of landslides.

Four localities (Konská, Háje, Lisková, Potok) have been studied in more detail as part of this project, which made it possible to clear up the formation, evolution and character of landslides in the basin concerned. In addition to drilling, detailed investigations also included geophysics, special field measurements, groundwater-level monitoring, geodetic monitoring of landslide movements, radionuclide measurements, measurements of failure-plane indications and movement activity.

The localuities were selected to provide further data and to resolve some practical problems concerning slope stability. The stability of landslides at individual localities was assessed and remedial works were proposed.

Individual landslides in the studied territory were characterized using "Landslide data forms" which are deposited at Geofond, Bratislava. These form have been employed in our statistical analyses aimed to study principles governing the evolution and areal distribution of slope failures.

Translated by M. Böhmer

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František Baliak–Jozef Malgot–Vlasta Jánová

Svahové poruchy v západnej časti Liptovskej kotliny

Resumé

Svahové pohyby v oblasti Liptovskej kotliny predstavujú fenomén, ktorý má vážne ekonomické dosahy. Územia porušené svahovými deformáciami sú značne znehodnotené a predstavujú priame alebo latentné

nebezpečenstvo pre existujúcu a plánovanú výstavbu. Výrazne vplývajú na využiteľnosť krajiny a tvorbu životného prostredia.

Mapované územie má plochu 380 km^2, zaberá západnú časť Liptovskej kotliny a okraje priľahlých pohorí v úseku medzi Ružomberkom a Liptovským Hrádkom. Odvodňované je riekou Váh a jej prítokmi.

Počas systematického terénneho výskumu bolo zaregistrovaných 898 svahových deformácií s celkovou plochou 58,24 km^2, čo predstavuje 15,3 % mapovaného územia. Veľké plošné rozšírenie svahových porúch vyplýva z priaznivých podmienok pre ich vznik a vývoj. Sú to predovšetkým geologicko-tektonické, geomorfologické, klimatické a hydrogeologické pomery územia a tiež fyzikálno-mechanické vlastnosti hornín.

Územie Liptovskej kotliny je budované horninami vnútrokarpatského paleogénu a pokryvnými kvartérnymi útvarmi. Podložie paleogénu a svahy priľahlých pohorí sú budované horninami mezozoika, z ktorých výraznú prevahu majú strednotriasové vápence a dolomity chočského príkrovu a slieňovce a slienité vápence krížňanského príkrovu. Paleogén je reprezentovaný horninami bazálnej transgresívnej litofácie, ílovcovej litofácie, flyšovej litofácie a neflyšového pieskovcovo-zlepencového vývoja.

Kvartérne pokryvné útvary majú z hľadiska vzniku svahových deformácií najväčší význam. Najrozšírenejšie sú deluviálne sedimenty s veľmi variabilným litologickým zložením, ďalej sú zastúpené eluviálne, deluviálno-fluviálne a fluviálne sedimenty, proluviálne náplavové kužele a sladkovodné vápence.

Tektonické pomery sú definované dvoma hlavnými systémami zlomov — staršie, zhodné s osou kotliny a mladšie priečne zlomy sj. smeru.

Z geomorfologického hľadiska prevláda na území erózno-akumulačný reliéf charakteru kotlinovej pahorkatiny a akumulačný reliéf zastúpený poriečnou nivou, terasami a proluviálnymi zvlnenými rovinami.

Klimatické pomery predstavujú pestrú paletu klimatických typov a podtypov. Na stabilitu svahov majú vplyv najmä dlhodobé zrážky v jarných a jesenných mesiacoch a náhle prívalové dažde v letných mesiacoch.

Hydrogeologicky priaznivé podmienky pre vznik a reaktivizáciu svahových porúch poskytujú nepriepustné slienité vápence krížňanského príkrovu, ktoré sa nachádzajú v podloží priepustných vápencov a dolomitov chočského príkrovu. Paleogénne horniny sú na vodu chudobné, najpriaznivejšie hydrogeologické podmienky majú sedimenty bazálnej transgresívnej litofácie. Vo flyšovej a ílovcovej litofácii je obeh podzemnej vody viazaný na vrstvy pieskovcov s pórovo-puklinovou priepustnosťou. Významným kolektorom podzemnej vody sú kvartérne fluviálne sedimenty Váhu a jeho prítokov.

Svahové deformácie sú viazané prevažne na deluviálne sedimenty a na zónu zvetraných ílovcov. Priemerné hodnoty fyzikálno-mechanických vlastností týchto zemín sú v tabuľke 1.

Hlavnými faktormi vzniku a vývoja svahových deformácií sú: hĺbková erózia vodných tokov, procesy zvetrávania, procesy svahovej modelácie, zrážkové a teplotné anomálie a antropogénne faktory.

Autori práce podávajú podrobnú charakteristiku jednotlivých typov svahových porúch, hodnotia ich z hľadiska charakteru pohybu, aktivity, morfológie povrchu.

Veľký dôraz sa kladie na analýzu zákonitostí vzniku, vývoja a plošného rozšírenia svahových porúch na svahoch priľahlých jadrových pohorí, po obvode akumulačných terás, po obvode travertínových kôp a v jednotlivých litofáciách paleogénnych hornín.

Hodnotené sú i hospodárske dôsledky svahových porúch.

Na základe analýzy stability svahov a ďalších zložiek inžinierskogeologického prostredia bola zhotovená mapa svahových porúch západnej časti Liptovskej kotliny v mierke 1:25 000 (obr. 2) a mapa inžinierskogeologického rajónovania, na ktorej boli vyčlenené tri základné rajóny — rajón nestabilných území, rajón relatívne stabilných území a rajón stabilných území. Západná časť územia bola spracovaná do máp mierky 1:10 000.

Západné Karpaty, sér. hydrogeológia a inž. geol. 11, p. 141—151,
Geol. Úst. D. Štúra, 1993

ALENA KLUKANOVÁ

The loess sediment types of Slovakia and their microstructures

2 figs., 8 pls., slovak summary

A b s t r a c t. The paper deal with microstrucıural analyses of four basic groups of loess sediments. They are: typical loess, sandy loess, clayey loess and loess-like sediments. They differ each other in their fabric, microstructure, genesis, physical and mechanical properties, tendency to collapse and others.

Introduction

The Slovak Carpathians are distinguished by a considerable vertical relief of the terrain, great climatic and morphologic zonality and variability of the geodynamic processes in the Quaternary. These factors have a considerable influence on formation of the loess cover of the Carpathian system, because they conditioned and determined the particularities of hypergeneous processes and their evolution. They determined the acidity or basicity of the environment, the content of Fe and Mn hydroxides, carbonates, chlorides, sulfates, chemical composition of pore solutions, organic matter and the origin of secondary minerals. All these factors were active to a different degree and in certain cases even determined the formation and origin of various loess lithotypes. We found four principal types of loess sediments in Slovakia. They are typical loesses, sandy loesses, clayey loesses and loess-like sediments. For all these types we give their microstructural characteristics, which need not be valid only for the Carpathian region, but they can be applied on a larger scale.

Method used

The microstructural analysis was done on samples with undisturbed structure by the scanning electron microscope (SEM) produced by JEOL. type JSM 840, at the Dionýz Štúr Institute of Geology (GÚDŠ) Bratislava. GRABOWSKA-OLSZEWSKA et al., (1984) classification, was used.

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Physical properties have been determined in the laboratory of soil mechanics in IGHP Bratislava and Geotest Brno according to methods corresponding to the respective Czechoslovak standards or in accordance with the generally applied procedures. The results are in tables 1 and 2.

The mineral composition was determined by the X-ray and DTA methods in GÚDŠ Bratislava. The results are in table 3 and 4.

Table 1 Physical properties of loess sediments

LOCALITY	LOESS TYPE	THE UNDER-GROUND DEEP	GRAIN-SIZE FRACTION %			natural moisture W_N %	liquid limit W_L %	plasticity limit W_p %	plasticity index I_p %	consistency index I_c	BULK DENSITY		specific density ρ $kg.m^{-3}$	pore content n %	saturation degree S_N %	carbonate content O_u %	organic matter content O_m %
			< 0,002 mm	0,002 - 0,063 mm	> 0,063 mm						of dry soil ρ_d $kg.m^{-3}$	of moisture soil ρ_n $kg.m^{-3}$					
MNEŠICE	typical loess	20,0	14,0	14,0	14,0	12,38	31,14	24,57	6,77	2,55	1379	1453	2721	4933	1506	17,28	1,63
VYŠKOVCE	sandy loess	1,5	7,38	40,0	52,40	4,29	23,80	20,68	3,12	6,25			2730			5,58	
VYŠKOVCE	sandy loess	2,5	9,43	35,34	54,70	3,35	24,71	21,26	3,45	6,19			2727			11,57	
HAJNAČKA	sandy loess	2,0	8,71	28,14	62,83	5,17	25,98	19,70	6,28	3,31			2741			17,56	
JESENSKÉ	clayey loess	1,5	28,14	48,79	13,52	6,54	39,71	22,36	17,35	1,91			2744			0,7	2,61
ŠAFÁRIKOVO	clayey loess	2,0	37,62	51,34	11,02	11,47	55,72	30,13	25,55	1,73			2739			1,12	4,09

Table 2 Physical properties of loess-like sediments

LOCALITY	LOESS TYPE	THE UNDER-GROUND DEEP	GRAIN-SIZE FRACTION %			natural moisture W_N %	liquid limit W_L %	plasticity limit W_p %	plasticity index I_p %	consistency index I_c	BULK DENSITY		specific density ρ $kg.m^{-3}$	pore content n %	saturation degree S_N %	carbonate content O_u %	organic matter content O_m %
			< 0,002 mm	0,002 - 0,063 mm	> 0,063 mm						of dry soil ρ_d $kg.m^{-3}$	of moisture soil ρ_n $kg.m^{-3}$					
KRČAVA	loess like sediment	0,5	45	48	7	12,1	53,3	20,5	32,8		1680		2690	34	90,4	1,01	0,1
IPEĽSKÝ SOKOLEC	---	1,5	22	62	16		36,1	18,7	17,4								
IPEĽSKÝ SOKOLEC	---	2,5	30	56	14		40,8	19,9	20,9								
FABIANKA	---	1,0	22	55	23		36,2	18,5	17,7								
RIMAVSKÁ SEČ	---	1,5	16	63	21		33,3	20,6	12,7				2674			2,52	1,38

Typical loess

The loess soils are characteristic by being non-bedded, primarily calcareous and with capillary porosity. They are generally dry, yellow to dark yellow colour with dominant grain-size composition ranging from 2 to 63 ˙m (aleuritic fraction). Samples of this type of loess soil (from the Mnešice brick plant near Nové Mesto nad Váhom) were thoroughly studied. Their stratigraphy was determined by Kukla et al. (1962).

Table 3 Mineral composition of loess sediments determined by RTG (*) and DTA (#)

Locality	Type of loess sediment	Mont-moril-lonite	Kaoli-nite	Illite	Feld-spar	Chlo-rite	Quartz	Calcite	Dolo-mite	Organ-matter	Anke-rite	Pyrite	Limo-nite	Goe-thite
Mnešice	typical loess	* #	*	* #	*	*	* #	* #	* #	#				#
Vyškovce	sandy loess	* #	* #	* #	*		* #	*	* #			#		
Hajnačka	sandy loess	* #	*	* #	*		* #	*	* #				#	
Jesenské	clayey loess	*	* #	* #	*		* #			#				
Šafárikovo	clayey loess	*		* #	*		* #			#		#		

Table 4 Mineral composition of loess-like sediments determined by RTG (*) and DTA (#)

Locality	Type of loess sediment	Mont-moril-lonite	Kao-linite	Illite	Feld-spar	Chlo-rite	Quartz	Calcite	Dolo-mite	Orga-nic matter	Anker-ite	Pyrite	Li-monite	Goe-thite
Krčava	loess-like sediment	* #	*	#			* #			#	#		#	#
Ipeľský Sokolec 1	loess-like sediment	* #	*	* #	*		* #	* #		#				
Ipeľský Sokolec 2	loess-like sediment	* #	* #	* #	*	#	* #	*	*					
Fabianka	loess-like sediment	*	*	* #			* #			#				
Rimavská Seč	loess-like sediment		*	* #	*	#	* #							

Microstructural analysis indicated that the basic but also the sole type of microstructure of typical loess sediment is the skeletal microstructure (sensu GRABOWSKA-OLSZEWSKA et al., 1984). The loess soil has expressively homogeneous, isotropic and non-oriented fabric. The schematic representation of the typical loess fabric is shown in Fig. 1. The plates I–II are typical loess from Mnešice.

The structural elements of loess are various the genetic types, from which the dominant are the non-clay grains of the aleuritic, resp. psammitic fraction. They are formed mostly from quartz, calcite, dolomite, more seldom feldspars and others.

The pelitic fraction is represented by primary and secondary clay particles, and in a lesser measure, even by non-clay particles. The clay particles are represented mainly by illite, montmorillonite and kaolinite. They form discontinues, non oriented soil matter found at the contacts of grains in the form of connectors and films on the aleuritic and psammitic grains. They have a leafy shape and polygonal boundaries. In the soil they occur in the form of single crystallas of the size ranging from 1 to 10 μm and were probably formed by eolian activity in the subaerial environment, as shown, apart from their size, by their angular shape and character of crystals. Apart from the above mentioned singles, clay particles occur in soil also in the form of complicated microaggregates of the size ranging from 1–100 μm These have a varied genesis. To these belong the secondary (autigeneous) particles formed by coagulation from the surface waters and secondary postgenetic particles, forming reaction edges with the amorphous SiO_2 as film around globules (KOMISAREVA, 1979). These particles, forming the microaggregates, have contacts most frequently of the edge to edge type and face to edge, which results in a considerable intermicroaggregate space takes place, which influences the capillary forces acting in the soil. The primary clay particles have contacts face to face type and face to edge. The phase contacts occur in the soil confer a considerable stability to the loess soils.

The non-clay grains forming the skelet are found most frequently in the aleuritic and psammitic fraction. The grain morphology varies according to their genesis. The soil contains single rounded aleuritic grains. Corrosion and intergranular types of pores developed only locally associated with fossil soil horizons, which we ascribe to the circulation of low concentration solutions. The samples contained all the contact types of non-clay particles. The dominating contacts are clay bridges and clay buttresses. The soil has an uniform grain and mineral composition.

The pore space of loess soils is formed principally by the intergranular types of pores of isometric singly longitudal shape. In common with the shape, the size of pores depends on size and shape of aleuritic and psammitic grains.

From the engineering geological point of view of physical properties, it is possible to value these loess soils as typical eolian cohesive soils. According to grain-size analyses, the soils are characterized by a high content of aleuritic fraction 67 to 72 %, by lower pelitic fraction content 13 to 17 %, and psammitic fraction 15 to 20 %. The soils are also characterized by a relatively low natural moisture, which ranges from 9.6 to 14.9 %. The water content depends on the content of clayey particles, which due to their nature and size of specific surface bind the predominant part of physical water in the soil. The liquid limit, as a sensitive indicator of clay mineral content, is also

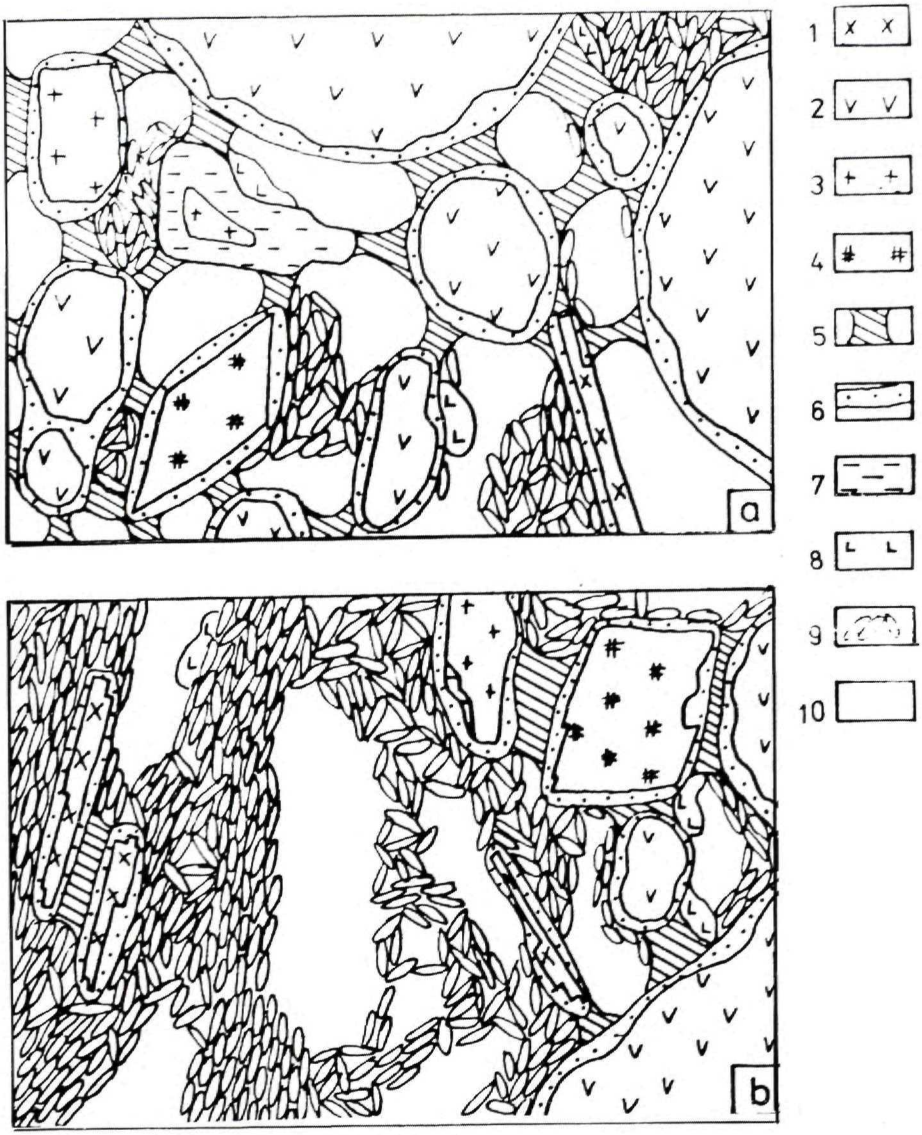

Fig. 1 The schematic representation of microstructure
a — typical and sandy loess (skeletal microstructure), b — clayey loess (matrix microstructure)
1 — 4 grains: 1 — mica, 2 — quartz, 3 — feldspars, 4 — carbonates; 5—9 clay minerals: 5 — clay bridges and clay buttresses, 6 — clay films, 7 — pseudomorphoses, 8 — resedimented particles, 9 — microaggregates, 10 — pores

low. According to the liquid limit value and consistency index we classify the loess as low to medium plastic, with strong to hard consistency. The physical properties of loess sediments are given in Table 1. The mineral composition is given in Table 3.

Sandy loess

The sandy loess are most frequently non-bedded or finely bedded. They are usually slightly calcareous, less porous than typical loesses, but have the same colour. This type of loess is characterized by a mixture of grains 2 to 63 μm and 200 to 500 μm size (fine-grained sand, medium-grained sand). The loess was analysed on samples taken from the Vyškovce locality in the Ipel basin and Hajnačka locality in the Fiľakovo mountains (southern Slovakia). Schematic representation of sandy loess microstructure is shown in Fig. 1a.

According to the microstructural analyses, the sandy loesses present a typical skeletal microstructure formed by predominating psammitic grains. On a microscale they are homogeneous with isotropic fabric. Plates III–IV are sandy loesses from Hajnačka.

The non-clay grains are, as a rule, wrapped in fine clay films. They present an angular to subangular shape (in the sense of Pettijohn et al., 1973) and are composed of grains of quarty, feldspars, mica and minerals of heavy fraction. The composition of the psammitic fraction is directly proportional to the petrografic composition of rocks in the source area. The contacts between the grains are of indirect type, that is, they are mediated by clay bridges. The grains are occasionally corroded, occasionally also perforated by intragranular types of pores of usually elongated shape.

The clay minerals are in the pelitic fraction and in the sediment they are found as of weakly aggregated films covering the aleuritic and psammitic grains, and also in the form of irregular clusters. They are represented by illite, montmorillonite and kaolinite. The enclosing microaggregates have the contacts types face to face and the microaggregates forming the clusters have contacts edge to edge and face to edge. According to the physical nature of forces, all the three types of contacts are found in the sandy loess: phase, point and coagulation contact.

The soil was also formed by eolian transport, but the source area of sandy loesses were areas with rock composition other than typical loess.

The grain-size analyses of the soil indicated: pelitic fraction (less than 2 μm) from 7.38 to 9.43 %, aleuritic (from 2 to 63 μm) from 35.34 to 40.0 % and psammitic (more than 63 μm) from 52.62 to 55.23 %. A higher content of the psammitic fraction at the detriment of the pelitic one results in a lower moisture, content lower values of plasticity limits, etc. Moisture at the liquid limit ranges from 23.8 to 24.71 %, the limit of plasticity from 20.68 to 21.26 %. According to the liquidity limit and consistency indexes the soil is classified as low plasticity and hard consistency soil. The carbonate content was varied from 5.58 to 11.57 %. Physical properties of sandy loess are in Table 1 and mineral composition is in Table 3.

Clayey loess

The clayey loess is non-bedded, and has low porosity, and lower carbonate content, with colour similar to typical loess. The largest proportion have aleuritic (grain-size from 2 to 63 μm) and pelitic fractions (less than 2 μm). This type of loesses occurs in Šafárikovo and Jesenské localities in Rimavská basin (southern Slovakia). Schematic representation of clayey loess is found in Fig. 1b. Plate V are clayey loess from locality Jesenské and Plate VI from locality Šafárikovo.

The clay loesses have a matrix, skeletal-matrix to matrix-laminar microstructure. On the microscale, these soils are heterogeneous, with predominantly isotropic fabric; however, areas of anisotropic structure were observed, which are caused primarily by oriented clay and less non-clay particles of elongated shape. The fabric elements are represented by pelitic, aleuritic and psammitic fraction, however the relationship between the individual fractions is variable.

The pelitic fraction is represented by clay minerals illite, montmorillonite and kaolinite, secondarily even by non-clay minerals, fine crystals of secondary calcite, and Fe-oxides.

The microstructural difference in content with the typical loess is seen in the dominant type of contacts between the microaggregates of clay minerals – face to face, in their better aggregation and in the form of matrix. The aleuritic and psammitic graines differ from the grains in typical loesses by the types of contacts: the concealed contacts dominate over the direct ones.

Clay loess pores are represented principally by the microaggregate types of ellipsoid to longitudal shape. The intergranular types of pores in the soil are also developed, however, they do not affect the properties of soils to such a measure as those in the typical loess.

Microstructural analysis of clay loess suggests their origin as eolian, but they were considerably transformed by the influence of climate and geomorphologic conditions of the basin.

The grain-size analysis of the soil from Šafárikovo locality shows it to contain 38 % of pelitic, 51 % aleuritic and 11 % of psammitic fraction. The Atterberg liquid limit is 56 %, the plasticity limit 30 %. The liquid limit and consistency index the soil classifies it as highly plastic of solid consistency. The $CaCO_3$ content amounts to 1.1 % and of organic matters is 4 %. Physical properties of clayey loess are in Table 1. Mineral composition determined by X-ray and DTA methods are in Table 3.

Loess-like sediments

Under loess-like sediments we understand the eolian material, which sedimented during various secondary processes (allochthonous loess-like sediments) or which was changed in situ (autochthonous loess-like sediments), e. g., non-eolian matter what was changed by the eolian process. Often, instead of eolian process, they were submitted to the process of loaming or gleization. They are less porous than typical loesses, some are completely non-calcareous, and they differ also in colour. This type was found in samples taken from the Krčava locality in the Podvihorlat hilly country, Ipeľský Sokolec locality in the Ipel basin, Fabianka locality in Lučenec basin and Rimavská Seč in Rimava basin.

On a microscale, the loess-like sediments are, as a rule, notably heterogeneous, and frequently have a mosaic structure. Under this concept we include soils in which zones of certain microstructural form repeat in an irregular manner. According to the orientation of the structures and especially structural elements, the loess-like sediments have both isotropic and anisotropic fabric. This means that the sediments may or may not show directional structures. The schematic representation of loess-like sediment fabric is shown Fig. 2. Plates VII–VIII are loess-like sediments from locality Krčava.

The heterogeneity is stressed also by the occurrence of several fundamental types of microstructures: we detected the matrix, skeletal, laminar even signs of the honeycomb microstructure. The fabric elements of loess-like soils are of various genetic types, with local domination of the clastic non-clay grains of aleuritic fraction, or the clay microaggregates of pelitic fraction.

The pelitic fraction is represented by primary, often secondary clay particles, and to a lesser measure, aslo by non-clay particles, such as secondary carbonates and in some areas of the Eastern Slovakian lowland also by the Fe and Mn oxides. The clay particles are represented by illite, montmorillonite and kaolinite. They form as a rule a connected, sometimes preferentially oriented matrix, occurring frequently in the form of isolated areas with matrix and honeycomb microstructure; sometimes they form a connected matrix with laminar microstructure, e. g., they are in the form of irregular loops or films on the aleuritic and psammitic grains in areas with skeletal microstructure. The secondary clay microaggregates, when present in the soil, form reactionary edges to pseudomorphoses along the clastic non-clay grains, or they form clusters or irregular shapes. The clay minerals present a varied shape; there were observed also kaolinite singles with crystalline pseudohexagonal and rhombic limitation. As a rule, however, they have a leafy and plate shapes. In the soil they are well aggregated and they are found in the form of complicated microaggregates of the size above 10 µm, but in other areas they are in the form varying from slightly aggregated microaggregates to singular element. Their structural position in loess-like sediments differs considerably from their position in the typical loesses. They probably originated from the weathered sub-base neogeneous rocks through reorientation and recrystallization. They have all the types of contacts and according to the physical natural of forces acting on the contacts, they have most frequently mixed contacts.

The non-clay grains forming the skeletal microstructure consists most of often by quartz, less by feldspars, mica and minerals of heavy fraction (granates, amphiboles, zircon, etc.). The primary grains of carbonates are lacking as a rule. The grain shape is varied, dependent on the postsedimentary changes of the sediment and mineral composition. They were observed to very from well rounded to angular grains. The contacts between the grains are of all types (there were observed also direct contacts, which do not occur at all in loess).

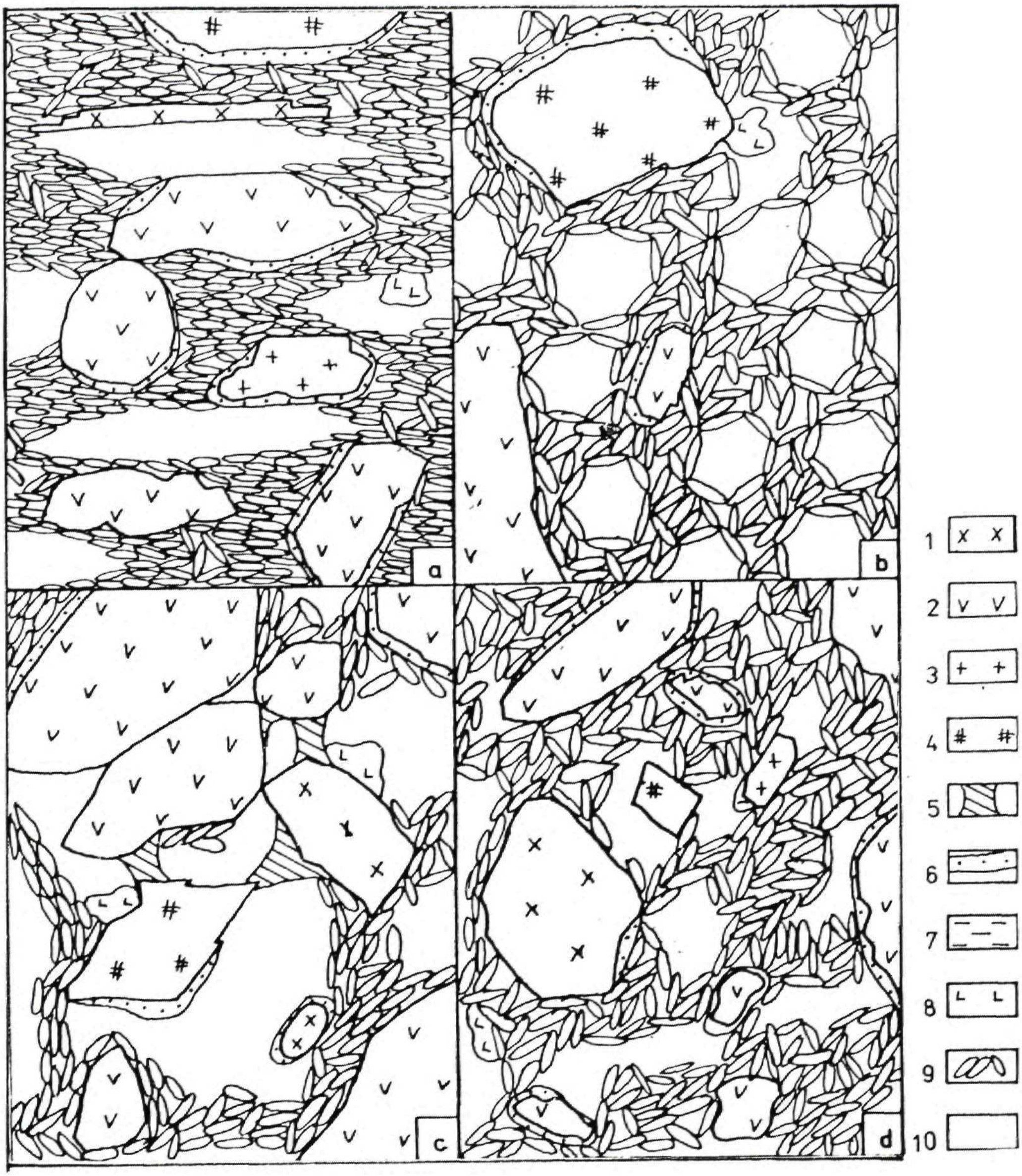

Fig. 2 The schematic representation of loess-like sediment microstructures
a — laminar microstructure, b — honey-comb microstructure, c — skeletal microstructure, d — matrix microstructure; 1—4 grains: 1 — mica, 2 — quartz, 3 — feldspars, 4 — carbonates, 5 — 9 clay minerals: 5 — clay bridges and clay buttresses, 6 — clay films, 7 — pseudomorphoses, 8 — resedimented particles, 9 — microaggregates, 10 — pores

The porous space is made by various types of pores, of varied shape, dependent on the type of microstructure and the grain-size composition of the soil. There were observed also pores of chamber type, which did not occur at all in the typical loesses. The fabric elements are locally of brittle deformation.

We have used the loess-like soil from Krčava locality for characterizing loess-like sediments. According to the grain-size analyses this loess-like soil is distinguish by a high particle content of pelitic fraction – 45 % (The loess-like sediments from southern Slovakia – from 16 to 30 %). The aleuritic fraction was found – 48 % (The loess-like sediments from southern Slovakia – from 55 to 63 %) and psammitic fraction – 7 % (The loess-like sediments from southern Slovakia – from 14 to 23 %. The content of organic matter determined by laboratory tests amounted 0.1 % and the carbonate content is 1.01 %. The value of carbonate content is significantly lower when compared with typical loesses of similar age. The loess-like soil is less porous, the pore content is 34 %. The natural soil moisture (12.1 %) depends on the type and quantity of clay particles, which due to their crystallographic and structural nature bind the predominant part of physical bound water in the soil. The degree of saturation is 90.4 %, the specific density 2690 $kg.m^{-3}$ and the bulk density of dry soil 1680 $kg.m^{-3}$. According to the value of liquidity limit (53.3 %) and consistency index, the loess-like soil is characterized as highly plastic clay of hard consistency.

Conclusion

The formation of the basic fabric of loesses, the organization and the mutual action of its elements, whether they are solid, liquid or gaseous phase is governed by various geochemical processes. It concerns above all the processes, which took place during the formation of the loess material (glacial crushing, frost weathering), its transport and geochemical processes, which acted during the deposition of the sediments. After the loess mass deposition and during the lithogenesis, there were taking place other processes, governed by site conditions. Since site conditions in the Western Carpathians, because of their relief are vary, process of lithogenesis resulted in four types of loess. They are typical loess, sandy loess, clayey loesses and loess-like sediments. The laboratory test showed that each of these types is distinguished not only by a varied fabric, but also by variable geotechnical properties.

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Alena Klukanová

Typy sprašových sedimentov Slovenska a ich mikroštruktúry

Resumé

Formovanie základnej vnútornej stavby spraší, usporiadanie a vzájomné pôsobenie jej elementov, či už sú v pevnej, tekutej alebo plynnej fáze, je dané geologickými procesmi a ich zvláštnosťami. Týka sa to predovšetkým procesov, ktoré sa odohrávali pri tvorbe sprašového materiálu, jeho transporte a geochemických procesov, ktoré pôsobili počas sedimentácie. Po usadení sprašovej hmoty počas litogenézy prebiehajú iné procesy, ktoré sú vyvolané stanovištnými podmienkami. Keďže stanovištné podmienky v Slovenských Karpatoch sú vzhľadom na ich členitosť rôzne, v procese litogenézy vznikali štyri typy sprašových sedimentov. Sú to typické spraše, piesčité spraše, ílové spraše a sprašoidné sedimenty. Laboratórne skúšky ukázali, že každý z týchto typov sa vyznačuje nielen rôznou mikroštruktúrnou stavbou, ale aj variabilnými geotechnickými vlastnosťami.

Explanation of Plates I—VIII

Plate I Microstructure of typical loess. Locality Mnešice brick plant near Nové Mesto nad Váhom
Fig. 1 Surface parallel to bedding. Isotropic fabric of skeletal microstructure
Fig. 2 Surface perpendicular to bedding. Isotropic fabric of skeletal microstructure

Plate II Microstructure of typical loess. Locality Mnešice brick plant near Nové Mesto nad Váhom
Fig. 1 Surface parallel to bedding. Skeletal microstructure. The dominating contacts between two grains are clay bridges and clay buttresses
Fig. 2 One part of disturbed globula

Plate III Microstructure of sandy loess from Hajnačka locality
Fig. 1 Surface parallel to bedding. Skeletal microstructure
Fig. 2 The sandy loess present a typical skeletal microstructure formed by predominating psammitic grains. The grains are weakly covered by clay minerals

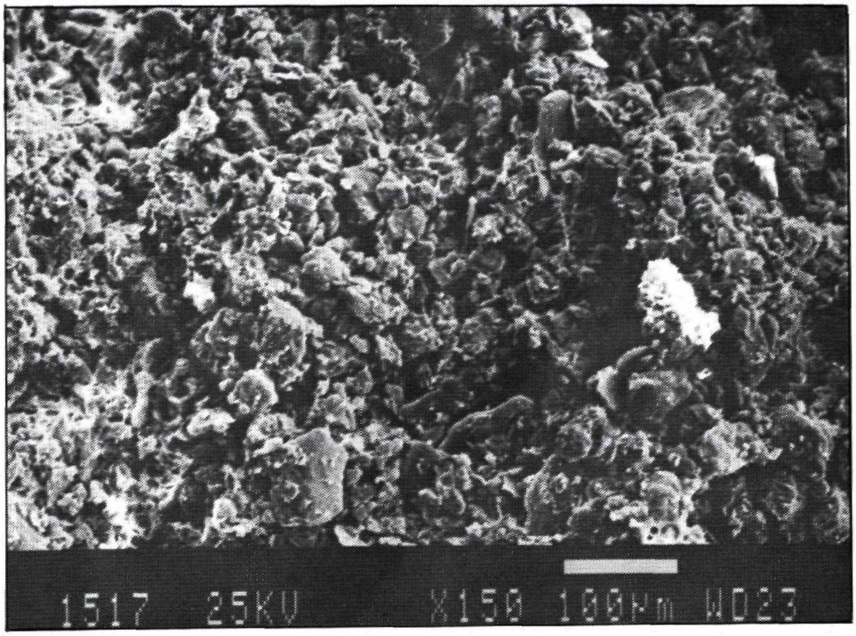
Plate IV Microstructure of sandy loess from Hajnačka locality
Fig. 1 Surface peerpendicular to bedding. The typical skeletal microstructure formed by psammitic grains
Fig. 2 Contacts between grains

Plate V Microstructure of clayey loess from Jesenské locality
Fig. 1 Surface parallel to bedding. Heterogenous fabric of skeletal-matrix microstructure
Fig. 2 Surface perpendicular to bedding. Skeletal microstructure

Plate VI Microstructure of clayey loess from Šafárikovo locality
Fig. 1 Surface parallel to bedding. Matrix microstructure
Fig. 2 Surface perpendicular to bedding. Matrix-skeletal microstructure

Plate VII and VIII Microstructure of loess-like sediments from locality Krčava
Fig. 1 Surface parallel to bedding. Matrix microstructure
Fig. 2 Surface perpendicular to bedding. Matrix-skeletal microstructure with the heterogenous fabric

Plate VIII
Fig. 1 Surface parallel to bedding. The skeletal microstructure
Fig. 2 Surface parallel to bedding. The honey-comb microstructure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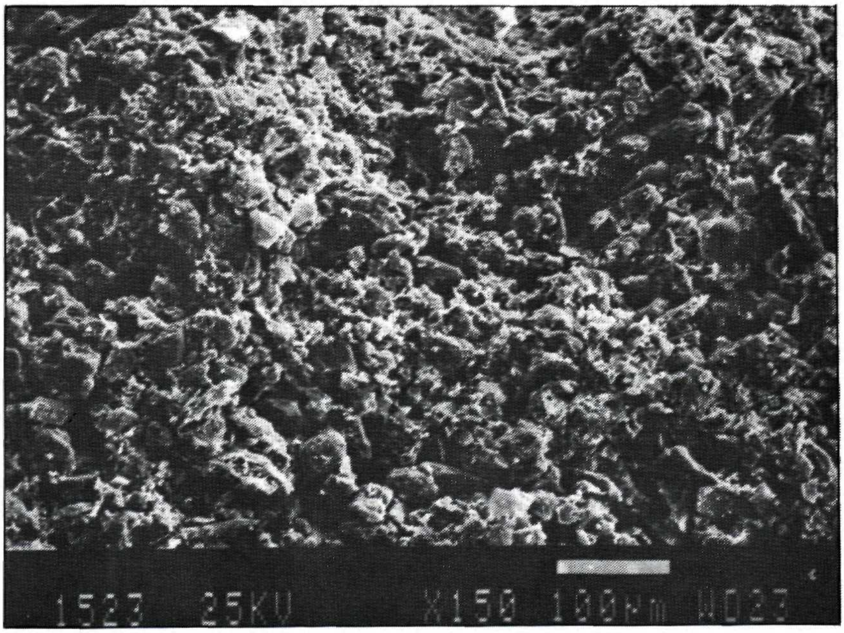
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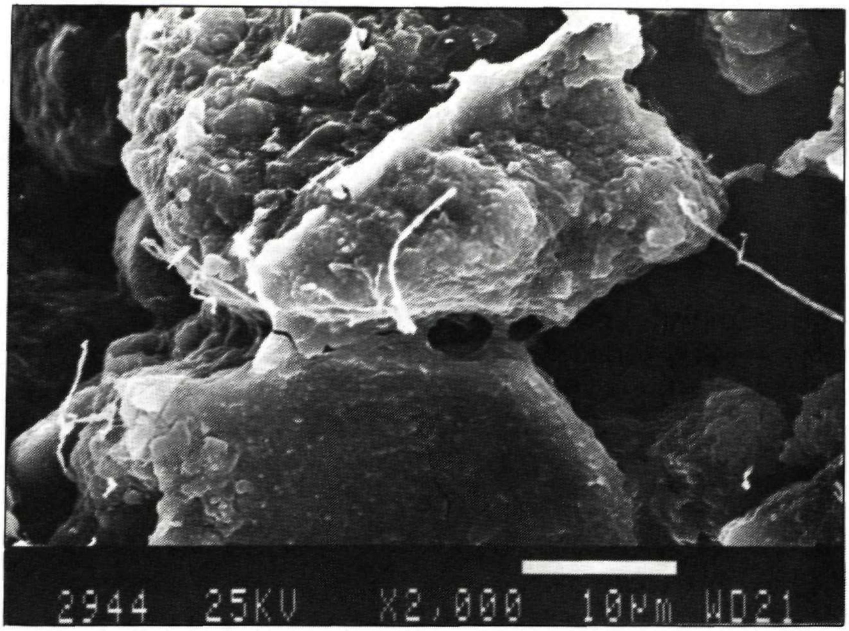
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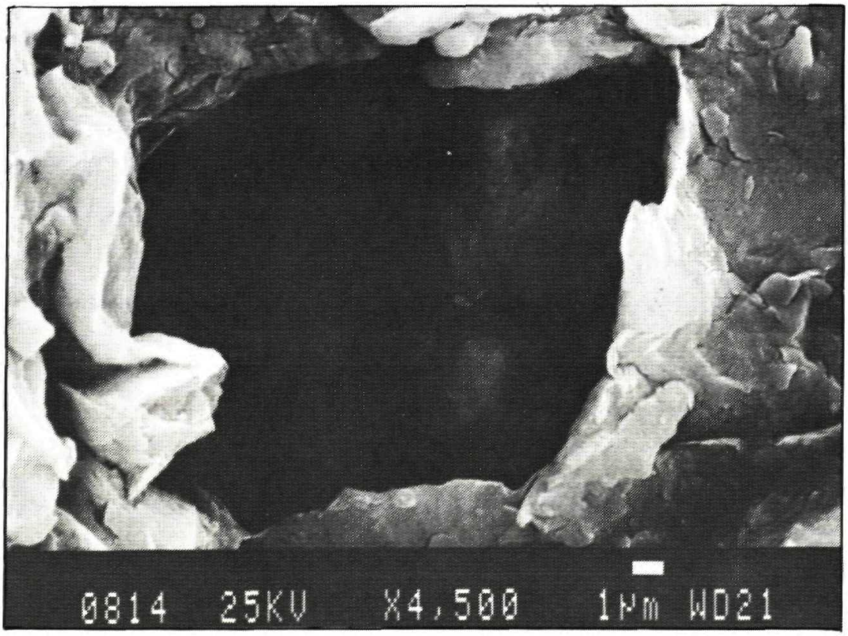
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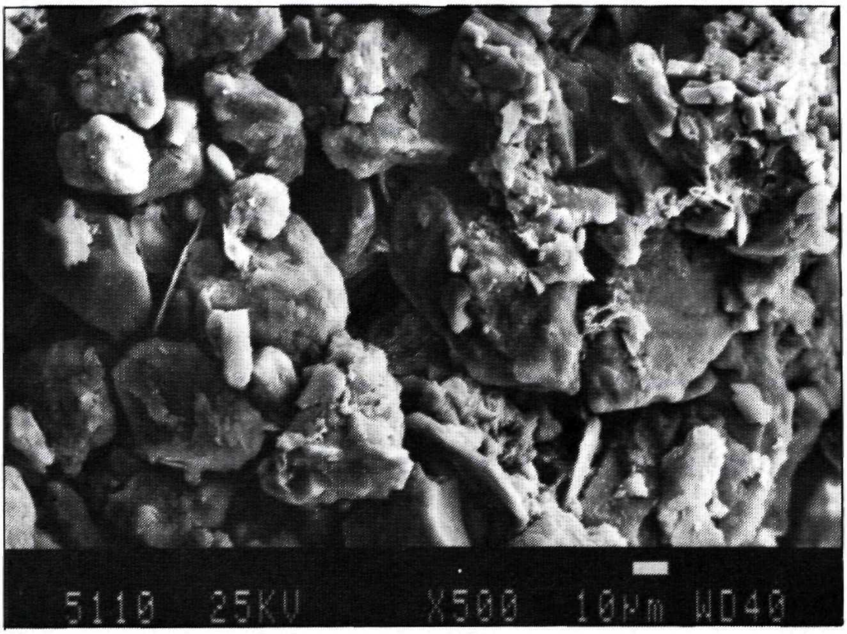
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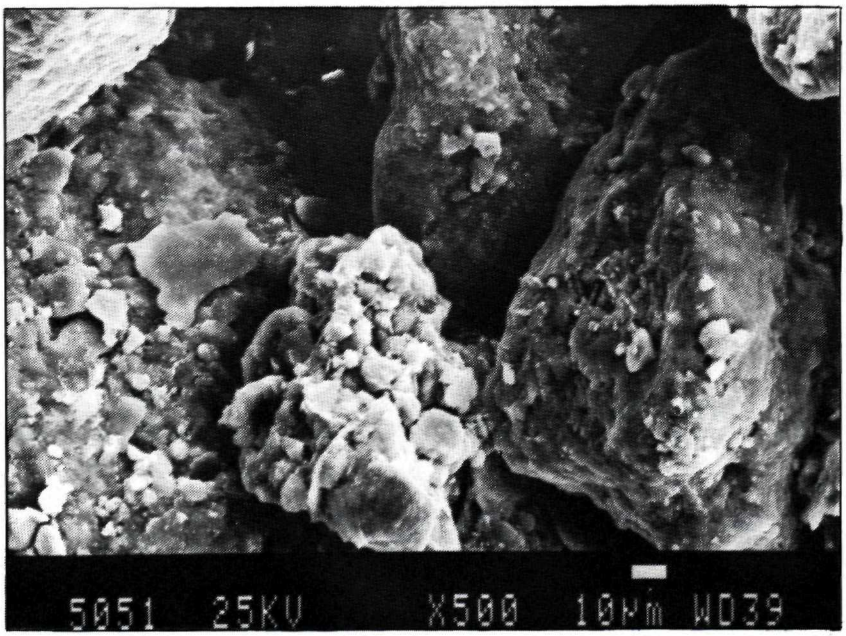
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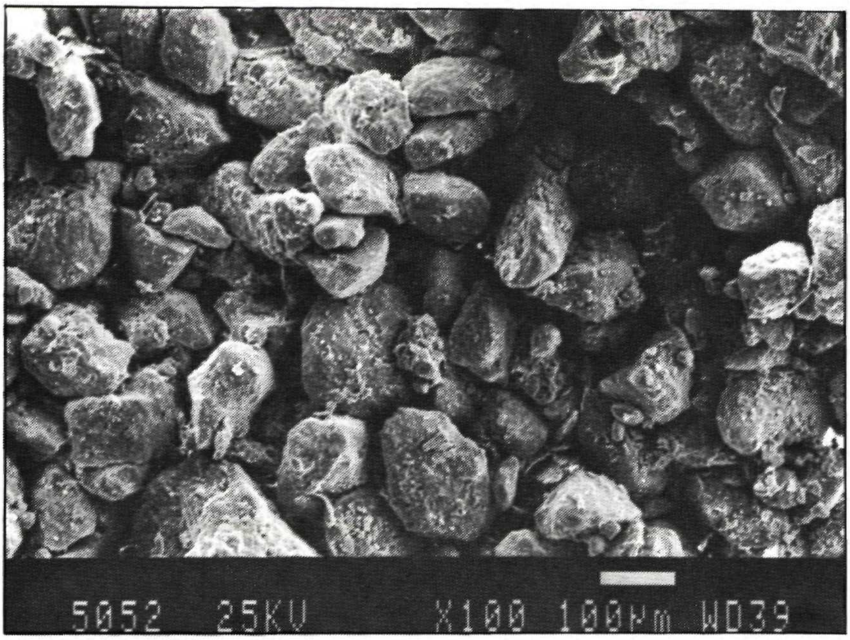
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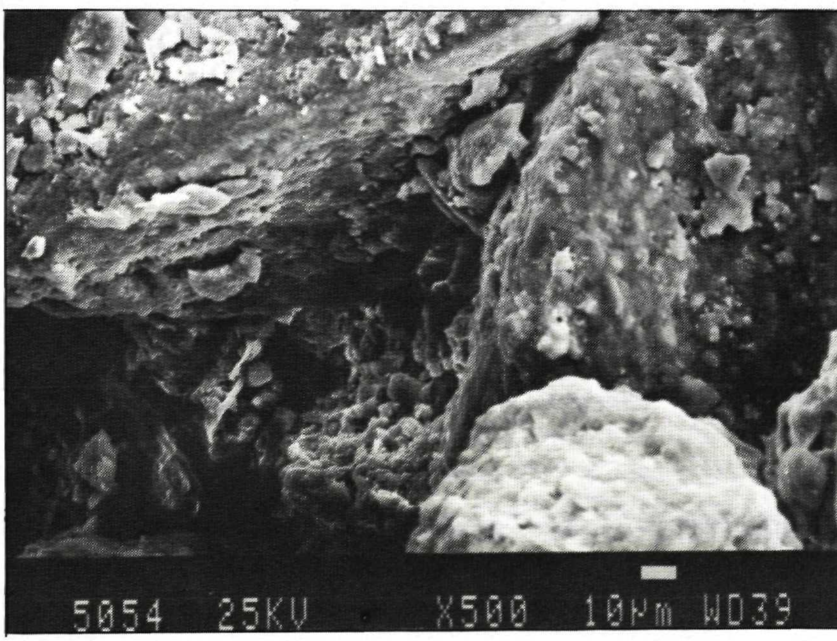
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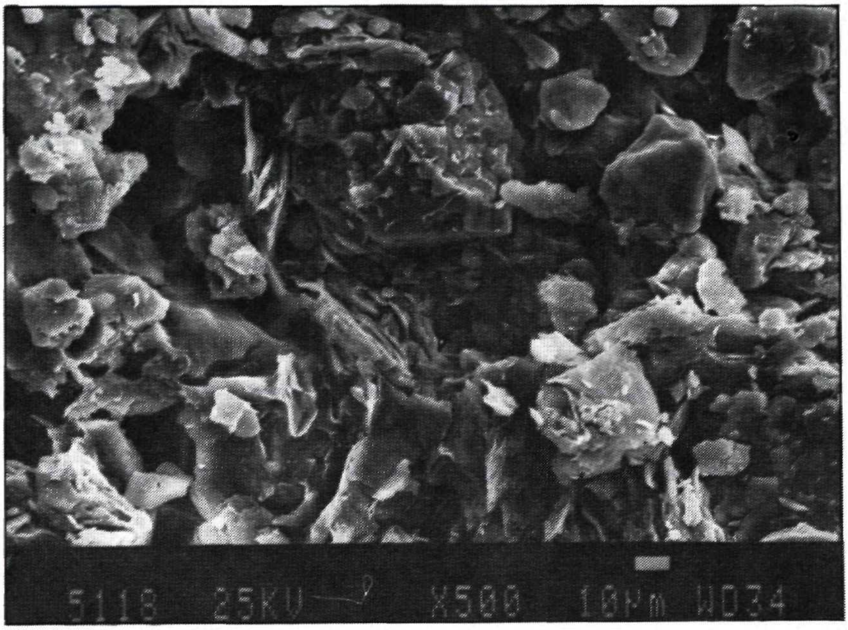
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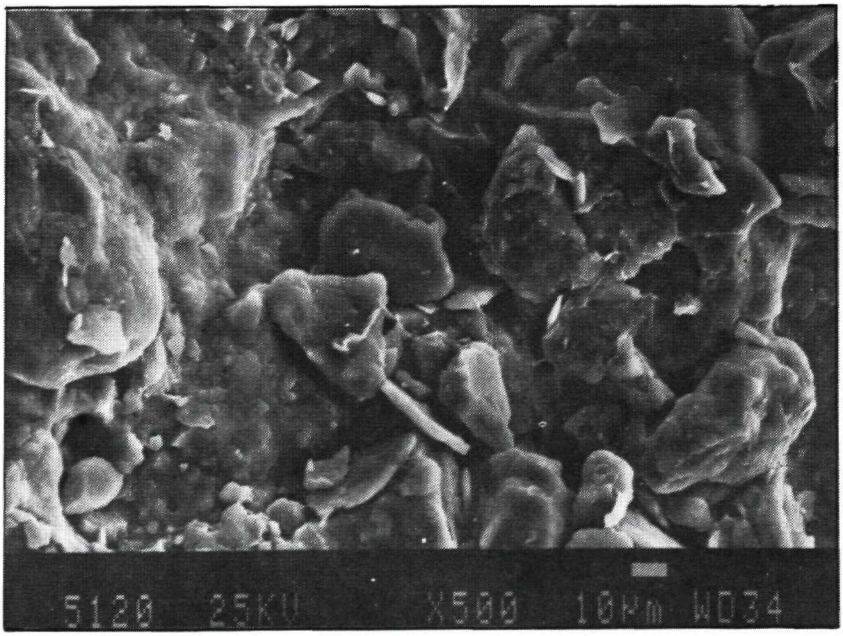
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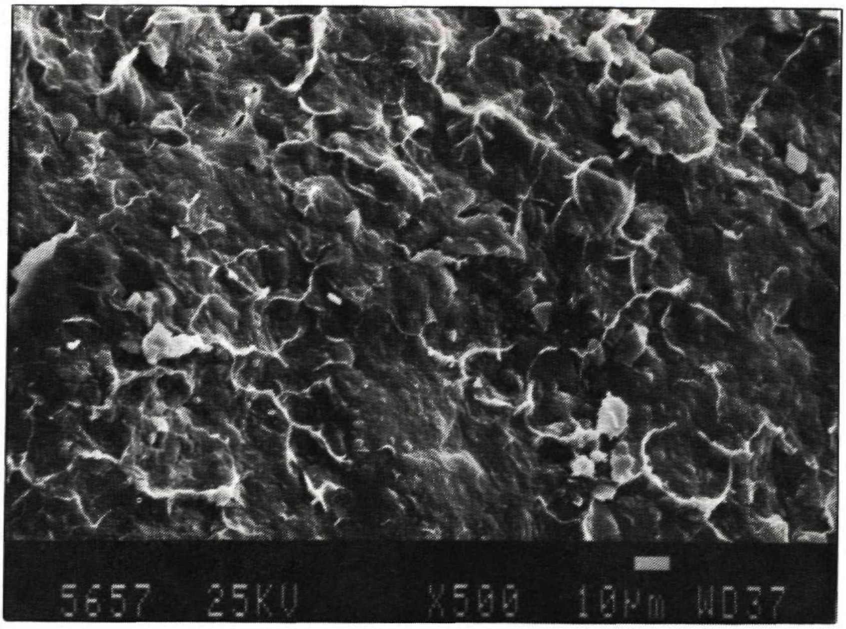
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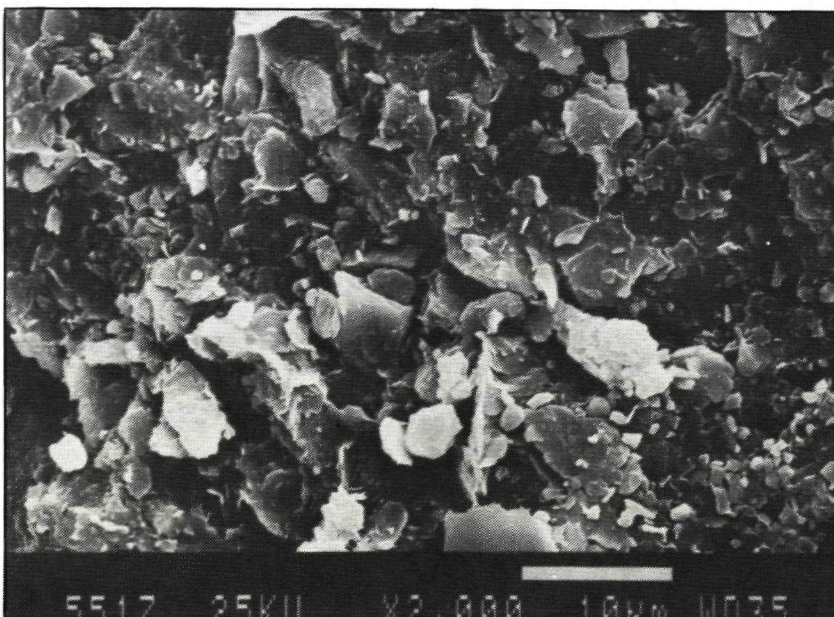
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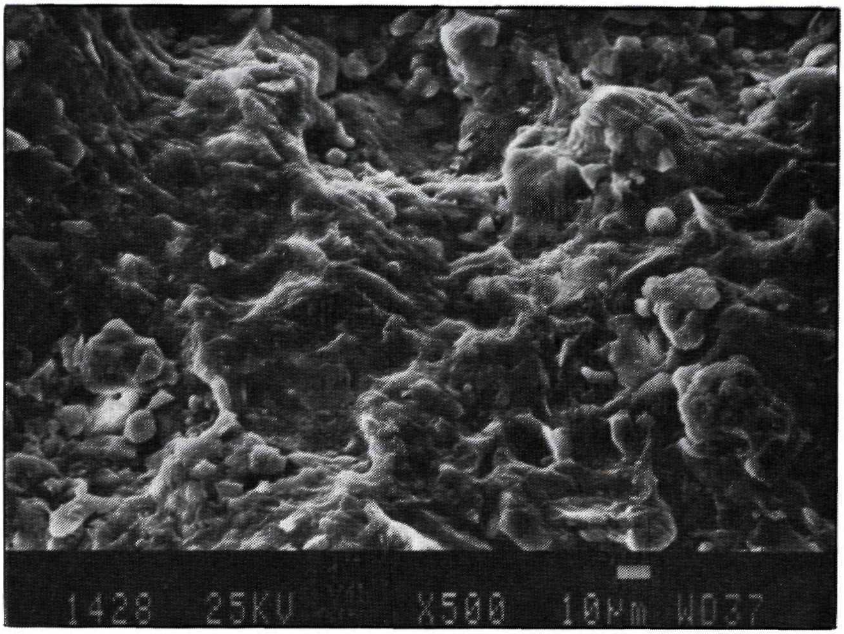
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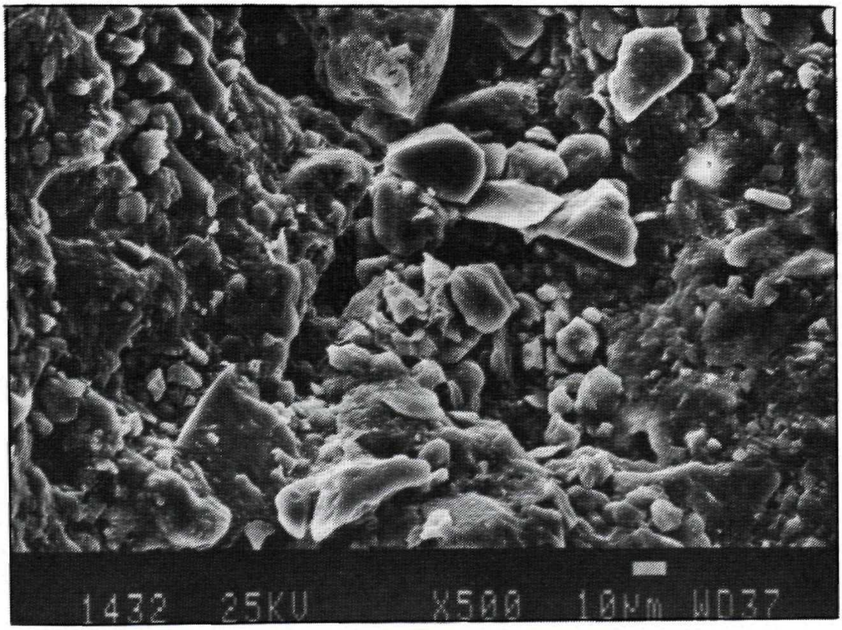
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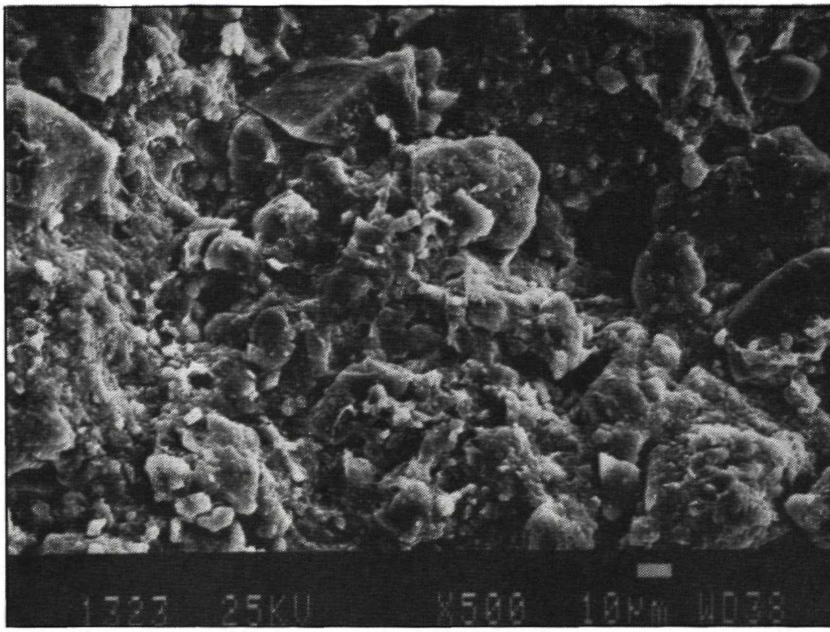
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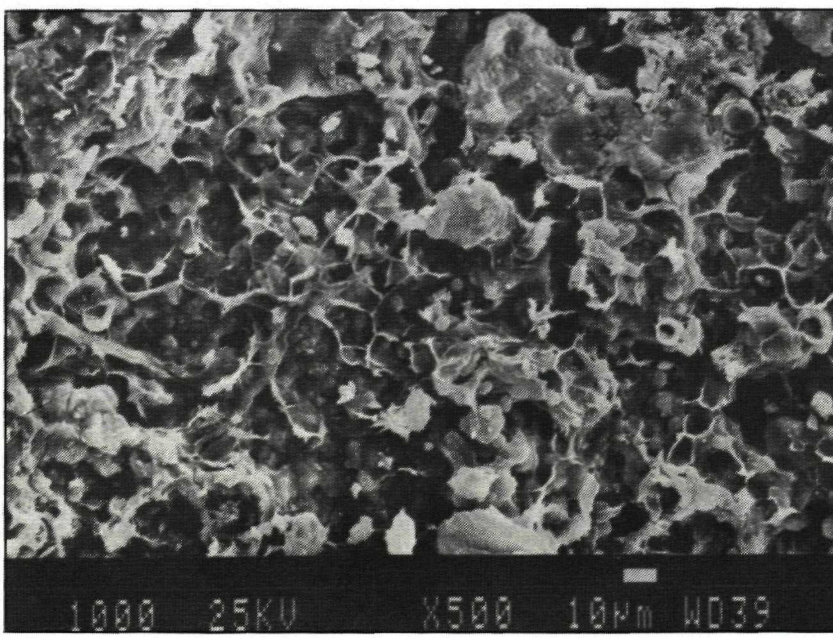
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RUDOLF ONDRÁŠIK

Geotectonic history reconstruction of West Carpathian geological structures for the assessment of state and behaviour of rocks

(12 figs., slovak resumé)

A b s t r a c t. Data obtained so far on the geological structure and geodynamic phenomena as well as on general principles controlling the evolution of geological structures made it possible to fundamentally reevaluate the previously valid views on the West Carpathian tectonic history in the Uppermost Neogene and Quaternary. It has been proved that the principal type of young differentiated tectonic movements is gravitational tectonics. The reconstruction of the history of young gravitational tectonics allowed us to assess its influence on the present-day state of the rock environment and to analyse regional regularities in the development of geodynamic phenomena.

Introduction

In addition to the study and analysis of their properties, the state of rocks can be recognized and their behaviour foretell by understanding the history (genesis) of rocks and geological history in the investigated area.

The importance of studying rock genesis for the evaluation of rock state and behaviour under the West Carpathian conditions was assessed in detail by MATULA (1969). He stresses the special role of the territory's tectonic regime which directly affects the evolution of geological structures, relief and its energy, evolution of cover units and exposing of the substratum, stress conditions, hydrogeological conditions and vertical climatic zoning.

Over time, technical practice has fully justified the application of this genetic approach to the study of rocks. A lot of new data were accumulated since the date of the publication of the above-mentioned work and therefore we feel it is appropriate to synthetize them so that they agree with the latest conceptions of the West Carpathian geotectonic history. We attempt to match these earlier data with the evaluation of rocks and geodynamic phenomena as well.

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Definition of terms

The term rock state designates lithologic composition, texture, water content in rocks as well as their stress and properties in a certain time period. A particularly significant role is played by their textural-structural characteristics controlled by the spatial distribution of minerals, bedding, fissures, secondary changes such as weathering, faulting etc., and structural bonds. For our purposes, structural bonds can be classified, according to Osipov and Sokolov (in SERGEYEV et al., 1985), as loose, coagulation, transient, crystallization-cementation and mixed.

Behaviour means changes in rock state over time, i. e. changes in their composition, water content, stress and properties as well as strain of their structures and movement. These changes may take place under constant conditions – in this case they gradually come to an end, or they may happen under changing conditions and then their evolution is complicated, changing over time.

Specific forms of rock behaviour are termed geological processes and the resulting forms are designated as geological phenomena. If we are interested solely in changes in the physical state of rocks, then we speak of geodynamic processes and phenomena.

Relationship between the age of rocks and their properties

In the West Carpathians there occur diverse rocks ranging in age from the Proterozoic to recent, which represents a time span of more than a thousand million years. Unless subjected to retrograde alterations, rocks of the pre-Paleozoic units (more than 250 m. y. old) are characterized by strong crystallization-cementation bonds and rock character. Rocks of Mesozoic units (65 to 250 m. y.) are dominated by strong crystallization-cementation bonds, but weaker transient and crystallization bonds occur as well. In Cenozoic rocks (less than 65 m. y.), weaker bonds prevail (transient, coagulation, mixed and loose). Strong crystallization-cementation bonds are common only in flysch rocks, largely of sandstone character, and in effusive Neogene volcanics. Similarly, in Cenozoic sedimentary units, the share of rocks with strong bonds increases with their age, i. e. Paleogene units (65 to 24 m. y.) contain more strong-bond rocks than Neogene ones (24 to 2 m. y.), the youngest Pliocene and Quaternary units (less than 5 m. y.) contain almost exclusively rocks with weak bonds (loose and mixed).

Massifs of solid rocks may also include layers of semirocks represented by clayey and marly sediments with unstable bonds (coagulation and mixed) little resistant to weathering. There also occur secondarily weakened zones of diverse genesis. They include various discontinuities ranging from fissures to thick faults as well as hydrothermally and pneumatolitically altered or weathered rocks.

The crucial evolutionary events for the assessment of weakened zones and present-day stress fields in the West Carpathians, which significantly control the state and behaviour of rock massifs, are the latest ones assigned into the neotectonic evolution stage which shaped the modern relief.

The formation of the modern West Carpathian relief commenced in the Upper Badenian, i. e. some 15 m. y. ago. During the subsequent evolution, old geological structures were significantly but irregularly reworked and new ones were formed in the geological setting composed of young mountain systems. That is why structures of different generations exist side by side or some tracts of geological setting contain multi-generation structures overlapping each other. This fact is responsible for the great diversity and inhomogeneity of the geological environment, which makes it difficult to study it and therefore our information on the environment is unevenly distributed and incomplete.

Main stages in the history of the West Carpathian geological structures

Review of opinions on the history of the West Carpathian geological structures

The history of the West Carpathian geological structures includes several successive stages of Alpine disturbances which also reworked pre-existing structures formed prior to the Alpine cycle. Three principal stages of the Alpine cycle have been distinguished (Andrusov, 1958, Maheľ, 1986):

1. Paleoalpine stage – Upper Badenian to Middle Cretaceous. It was concluded by folding of the Central West Carpathians and thrusting of Mesozoic nappes in the Upper Cretaceous.

2. Mesoalpine stage – Upper Cretaceous to Lower Miocene, which was concluded by folding of the Outer Flysch Belt and thrusting of flysch nappes.

3. Neoalpine (neotectonic) stage – Lower Miocene (Badenian) to Quaternary, which started with intensive volcanic activity and vertical tectonic movements. The tectonic movements of this stage were designated by some earlier authors as germanotype tectonics. They gave rise to the present-day shape of the West Carpathians composed of a mosaic of mountain ranges and basins (Lukniš, 1964, Mazúr, 1964, 1965). Intermittent volcanism persisted until the Early Pleistocene. Vertical tectonic movements continue till the present day and are characterized by an overall uplift of the West Carpathians with notable differences in the movement of individual blocks confined by faults.

In agreement with the new global tectonic conception, the whole evolution of the West Carpathians is influenced by the approaching and collision of the African and Eurasian plates (e. g. Horvath–Royden, 1981). The Mesozoic geosynclinal development in the end of the Paleoalpine stage (between the Turonian and Senonian, i. e. some 70 m. y. age) was followed by folding and thrusting of Mesozoic nappes. Maheľ (1986) explains the folding and thrusting in this period by double subduction from the northwest under the northeastern edge of the Pannonian block and under the northeastern margin of the southern Veporicum with a subsequent block collision. Another subduction zone persisted until the next period in front of the northwestern and northern limits of the Fatro-Tatric segment. The nappe thrust lines trend NE–SW. Folding and thrusting in the adjacent Eastern Alp area presumably advanced to the north (Clar, 1973 in De Jong–Scholten, 1973), with a flysch geosyncline being preserved in the foreground of the nappes.

In the Mesoalpine stage, the sedimentary area of the flysch geosyncline was shortened as a result of oceanic-crust subduction beneath the Central West Carpathians. The sedimentary area was subsequently folded and thrusted onto the edge of the Eurasian platform.

Horvath–Royden (1981), Royden et al. (1982, 1988) assume that in the Upper Cretaceous, i. e. prior to the beginning of the Mesoalpine stage, Adriatic tip of the African plate collided with the edge of the Eurasian plate and consequently the Pannonian-Carpathian block was laterally expelled to the east. This event was accompanied by the subducton of the Eurasian plate towards the south and west, gradual narrowing of the flysch sedimentary area and thrusting of flysch nappes onto the Eurasian plate margin. The thrusting began in the Eastern Alps in the Ottnangian–Eggenburgian (23 to 19 m. y.) and continued in the West Carpathians in the beginning of the Karpatian (19 to 16.5 m. y.). The stage of lateral expulsion was associated with heating of the upper mantle and lower crust as well as with the Lower Miocene (22 to 15 m. y.) volcanism which persisted until the Quaternary. This was followed by a diapiric uplift whose centre was situated in the Pannonian area and which resulted in crust extension in the east-west direction in the Middle Miocene (17 to 12 m. y.). This period, corresponding to the end of the Mesoalpine and beginning of the Neoalpine stage in the West Carpathian history, was also the period of culminating volcanic activity. This stage of extension is designated by the above-mentioned authors as the initial stage in the development of the Great Hungarian Plain. In the Upper Miocene (12 to 5 m. y.) there was only local crust extension and lithosphere cooling with subsequent subsidence which continued in the Great Hungarian Plain until the Pliocene and Quaternary (5.0 to 0 m. y.). The thickness of Pliocene sediments there attains as much as 510 m and that of the Quaternary is as much as 690 m. The above authors refer to this evolution stage as thermal one. The diapir uplift gave rise to tensile stress in the apex of the diapir arc which, with regard to analogous situations elsewhere, has been estimated at 200 MPa. As a result, the crust thinned above the apices of the diapir in its partial sections by up to 6 km. All this period was also characterized by increased horizontal stress and horizontal thrusting along a complex fault system forming full-apart depressions, such as the Vienna Basin, as well as near-fault depressions. Thrusting of flysch onto the Eurasian platform foreground continued as well. The thrusting in the northeastern part of the Carpathian arc persisted until the Badenian (16.5 to 13.3 m. y.). At the northeastern and eastern flanks of the East Carpathians, the thrusting went on until the Pannonian (10.5 to 7.0 m. y.), and at the southeastern margin until the Pliocene to Pleistocene (7.0 to 0.1 m. y.).

Balla (1982) links the arching of the West and East Carpathian arcs with strike-slip displacements along transform faults through the Pannonian Lowland, the faults trending SW–NE and bending northward into eastern Slovakia. The southeastern flank was presumably displaced to the northeast along these faults. With the principal direction of horizontal stress from the south to the north, the eastern tract of the West Carpathians rotated anticlockwise and at the same time the West Carpathians were arched to the north. According to Balla, the rotation movement is indicated by paleomagnetic measurements in neovolcanics. It started in the Hungarian Zwischengebirge (Intramountains) in the Oligocene and ended in eastern Slovakia in Middle Miocene.

Similar conceptions have also been put forward by some Slovak authors (Pospíšil–Vass, 1983, Kováč et al., 1989 etc.). Transform movements, of closely unspecified age, presumably took place along a number of faults as is suggested on a tectonic map of the Czechoslovak West Carpathians (Maheľ et al., 1984). The transversal movements are likely to have controlled the evolution of some basins in the West Carpathians as well.

The diapir-uplift stage with the formation of depressions in the Pannonian area and West Carpathian foreground was analysed by Čech–Zeman (1984) and Čech (1988). The latter author views the formation of these depressions as polygenetic in relation to stress. Nevertheless, he assumes that the role of transversal displacements in the formation of depressions is overestimated by some authors and that vertical movements were much more significant.

The above views, which are in accordance with a model of orogenic continnetal evolution put forward by Meissner (1989), thoroughly resolve the problem of volcanism migration and folding of the outer Flysch Belt advancing from the west to the east as well as subsidence of the Pannonian depression central parts. However, they only insufficiently deal with the question of relationship between horizontal and vertical stresses in earth crust and their changes over time.

Analysis of West Carpathian geological structures with regard to the evolution of geodynamic processes

Reconstruction of stress state of rock setting

Our reconstruction of the stress history of the rock setting is based on the premise that the stress in the initial stages corresponds to gravitational field whose maximum-stress axis σ_2 and σ_3 are horizontal, they correspond to lithostatic load in quiescence and deviations from this state are associated with tectonic stresses and changes in lithostatic load. There is evidence suggesting that the West Carpathian stress field changed over time due to changing lithostatic load and tectonic pressures.

No extreme values of recent stresses have been noted in near-surface environment of the Slovak West Carpathians. Increasing horizontal stresses, exceeding values derived from their depth below surface and deformation properties, have been noted in basins, e. g. in the Bánovská kotlina Basin where Paleogene sediments display stresses 0.4–0.6 MPa (Mencl, 1988). Minor volumes of Paleogene flyschoid rocks thrust onto young Pleistocene fluvial deposits in the Turčianska kotlina Basin (Záruba, 1964) and horizontal calcite-filled fissures in near-surface levels of Neogene sediments in the Moldavská kotlina Basin (Nešvara–Ondrášik, 1978) provide indirect evidence of increased horizontal stresses.

Horizontal stresses are commonly reduced above the division plane of landslides and increased in their accumulation portion as was noted by Fussgänger–Jadroň (1977). A similar state may be expected in the upper and foothill tracts of steep slopes devoid of landslides. Furthermore, the principal stress axes on the slopes deviate from the vertical and horizontal levels (Goodman, 1980). The axes, however, may deviate also for reasons other than the presence of steep slopes, mostly in the vicinity of discontinuities, underground hollows and near the contact of two geological bodies or as a result of regional tectonic stresses. Tectonic stresses cause thrusting and displacements. Regional tensile stresses give rise to normal faults as well as diverse manifestations of gravitational tectonics and related geodynamic phenomena. It has turned out that abundant slope failures in the Slovak Carpathians are associated with gravitational tectonics.

A significant role in the development of rock stresses is played by groundwater pore pressure. The effect of groundwaters on stress fields and rock deformations has not yet been sufficiently investigated.

The analysis of the West Carpathian history suggests that increased horizontal stresses of regional scale can be expected in Paleo- and Mesoalpine evolution stages of the West Carpathians. Their role in the formation of zones of weakness can best be studied in crystalline rocks which were not subjected to such an intensive folding as sedimentary rocks. Nevertheless, also in the case of crystalline rocks we must be very careful in making conclusions because crystalline massifs emerged from depth in different time periods of orogenic history (Kráľ in Kraus, 1989) and underwent diverse evolution even during the latest stages. Individual parts of the massifs were significantly affected by local stress fields which may have been quite different from regional ones.

Horizontal stresses culminated in the Upper Cretaceous at a time when Mesozoic nappes were being thrust in the Central West Carpathians along ENE–WSW trending thrust lines. The maximum main stresses of tectonic forces were perpendicular, i. e. their direction was NNW–SSE. This direction of the maximum main stresses controls the existence of numerous high-angle to vertical faults and fissure systems trending roughly N–S and NW–SE, i. e. in the direction of assumed maximum shear stress. Scheidegger (1982) supports this assumption by prevailing directions of Central European basins in the pre-Tertiary times which follow fault zones of displacements. These directions occur on the Inner West Carpathian territory as well (Fig. 1). The author analysed them in detail as part of a territory evaluation for projected hydroelectric power plants and for assessment of construction engineering-geological conditions in several regions of Slovakia (Ondrášik, 1988, Ondrášik et al., 1987, 1990).

Any reconstruction of geotectonic history of geological structures requires good knowledge of the behaviour of the least resistant members, i. e. those whose rock state undergoes the most substantial changes in response to changing conditions. These are usually rocks with the relatively weakest structural bonds. To understand the behaviour of rock units of different hierarchic levels, it is necessary to know the properties of their rocks with the relatively weakest structural bonds and their position within a higher geological unit. To achieve this, all available data on the geological structure of the territory concerned and its lithostratigraphic and/or geotectonic units should be employed. This allows to estimate weak components in the rock environment of each studied area and to prognose their response to technical activity. This knowledge is particularly useful in sedimentary formations. A more complicated pattern characterizes crystalline units which contain rock types with weak bonds, such as phyllites, mica schists, biotite gneisses etc., as well as various dislocations and hydrothermally degraded zones whose distribution is largely irregular. In this case, geomorphic criteria can successfully be used. E. g. our application of geomorphic criteria in granitoid massifs was based on the following premises (Ondrášik, 1985): 1. erosion has selective character and is preferentially bound to zones pre-weakened by faulting, 2. selective erosion is supported by contemporaneous differentiated movements along faults, 3. sunken blocks accumulate cover units and, on older relief

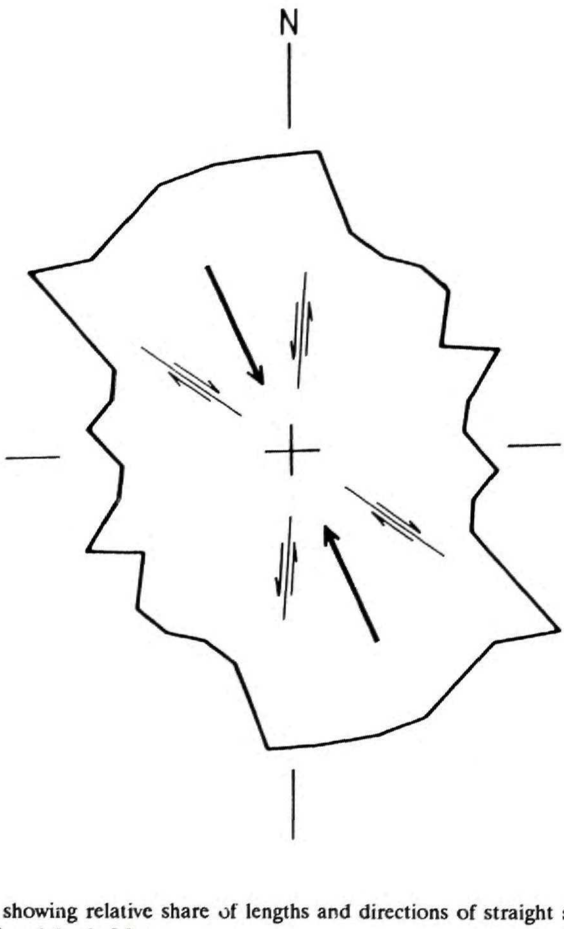


Fig. 1 Rose diagram showing relative share of lengths and directions of straight stretches of valleys in the western Slovenské rudohorie Mts.

elements, also fairly thick eluvium, 4. on elevated blocks, slightly weathered rock substratum is exposed on the surface, 5. fault dislocations have a zonal character and their strike is parallel with dominant fissure systems, 6. general strike of a higher-order fault dislocation need not necessarily be identical with those of individual lower-order fault dislocations in all its parts, 7. fault dislocations displaying contemporaneous tectonic activity are associated with slope failures disturbing pre-Quaternary substratum, 8. recent differentiated movements are reflected in the shape of valleys and stream gradients.

Data obtained by studies of geological structures suggest that gravitational movements of the earth crust upper portions along inclined discontinuity planes, weak and weakened zones are associated with its vertical tectonic movements. Such discontinuity planes and zones of weakness include e. g. subduction sutures and nappe thrust zones as well as plastic zones and discontinuities of diverse dimensions and genesis. Fairly extensive plastic zones in the earth crust presumably exist at depths ranging from 10 to 20 km. Their existence is indicated by zones of reduced seismic velocities (Stewart, 1971, Anderson et al., 1983) as was also proved by a more than 10 km deep drillhole situated in Kola Peninsula (Nikolayevskiy, 1987).

Gavrilenko and Gueguen (1989) associate the existence of the plastic lower layer of the crust with liquids enclosed in nearly horizontal, vertically isolated discontinuities. Compressed liquids in the closed discontinuities cannot be expelled into lower-pressure areas and therefore high neutral stresses build up corresponding to the lithostatic load of the overlying rocks. As a result, even crystalline rocks with strong crystallization-cementation bonds behave like viscose-plastic materials. The model put forward by us assumes the presence of the discontinuous discontinuities with enclosed

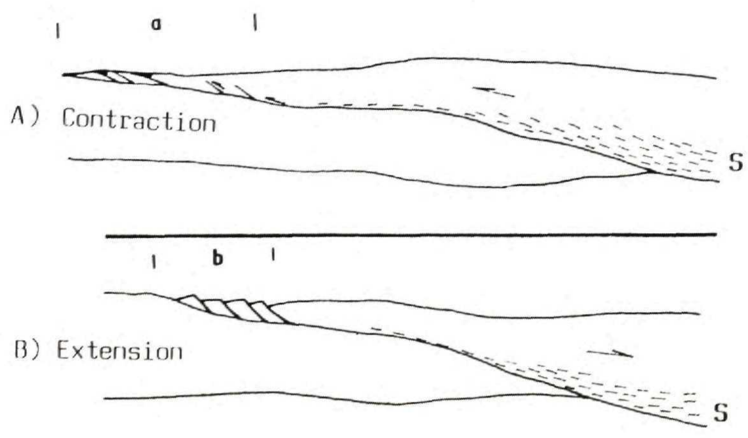


Fig. 2 Schematic relationship between thrust zones and faults in contraction period (A) and extension period (B) through faults (after Daly, 1988).
a — thrust and fold zone, b — system of horsts and depressions, S — shear zone widening with depth

liquids at depths of 10–32 km, the majority of occurrences lying at a depth of 17 km. To depths of 10–15 km there prevail vertically continuous discontinuities allowing expulsion of liquids from high-pressure zones to lower-pressure ones or eventually to the surface in the form of so called juvenile waters or gases. The upper layers of the crust generally behave like a brittle material although there occur plastic beds or even whole formations.

In the plastic zone, changing stresses result in continuous extension or shortening, whereas the overlying levels undergo brittle deformations. Some authors (e. g. ANDERSON et al., 1983, NIKOLAYEVSKIY, 1987) assume the existence of arched (listric) faults in the upper levels of the earth crust. The faults are steeply dipping in the upper levels but at depth their dip gradually decreases. Some others suppose dissection by even faults of "domino-like" distribution.

Notable changes in stress in the upper levels of the earth crust are associated with movements of the lithosphere and upper mantle. These take place e. g. by subduction, block collision as well as anticlinal and synclinal warping as was noted e. g. by STEWART (1971), and ANDERSON et al. (1983).

The changing stress results in gravitational movements along inclined discontinuity zones. Such zones mostly include zones of old thrusting dating from the period of horizontal tectonic pressures, as is suggested e. g. by DALY (1988, Fig. 2). In places where directions of the maximum horizontal stresses from the foregoing stage are not identical with modern direction of pressure releasing, we assume movements along pre-existing planes combined with movements along newly formed creep zones and discontinuity planes. This increases the irregularity of movements in space which may include relative displacements along faults parallel or nearly parallel with the direction of the movement.

The movements in the upper levels of the earth crust are also partly caused by lunar movements and seismic tremours. A significant role is also played by neutral stresses of pore solutions at contacts between aquifers and overlying aquicludes.

The gravitational movements of large earth-crust sections are very slow and irregular, with a pulsative character of moving areas of releasing and concentration of stress as well as movements. The stages of a sudded acceleration of the movement with subsequent releasing of stresses is likely to be linked with earthquake foci.

The existence of such discontinuity zones dipping from the Outer West Carpathians towards the Pannonian Basin as well as the existence of listric faults are indicated by refraction seismic profiles across the West Carpathian region (ROYDEN, 1988, TOMEK et al., 1989). The shortening of the Carpathian area in the early stages of history probable caused thrusting along these zones. Because of predominant crust extension in the West Carpathian region, downward movements probably take place along these discontiuity zones in the neotectonic stage.

Dynamics of basin evolution

The evolution of depressions and horsts with manifestations of block tilting is related to movements along inclined discontinuity planes and sinking along listric faults.

During the sinking along listric faults, the movement vector is controlled by their deep-seated relatively flatly dipping section, as is illustrated in Fig. 3. In the near-surface levels, the original maximum stress σ_1 prior to the movement was vertical and the two others were horizontal (Fig. 3a). The movement, however, results in the reduction of horizontal stresses (relative tensile stresses) and/or formation of absolute tensile stresses (Fig. 3b), a process which increases the difference between the main maximum stress σ_1 and main minimum stress σ_3 as well as increases tangential stresses. The induced change in the stresses gives rise to rock strain and deviation of the main axes of stresses as is schematically illustrated in Fig. 3c. In the direction of maximum tangential stresses, shear planes begin to form and near-fault deformations develop in the form of partial normal faults or schistosity or dragging reworking and

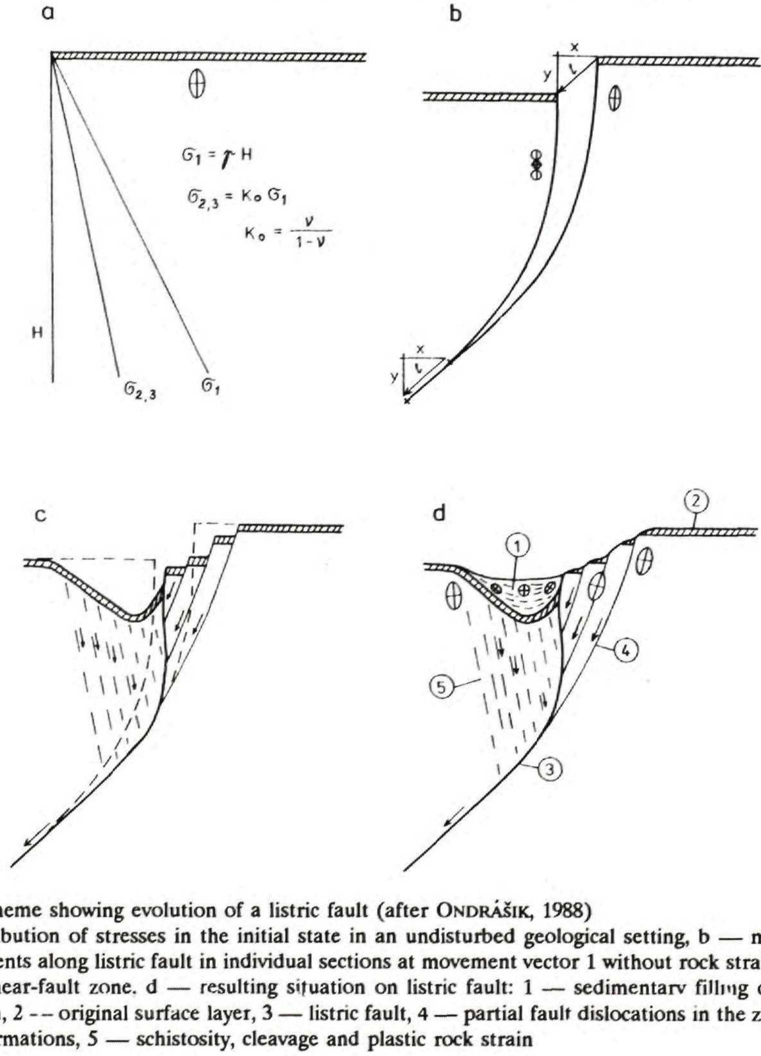


Fig. 3 Scheme showing evolution of a listric fault (after ONDRÁŠIK, 1988)
a — distribution of stresses in the initial state in an undisturbed geological setting, b — magnitude of displacements along listric fault in individual sections at movement vector 1 without rock strain, c — rock strain in near-fault zone, d — resulting situation on listric fault: 1 — sedimentary filling of near-fault depression, 2 — original surface layer, 3 — listric fault, 4 — partial fault dislocations in the zone of near-fault deformations, 5 — schistosity, cleavage and plastic rock strain

cleavage (Fig. 3c). These near-fault deformations begin to develop as soon as horizontal stresses decline and therefore a loosened space in the upper section of the listric fault as is illustrated in Fig. 3b will in fact never be formed. It will only give rise to temporary fracturing or formation of open fissures and crevices which may act as routes of percolating water with colloids as well as clayey, sandy and gravelly fraction from the surrounding rocks or from the surface. The situation gradually becomes consolidated and earlier fracturing is only indicated by clayey and loamy fissure fillings. This process is particularly evident in crystalline rocks, as was proved by exploration works as well (MATYS–ONDRÁŠIK, 1991, ONDRÁŠIK et al., 1987).

The near-fault deformations develop irregularly and so the course of the main fault is mostly complicated. If its dip is steep and vertical differences are substantial, the main fault affected by partial near-fault deformations may become crooked as shown in Fig. 3d. The shape of the main fault is largely even more complicated. Its formation is also accompanied by movements along pre-existing discontinuities which were founded at different stress fields and therefore the course of the faults need not

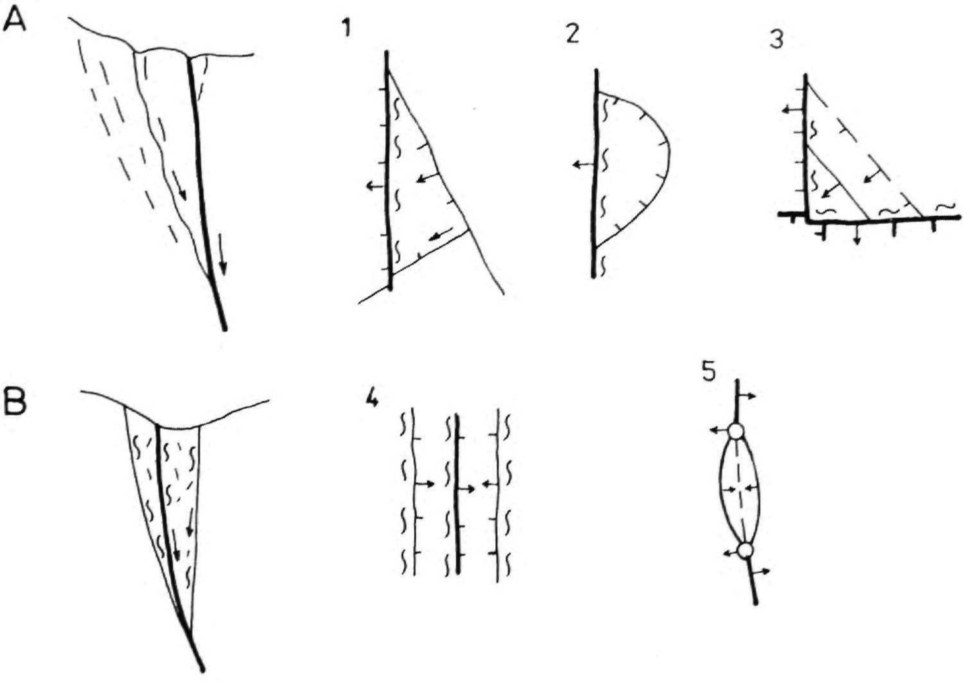


Fig. 4 Two kinds of near-fault deformations noted in crystalline unit near the upper Ipeľ River
A — asymmetric near-fault deformation developed either along lower-order fault dislocations (on ground plan 1) or along newly formed dislocations and has the character of division plane of a landslide (on ground plan 2) or the so called "corner effect" takes place by the intersection of two faults (on ground plan 3), B — symmetric near-fault deformation controlling the course of a valley (on ground plan 4) or passes across mountain ridges (on ground plan 5)

necessarily be identical with the maximum tangential stresses reached throughout the history of the listric fault concerned. The main movement may also shift from the original main fault to marginal, more flatlying faults which previously had the character of near-fault deformations. A wide zone of rocks is eventually intensively fractured and faulted.

Depression formed on the inner side of a listric fault is further shaped by erosion or is filled with sediments. Deformations disturb slopes formed in this manner and, on foothills or even in marginal parts of basinal filling, main stresses deviate and horizontal stresses build up as shown in Fig. 3d.

Some types of near-fault deformations, as were observed in a granitoid massif near the upper tract of the Ipeľ River, are illustrated in Fig. 4 (Ondrášik et al., 1987). Results of theoretical and experimental solutions concerning the evolution of a fault zone and gradients of vertical movement component in a sedimentary cover above faulted basement are given by Grigoriev et al. (1987).

Deep-seated fault zones connect isolated aquifers and act as routes for ascending solutions and gases, frequently aggressive ones, from deep structures. Near the surface, these are contaminated with waters of vadose origin. Water circulating along fault zones is aften hot and dissolves fine fractions of tectonically fractured rocks giving rise to clay minerals as is the case in up to 2 m-thick clay layers amidst crystalline rocks encountered by an explorarory adit for the Ipeľ hydroelectric power plant (Ondrášik et al., 1987). The in-situ-altered clay material can sometimes hardly be distinguished from clay washed into the fissure from the surrounding. When the movements come to an end, the loose fractured material gradually becomes consolidated. Open-space fissure zones become routes of groundwater circulation. In contrast, clay-filled zones act as impermeable barriers to fissure waters. E. g. such a water-bearing dislocation was intersected by a hole drilled in a side above Šútov quarry as part of the exploration for Šútovo hydroelectric power plant in the Kriváňska Malá Fatra Mts. The dislocation dips at 70°. Several drillholes up to 80 m deep intersected a number of water-bearing horizons with substantial free overflow. E. g. a horizon intersected by drillhole J-5 at a depth of 9 m yielded 111 l/s. Water levels in the individual drillholes influenced each other, and water from a brook above the drillholes disappeared (Polášková, 1967).

The faults themselves represent a broad zone of complex structure and manifestations of partial movements. They are overlain by plastic sediments which adapt themselves to these partial movements in the substratum by plastic deformations whereas competent layers amidst them are boudinaged. The process is accompanied by their tilting as was the case with Malá Fatra fault near Lipovec (Ondrášik, 1988).

Neotectonic movements as a regional factor controlling the formation and evolution of modern geodynamic processes in the Slovak Carpathians

Gravitational tectonics disturbs large tracts of the earth crust. The movements are triggered by any deviation from dynamic equilibrium. Nowadays, the dynamic equilibrium in the West Carpathian earth crust is regionally disturbed by differentiated vertical movements between the relatively subsiding Pannonian depression and raising Outer West Carpathians. The subsidence of the former is suggested by Quaternary sediments accumulated in the Pannonian Basin. On the other hand, the uplift in mountain ranges of the Inner as well as Outer West Carpathians is indicated by increased levelled Neogene surfaces and Quaternary terrace horizons. A map of tendency to young vertical movements, corresponding to Moho discontinuity dips (Fig. 5), was compiled by Mazúr and Kvitkovič (in Bližkovský, 1986) on the basis of an analysis of thicknesses of Late Neogene and Quaternary deposists and relative differences in altitudes of levelled surfaces. Stress released in the roof of the arches and gravitational pressure parallel with Moho-discontinuity dips give rise to opposite movements in the upper and lower levels of the crust. In the lower crust levels we assume movements in the direction of Moho-discontinuity dip, i. e. from the Pannonian depression towards the Outer Carpathians, whereas movement in the upper crust levels is opposite, i. e. from the Outer Carpathians to the Pannonian depression. It has not yet been cleared up whether the releasing of stresses in the diapir roof in the Pannonian depression is associated exclusively with its uplift or whether, as a result of cooling of partially melted material in the roof of the diapir, its volume diminishes and the overlying crust in the arch roof subsequently subsides and adjacent

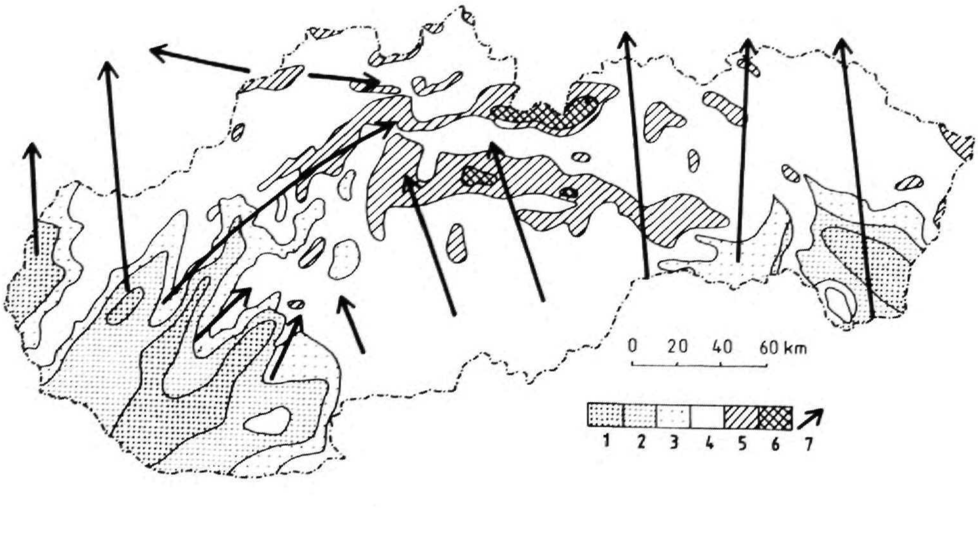


Fig. 5 Neotectonic displacements on the Slovak territory (after Mazúr—Kvitkovič in Bližkovsky, 1986). Vertical displacements of the levelled Upper Badenian surface are given in metres
1 — deeper than -3000 m, 2 — from -1500 to -3000 m, 3 — from 0 to -1500 m, 4 — from 0 to 900 m, 5 — from 900 to 1500 m, 6 — more than 1500 m, 7 — Moho-discontinuity dip (after Novotný in Bližkovský, 1986)

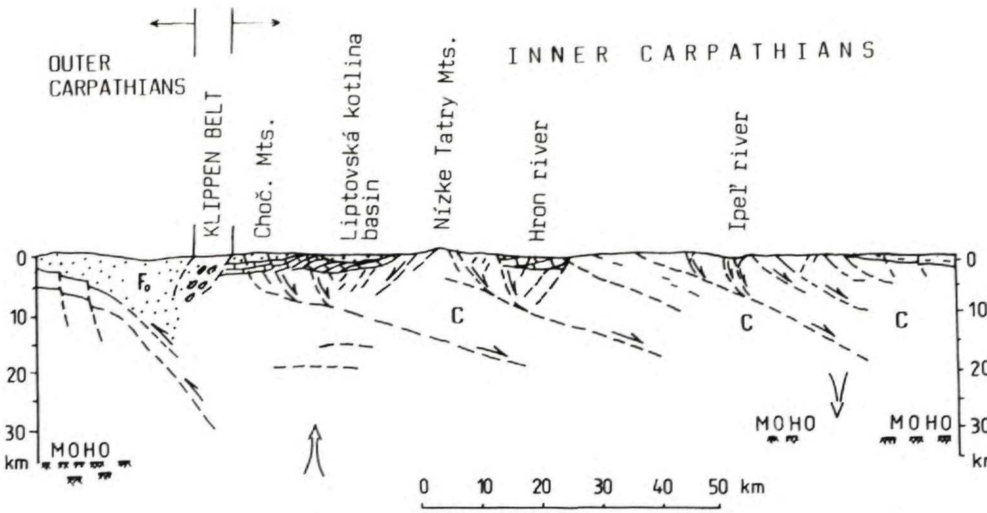


Fig. 6 Schematic kinematic model across the West Carpathians (modified after TOMEK et al., 1989)
C — crystalline unit, Fo — Outer flysch, Mesozoic and Cenozoic sedimentary complexes are shaded, arrows mark directions of movement in the neotectonic stage

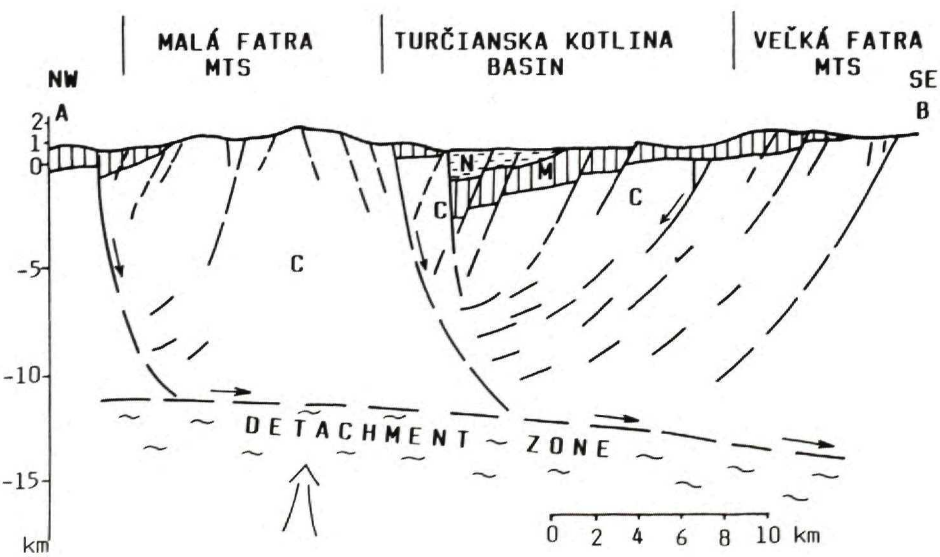


Fig. 7 Schematic kinematic model illustrating evolution of the Turčianska kotlina Basin along geophysical profile K III (after ONDRÁŠIK, 1988)
C — crystalline unit, M — Mesozoic and Paleogene, N — Neogene, arrows mark direction of movement

tracts of the Inner West Carpathians move along inclined discontinuity planes. A scheme of the gravitational movements in the upper crust levels across the West Carpathians compiled on the basis of a geophysical section is shown in Fig. 6.

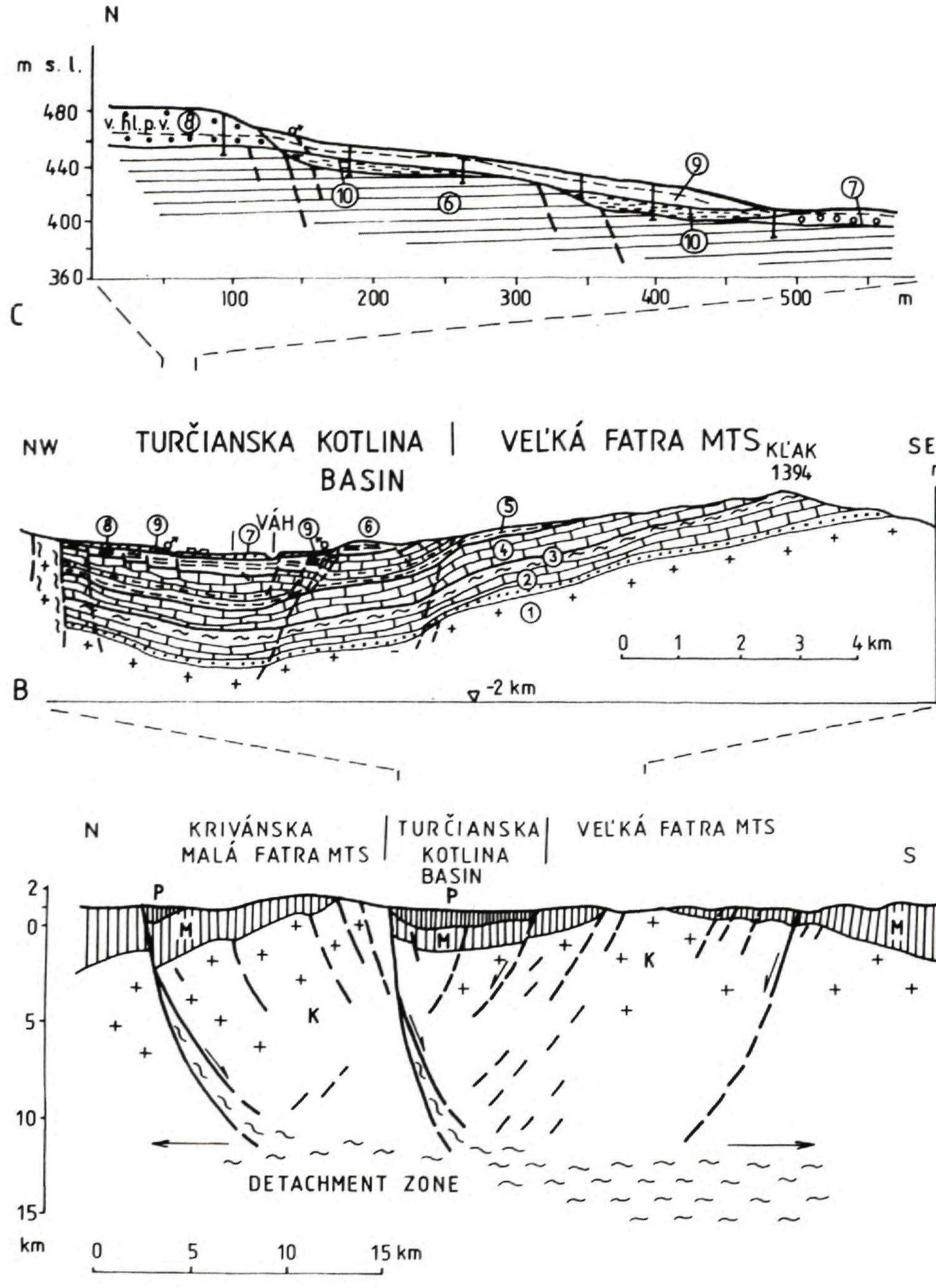
Gravitational movements were even more distinct above partial arched elevations of the upper mantle as is illustrated by schemes in Fig. 7 and 8 based on geological maps (Maheľ, 1964), geophysical profile K-III (Beránek et al., 1979) and geological sections by Buday (1961), Andrusov and Kuthan (1944) in the Malá Fatra and Turčianska kotlina areas.

According to Kopecký (1972), the uplift in the West Carpathians since the Upper Badenian (some 15 m. y.) totalled 800 m (i. e. about 0.05 mm/yr) in the Outer Flysch Belt, 1600–2000 m (i. e. about 0.1–0.13 mm/yr) in the Vysoké Tatry Mts., whereas the Danube Lowland subsided by as much as 5000 m (i. e. about 0.33 mm/yr). Hanzel et al. (1984) state that the uplift of the Vysoké Tatry Mts. relative to the Liptovská and Popradská kotlina Basins took place mostly since the Pannonian times, i. e. in the last 10 m. y., which indicates an annual rate of 0.16 to 0.2 mm. The thickness of Quaternary deposits (as much as over 400 m) on the subsiding block makes it possible to infer the subsidence rate in the Quaternary amounting to 0.5 mm/yr.

Relative vertical displacement between the Malá Fatra Mts. and Turčianska kotlina Basin attained 1600–2000 m which, over the last 15 m. y., corresponds to 0.06–0.35 mm/yr (Ondrášik, 1985).

The rate of these movements varies greatly over time and that is why different time periods display different subsidence or uplift even in the same area. The movement rate changing over time is suggested by the results of repeated measurements and resulting interpretation of vertical movements on maps of different time periods. The differentiated movements along faults are likely to be related to seismic tremours whose hypocentres in the West Carpathian territory largely lie at depths below 10 km, their magnitude attains 6.5 Magnitudo and take place once in 200–400 years (Zátopek, 1979).

The diapiric uplift of the Carpathians, whose centre lay in the Pannonian Basin, and a partial anticlinal uplift at the margin of the Inner West Carpathians along the Peripieninic lineament resulted in irregular spreading of the earth-crust upper levels and their faulting into a block mossic composed of horsts and basins. The outer margin of the Central West Carpathians in thus lined with asymmetric horsts inclined to the north and asymmetric basins. The horsts and basins are often arranged to form irregular anticlinoria and synclinoria. Such horsts include the Malé Karpaty, Malá Fatra, Choč and Vysoké Tatry Mts. whereas Turčianska kotlina and Liptovská kotlina are examples of asymmetric basins. Horsts with sedimentary envelope are inclined towards the outer side of the Carpathian arc. In the most elevated areas, the sedimentary cover was removed by Late Neogene erosion and the crystalline core was exposed on the surface. Horsts on the inner side of the Carpathian arc confined by steeply dipping faults (Fig. 6, 7, 8) which locally separate crystalline rocks from the Paleogene and/or even Neogene filling of the depressions. This contact is frequently covered with enormous proluvial deposists. Similar horsts, but with different tilting, occur in the other core mountains. Understanding the mechanism of their evolution makes it possible to understand regional principles which gave rise to irregularities in



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the geological structure and related slope failures as well as further geodynamic processes.

Gravitational movements of large structures in the earth crust significantly control the evolution of smaller structural units in near-surface horizons of the earth crust. Local elevations in horsts are responsible for the formation of transversal depressions and passes cutting mountain ranges. Lamač pass in the Malé Karpaty and Strečno pass in the Malá Fatra are good examples of this. In the latter, the process probably also involved torsion stresses due to different tectonic regimes in the Lúčanská and Kriváńska Malá Fatra (Fig. 7, 8). Pre-existing depressions and grabens evolved further as well. As shown in Fig. 9, the rate of Neogene deposition suggests that the subsidence started in the Ipeľská kotlina Basin and later it spread into marginal depressions. Deposition in the Inner Carpathian depressions and partial depressions of the Danube Basin began and evolved gradually in different periods in the end of the Lower and during the Upper Miocene. In some basins, Neogene sediments were completely eroded away or only their remnants were preserved.

Faults separating a horst from a depression cause abrupt changes in stream long profiles. The elevated block is subjected to erosion whereas the sunken block is a suitable place for the deposition of voluminous alluvial fans (Fig. 8) which are sometimes joined together to form a continuous belt of foothill proluvia and alluvial fans of several generations. The thickness of proluvia at Malá Fatra foothills and in Turčianska kotlina attains as much as 34 m (Fussgänger–Jadroň, 1975) and in the upper Ipeľ valley 35 m (Matejček, 1985). Deluvial and glacial sediments at the foothills of the Vysoké Tatry Mts. adjoining the Liptovská and Popradská kotlina basins attain as much as 400 m in thickness (Hanzel et al., 1984).

In addition to accumulations of cover units, relatively sunken blocks may also contain preserved thick eluvia (up to 10–20 m thick in the West Carpathians) which are sometimes buried beneath younger sediments. In contrast, relatively elevated blocks undergo erosion of the weathered surface and, as a result, weathered or fresh rocks are exposed on the surface. Thick eluvia have been preserved even on the tops of mountain ridges in fractured zones above listric faults as is the case e. g. in the sunken fractured part of the Veľká Lúka massif in the Lúčanská Malá Fatra (Ondrášik, et al., 1990). The thickness of intensively weathered rocks here is up to 20 m (Šalagová, 1983).

Fig. 8 Schematic sections of different hierarchic levels (Ondrášik, 1989)
A — Kinematic model of the evolution of the Turčianska kotlina Basin, K — crystalline unit, M — Mesozoic, P — Paleogene, B — Schematic section of northern slopes of the Veľká Fatra Mts. and Turčianska kotlina Basin, 1 — crystalline unit, Envelope unit: 2 — Mesozoic sandstones, claystones and carbonates, 3 — thrust zone, Krížna nappe: 4 — Middle Triassic limestones and dolomites, 5 — claystone and marlstone formation of the Carpathian Keuper; Inner Carpathian Paleogene: 6 — claystones, sandstones and conglomerates; Quaternary: 7 — fluvial gravelly sediments, 8 — gravels and loams of proluvial alluvial fans, 9 — landslides. C — Section of a landslide slope near Turany. 6 to 9 as in section B, 10 — marly clays, presumably Neogene to Early Quaternary

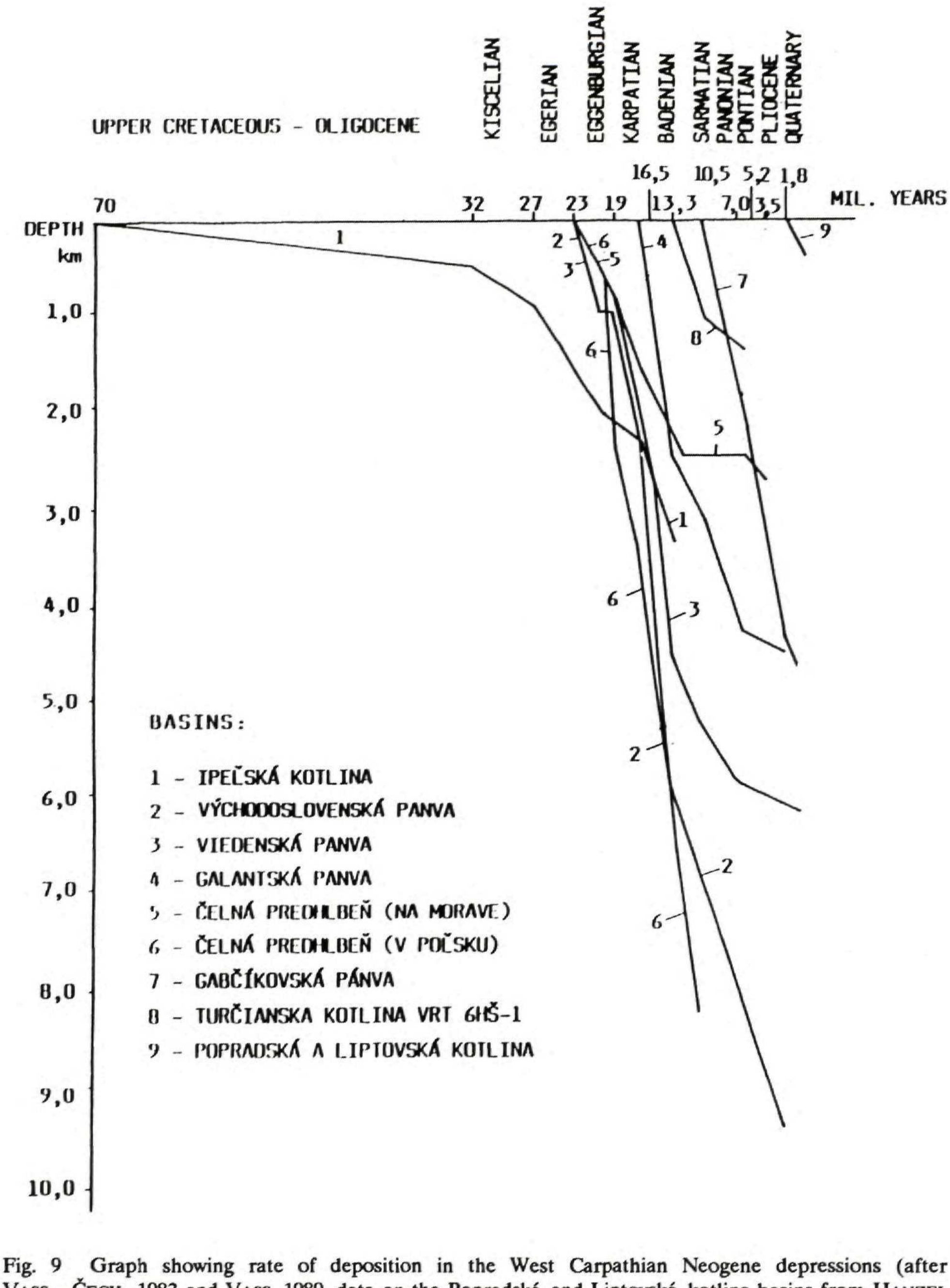

Fig. 9 Graph showing rate of deposition in the West Carpathian Neogene depressions (after VASS—ČECH, 1983 and VASS, 1989, data on the Popradská and Liptovská kotlina basins from HANZEL et al., 1984)

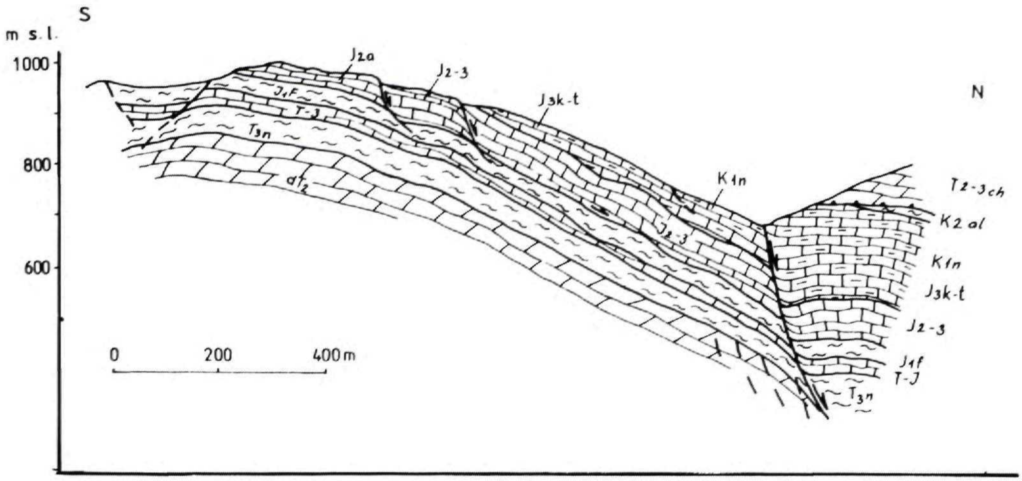

Fig. 10 Schematic section of slope failure in Mesozoic sediments in the vicinity of a listric fault on the northern slopes of the Veľká Fatra Mts.
Krížna unit: Triassic: dT_2 — dolomites, T_{3n} — claystones, marlstones interlayered with dolomites and sandstones, T—T — limestones; Jurassic: J_{lf} — claystones, marlstones, $J_{2\text{-}3}$ — limestones, $J_{3k\text{-}t}$ — marly limestones; Cretaceous: K_{ln} — marly limestones intercalated with marlstones, K_{3al} — marlstones, sandstones. Choč unit: Triassic: $T_{2\text{-}3ch}$ — dolomites. Arrows mark direction of movement

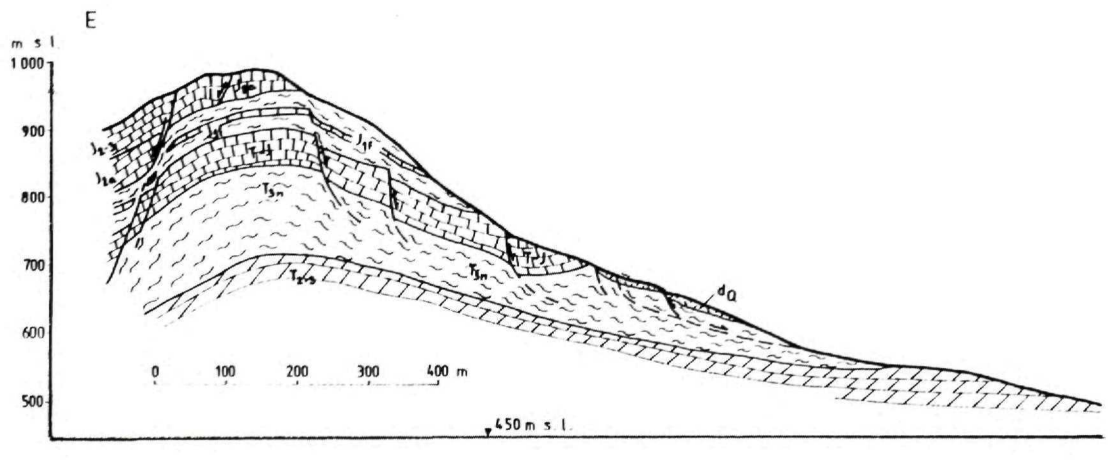

Fig. 11 Schematic section of slope failure in Mesozoic sediments on northern slopes of the Veľká Fatra Mts.
Krížna unit: Triassic: $T_{2\text{-}3}$ — dolomites, T_{3n} — claystones, marlstones interlayered with dolomites and sandstones, T-J — limestones; Jurassic: J_{lf} — claystones, marlstones interlayered with limestones, J_{2a} — limestones, $J_{2\text{-}3}$ — limestones. Quaternary: d_Q — deluvial sediments. Arrows mark direction of movements

Tectonic depressions are lined with slope failures associated directly with differentiated movements along faults (Fig. 10). If plastic formations were reached by erosion there starts a slow downslope movement towards the centre of depression accompanied by landslides in the frontal sections (Fig. 11). The downslope movement mostly takes advantage of pre-existing discontinuity planes such as nappe thrust lines, bedding planes or has the form of a viscous-plastic flow of clayey and marly formations carrying also overlying rigid complexes. Fig. 12 exemplifies different types of downslope movements on opposite flanks of a fault in monoclinal flysch complexes.

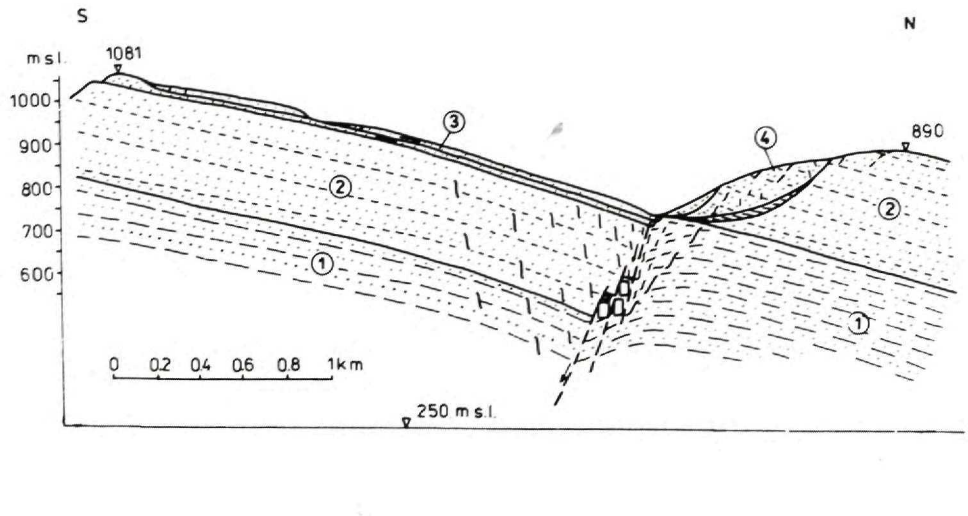

Fig. 12 Section of slope failures on slopes of a fault valley in the Skorušinské vrchy Mts. in the Outer Flysch Belt (KOVÁČIK—ONDRÁŠIK, 1989)
Flysch complex (Paleogene): 1 — thick-bedded sandstones intercalated with claystones, 2 — claystone—sandstone formation. Slope failures: 3 — planar creep of sandstones along claystone intercalations, 4 — landslide across beds along a rotation shear zone

The gravitational movements of rock masses from elevated structures to adjacent depressions causes relative tensile stresses with fracturing in the upper parts of the elevated structures and increased horizontal stresses in their lower parts and in adjacent depressions (Fig. 10, 11). This is exemplified by the elevation of the Vtáčnik Mts. where downslope movements towards a nearby depression damaged a coal shaft in Neogene sediments of the Handlová brown-coal field at a depth of more than 300 m (ZÁRUBA–MENCL, 1987).

Young, mostly unconsolidated sediments accumulate in basins and depressions. If the water table in them is lowered, they start to consolidate and subside. In construction pits and cuts and sometimes also in streambanks, suffosion and liquid sands may occur. Aeolian sands sensitive to winnowing and loesses likely to compact and subside piled up on the periphery of basins and lowlands during the Pleistocene. Local depressions in basins and lowlands frequently contain marches such as Jurský Šúr and peat bogs in Záhorie at Malé Karpaty foothills. Fine-grained, poorly permeable sediments are laid down in the subsiding flooded areas and therefore their substratum contains aquifers with confined groundwater level. The existence of these confined groundwaters makes it very difficult to dewater such water-logged sites, the most serious problems of this kind being encountered in the Eastern Slovakian Lowland. Local marshes of mountain peat-bog character also occur in depressions on flat water divides as a result of eluvial colmatage e. g. in the Lúčanská Malá Fatra (Ondrášik et al., 1990).

Fault zones in carbonate complexes give rise to distinct manifestations of surface as well as underground karst phenomena. Faults also connect individual carbonate formations separated from each other by layers of sediments resistant to karstification, which rendered it impossible to construct dams in a number of otherwise suitable valleys underlain by Mesozoic carbonate formations (Nešvara, 1970, Šarík, 1982). Fault zones also give rise to linear surface and underground karst phenomena in otherwise poorly permeable silicified limestones and dolomites as is the case below the dam of the upper reservoir of the Čierny Váh hydroelectric power station (Nevický, 1980).

Conclusion

The knowledge of the geological structure of the West Carpathians as well as their individual parts and reconstructions of their neotectonic history have been useful in a number of cases, particularly in locating exploration works and interpretation of exploration results. They can also be successfully employed in evaluating and prognosing slope failures as well as further geodynamic phenomena, which is exemplified by several cases. It is therefore desirable to proceed in this study of the geological setting and pay attention to weak and weakened zones not only in projects of regional character but also in exploration for concrete structures.

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Rudolf Ondrášik

Rekonštrukcia geotektonického vývoja geologických štruktúr pre hodnotenie stavu a správania hornín v Slovenských Karpatoch

Resumé

Na území Západných Karpát sa vedľa seba vyskytujú horniny od proterozoika až po súčasnosť, čo predstavuje časové rozpätie viac ako 1 miliardy rokov. Horniny z predmezozoických útvarov (staršie ako 250 miliónov rokov), ak nie sú postihnuté retrográdnymi premenami, sa vyznačujú pevnými kryštalizačnými väzbami a skalnou povahou. V najmladších útvaroch nie sú horniny vôbec spevnené. Všeobecne platí, že čím sú útvary staršie, tým je v nich viac pevnejších hornín. Ale aj uprostred masívov skalných hornín mezozoika sa môžu vyskytovať polohy slabo spevnených poloskalných ílovitých a slienitých sedimentov s veľmi nepriaznivými stálostnými vlastnosťami. Vo všetkých skalných horninách, bez ohľadu na ich vek, sa vyskytujú druhotne oslabené zóny rôznej genézy. Patria sem rozmanité diskontinuity od puklín až po široké zlomové poruchy, ako aj hydrotermálne, pneumatolyticky a zvetrávaním degradované horniny. Najmladšie horniny z konca pliocénu a z kvartéru, t. j. z posledných asi 2—3 miliónov rokov, predstavujú prevažne nespevnené alebo slabo spevnené sedimenty, ktoré sa označujú ako pokryvné útvary. Z hľadiska hodnotenia oslabených zón a súčasných polí napätí sú rozhodujúcimi najmladšie fázy vývoja Západných Karpát, ktoré pretrvávajú do súčasnosti, t. j. neotektonická etapa vývoja.

Hromadiace sa poznatky z výsledkov štúdia geologických štruktúr ukazujú na spätosť tektonických výzdvihov zemskej kôry a pohybov jej časti po uklonených zónach nespojitosti. Medzi takéto plochy nespojitosti patria napríklad subdukčné zóny a násunové zóny príkrovov, ale aj plastické zóny rôznych rozmerov a genézy. Rozsiahlejšie plastické zóny sa predpokladajú v zemskej kôre v hĺbkach 10—20 km. Prejavujú sa ako zóny znížených rýchlostí šírenia seizmických vĺn (Stewart, 1971, Anderson et al., 1983), ako to bolo doložené i výsledkami viac ako 10 km hlbokého vrtu na Kolskom polostrove (Nikolajevskij, 1987).

Gavrilenko-Gueguen (1989) existenciu plastickej zóny v spodnej časti kôry dávajú do súvisu s kvapalinami uzatvorenými v subhorizontálnych, vertikálne nespojitých diskontinuitách. Keďže stlačené kvapaliny z uzatvorených diskontinuít nemôžu unikať do prostredia s nižšími tlakmi, vznikajú vysoké neutrálne napätia zodpovedajúce litostatickému tlaku nadložia a hornina sa správa viskózno-plasticky. V modeli, ktorý predložili, sa nespojité diskontinuity s uzatvorenými tekutinami vyskytujú v hĺbkach 10—30 km s maximom v 17 km. Do hĺbky 10—15 km prevládajú vertikálne nespojité diskontinuity s možnosťou prúdenia kvapalín a s ich únikom zo zón zvýšeného napätia do nadložných zón s nižším napätím. V tejto zóne kvapaliny ovplyvňujú efektívne napätie veľmi nerovnomerne a kôra sa správa krehko.

V plastickej zóne sa pri zmene napätí uplatní spojité roztiahnutie alebo skrátenie, v nadložných častiach však dochádza ku krehkému porušeniu. Podľa jedných autorov (napr. Anderson et al., 1983, Nikolajevskij, 1987) vo forme strmo uklonených zakrivených, smerom do hĺbky sa zmierňujúcich zlomov (listrických), podľa iných je to po rovných zlomoch s "dolomitovým" naskladaním blokov.

Výrazné zmeny napätia vo vrchnej časti zemskej kôry súvisia s pohybmi litosféry a vrchného plášťa. Je to napríklad pri subdukcii, kolízii blokov, ale aj pri antiklinálnych a synklinálnych priehyboch litosféry.

Profily z refrakčnej seizmicity cez územie Západných Karpát (ROYDEN-HORVÁTH et al., 1988, TOMEK et al., 1989) poukazujú na zóny nespojitosti a na existenciu listrických zlomov. Pri skrátení priestoru Karpát v starších fázach vývoja po týchto zónach zrejme dochádzalo k násunom. V neotektonickej etape vývoja pri prevládajúcom roztiahnutí vrchnej časti kôry Západných Karpát sa na zónach nespojitosti pravdepodobne uskutočňuje spätný pohyb od vyzdvihovaného vonkajšieho oblúka Západných Karpát k poklesávajúcim centrálnym častiam Panónskej nížiny.

Následkom diapirového výzdvihu Západných Karpát s centrom v Panónskej nížine a čiastkovým antiklinálnym výzdvihom okraja centrálnych Západných Karpát pozdĺž peripieninského lineamentu došlo k nerovnomernému rozťahovaniu vrchnej časti zemskej kôry, k jej rozpadu na mozaiku blokov a ku vzniku asymetrických, k severu uklonených hrastí a asymetrických kotlín. Do veľkej miery boli usporiadané do nepravidelných antiklinórií a synklinórií. Medzi také hrasti patria Malé Karpaty, Malá Fatra, Chočské vrchy, Vysoké Tatry. K asymetrickým kotlinám patrí Turčianska kotlina a Liptovská kotlina. Hrasti so sedimentárnym obalom sú uklonené k vonkajšej strane karpatského oblúka. V najexponovanejších častiach sedimentárny obal v mladšom neogéne podľahol erózii a na povrch vystúpilo obnažené kryštalické jadro. K vnútornej strane Karpatského oblúka sú hrasti obmedzené strmo upadajúcimi zlomami, na ktorých sa miestami stýka kryštalinikum s paleogénom, prípadne i s neogénnou výplňou depresií. Tento styk je z veľkej časti prekrytý mohutnými proluviálnymi uloženinami. Podobný typ hrastí s rozdielnymi prejavmi naklonenia predstavujú i ďalšie jadrové pohoria. Pochopenie mechanizmu ich vývoja umožňuje i pochopenie regionálnych zákonitostí vzniku nerovnorodosti geologickej stavby a na ne viazaných svahových pohybov, ako aj ďalších geodynamických procesov.

ZÁPADNÉ KARPATY
séria

hydrogeológia a inžinierska geológia 11

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