INŽINIERSKA GEOLÓGIA A HYDROGEOLÓGIA

ARNOLD NEMČOK*

GEOLOGICAL CONSTRUCTION OF SLOPES AND ITS INFLUENCE ON THE ORIGIN AND DISTRIBUTION OF LANDSLIDES IN THE WEST CARPATHIANS

(Slovak summary)

Abstract. The landslide areas in the West Carpathians are restricted to the flysch zone, Klippen belt, margins of the volcanic mountains and inner Carpathian depressions. Investigations of the author showed that the majority of ladslides occurs in lower, less in central and rarely in upper part of the flysch slopes.

Landslides in the majority of the West Carpathian areas represent an atypical phenomenon. These mountain areas are composed of the old Paleozoic crystalline massifs, further of young Paleozoic, Mesozoic and Paleogene coarse- and medium-detritic carbonate and carbonate-clayey rocks (conglomerates, limestones, dolomites, sandstones and marlstones) and central parts of the volcanic mountains composed of the Neogene extrusives and their pyroclastics in the tufa facies. Geological structures of all these areas are consolidated so that a morphological development of slopes is normal and is being liable to the law of long-termed slope modelation. All rocks constructing a slope are being liable to weathering approximately conformably. A weathered material, which accumulates on a slope, is being replaced by factors of denudation or transport action of surface waters in more down situated parts of relief (valleys, basins etc.). Landslides here are very rare.

Landslide areas in the West Carpathians are restricted to the area of the flysch zone, klippen belt, margins of the volcanic mountains and inner Carpathian depressions.

Landslide areas of the Carpathian flysch zone

Regions of the eastern Moravia, north-eastern, northern and north-western Slovakia with Pavlov, Ždánice, Vizovice, Vsetín hills, Beskyds, White Carpathians, Javorníky, Kysuca highlands, Oravian Magura, Ondava highlands, Čerhov mountains, Skorušiná mountains, Spiš-Magura, Levoča mountains and Šariš highlands, belong to those in Czechoslovakia with a great number of landslides.

The principal structural element of the mentioned orographic units is a complex of rocks, which are characterized by the flysch facies, i. e. alternation of pelitic, aleuritic and psammitic rocks both vertically and horizontally. Less frequent are intercalations of psefitic, carbonate, siliceous rocks and extrusives. We may find three types of geological ground in the flysch complexes from the view of forming of landslides:

* Doc. dr. A. Nemčok, C. Sc., Department of Foundation of constructions, Geology and Dams of the Building Faculty of the Slovak Technical Institute, Gottwald sq. 2, Bratislava.

a) coarse flysch, represented by sandy sequences with intercalations of conglomerates. They are sometimes of such a thickness that they form mountain ridges and have local names: Hradiště, Godula, Ždánice, Ciężkowice, Istebná, Magura sandstones etc. They form for instance the top parts of Moravian-Silesian Beskyds, mountain massif of Oravian and Spiš Magura. Landslides here are very rare.

b) Coarse-rhythmical flysch with beds of sandstones intercalating with beds of slaty clays, mudstones and marlstones. Of such character is for instance the Karp series of the Dukla unit, the Krosno, Zlín and Mal'cov beds etc. In the regions formed by this type of flysch, landslides are more frequent.

c) Fine-rhythmical flysch is composed of shaly sequence of claystones, mudstones and marlstones intercalating with thin beds of sandstones of some cm in size. Of such charakter are for instance the Těšín shales, Veřovice and Frýdek beds, Hustopeče and Beloveža beds, under-menilite flysch a. s. o. The latter rocks form slopes, feet of hills, and valleys. The main part of the Carpathian flysch landslides is concentrated at slopes made of the mentioned sequences of the fine-rhythmical flysch.

Landslides, in relation to the morphology, are restricted mainly to the lower, less to the central and very frequently to the upper part of the flysch slopes. This phenomenon is closely related to the geological construction of slopes. The common feature of all flysch landslide areas is that slopes under surface complexes are composed of two, physically and mechanically different elements; the lower element of the slope is formed of fine-rhythmical flysch and upper part or complex is composed of coarse-rhythmical flysch or sandy beds. The border between them is usually in the center or in the upper part of slopes near the water-divide ridges. Weathering and subsurface water regime represents a reason of forming and accumulation of surface covers of enormous thicknesses due to two physically and mechanically different environments. Material of the surface mantle is a mixture of weathered materials of the upper and lower complexes and lies in the central and lower part of slope on the plastic substratum of the fine-rhytmical flysch. The latter weights a slope, holds rainfalls and subsurface waters and so in essentiality contributes to the origin of unbalanced state on a slope. Under suitable conditions, as are for instance rich rainfalls, thaw of snow, undermining of a slope by water, sapping etc., mantle rocks begin to move.

Further structural feature, which characterizes the flysch landslide slopes, is that landslides form on such slopes, which cut the frontal part of sequences. This phenomenon is probably connected with the fact that weathering of frontal parts of sequences is more intensive and deeper than on slopes, which are parallel (or almost parallel) with beds (i. e. where are dip slopes). Rainfalls and subsurface waters, affects of temperature changes, freezing and thawing penetrate deeply into sequences along bedding joints and joints; due to this fact, very thick weathered materials originate and under conditions described, they may slide.

The mantle rocks represent the most frequent material forming the landslides of the flysch regions, as it was registered. The main sliding plane runs along a border of the mantle rocks and substratum. Only exceptionally, the latter reaches also a substratum. A sliding material is composed of slope muddy-sandy loams with fragments and boulders of sandstones. The planar and current landslides are the predominant types of the flysch landslides.

Areas, constructed only by fine-rhythmical flysch (filling of valleys etc.) have only slightly contrast, moderately undulated upland relief with flattened slopes.

In such areas landslides are restricted to erosional rills, wash-outs, stream banks and those of rivers originated by reverse deep or lateral erosion of occasional or permanent water flows, or the latter are restricted to the places of incorrectly made cuts and other engineering works. Predominant type of landslides here are landslides along rotary slide planes and planar ones. Landslides are very rare on the shallow slopes, which are not affected by river erosion. They originate after extreme and long-termed rainfalls when the mantle rocks are completely wet and form the muddy currents.

Landslide areas in the klippen belt

The klippen belt forms an extremely long, narrow belt, the geological construction of which affords suitable conditions for the origin of landslides. The klippen belt is very rich in landslides of various types. The most characteristic are large current landslides, which by a plane size and thickness resemble those originating at the margins of volcanic traps. This phenomenon is caused by the morphological feature of the klippen belt where the elevated parts of rielief are composed of rock klippens (also pseudoklippens), i. e. the block masses and lenses of hard limestones, marlstones, sandstones, conglomerates, siliceous rocks and coarse and coarse-rhythmical flysch. Depressed parts of the klippen belt, i. e. feet of slopes, and saddles are made up of the klippen mantle composed mainly of marls, marlstones, marly shales and fine-rhythmical flysch or flysch-like beds of the Middle and Upper Cretaceous age. There are many slopes in the klippen belt, the upper part of which is formed by hard, resistent to the weathering rocks, and the lower one by soft, medium hard weakly resistent to the weathering rocks. Under the mentioned conditions of geological construction thick layers of weathered materials originate on slopes, which lay and weight mainly at the lower parts of the latter formed by plastic soft rocks. Under an influence of underground and surface waters these masses slide. In the klippen belt, landslides are restricted mainly to the Cretaceous beds with carbonate concretions (in the fine-rhythmical flysch facies), Púchov beds and near-klippen Paleogene flysch. These landslides are predominatly current, less planar and block ones. The sliding material is represented by loamy-stony debrises. Instances: the vicinity of Lednica, Vršatecké Podhradie, Púchov, Nosice, Bytča, Chlebnica, Pokryvače, Zázrivá, Kozinská, Dlhá, Oravský Podzámok, Podbiel, Tvrdošín etc.

Landslide areas at the margins of the Tertiary volcanic mountains

In the central part of Kremnicko-Štiavnické rudohorie, Prešov-Tokaj hills and Vihorlat landslides are not known. Landslides we do not find at the margins of the volcanic mountains where the lavas and pyroclastics lay on rocky Mesozoic and older sequences. The sporadic occurrences we may find at the places, where the volcanic traps lay for instance on the Werfenian shales, Keuper etc. The essential part of landslides (the largest in Czechoslovakia) occurs on slopes, where the volcanic traps lay on the shaly sequences of the Paleogene and soft fine-grained Neogene suites.

The upper part of slopes at the periphery of volcanic mountains is composed mainly of rocky blocks of andezites, basalts, rhyolites and their pyroclastics and the feet are made up of plastic shaly sequences and soft clayey-muddy-sandy rocks. As we see, there are again two physically and mechanically different environments. Volcanic traps at their margins were gradually disintegrated. The disintegration passed so, that whole blocks were broken away or margins of traps were disintegrated along joints and fractures in the form of block or stony debris, most frequently in the form of dump piles and rock falls. Disintegration of the margins of volcanic traps is caused also by a tectonic disintegration, with which a weathering, water permeability and other features are connected. The latter is caused also by original plastic features of the substratum.

Various phenomena described cause the origin of slope debris, which weights the slope, prevents an outlet of surface waters, holds subsurface waters; larger blocks submerge in the plastic substratum and slide down to valleys. On slopes, an unbalanced state originates, which evokes a sliding. The rate of slide movement is regulated by a régime of the both surface and subsurface waters. During the enormous rainfalls the rate may be very quick and of catastrophal character; during normal rainfalls or dry periods a sliding is slow and may be replaced by normal long-termed slope modelation.

Landslides at the margins of volcanites have a character of block and current landslides. The masses of loamy and stony debrises, also a block ones are sliding. The main sliding plane runs along the border of substratum and mantle rocks, sometimes also in the substratum. Instances: Handlová, Králiky, Ľubietová near the northern margin of Kremnicko-Štiavnické rudohorie, Hájna Hora near Brezno, northern margin of Tokaj hills — Veľká and Malá Izra and near the northern near Prešov, Abramovce and Varhaňovce. Further landslides occur near the northern margin of Tokaj hills — Veľká and Malá Izra and near the northern margin of Vihorlat — Kamienka near Kamenica nad Cirochou, near the Veľké Okno lake etc.

Landslide areas in the inner Carpathian depressions

Further essential part of landslide areas is concentrated in the inner Carpathian hollows. The filling of the hollows is composed of the Paleogene flysch sequences (predominantly shaly), the Neogene soft claystones, mulstones, sandstones, marls and tuffites with intercalations of gravels and Quaternary deposits. Development of the inner Carpathian hollows is very various and their fillings are geologically also very variegated. A part of them belongs to the great marine Pannonian basin — Ilava, Bánovce, Nováky—Handlová, Ipeľ, Lučenec and Rimava hollows, the others form an independent closed hollows with fresh-water filling (or without a fresh-water filling) — Žilina, Orava, Turiec, Liptov, Poprad, Hornád, Bystrica, Brezno, Polom, Rožňava, Ždiar and Zvolen basins.

A morphology of basins is characterized by moderately undulated relief. There are medium- and higher uplands and low tabulae in the basins. Landslides originate on moderate slopes, mainly at the margins of tabulae. They are connected with the mentioned (slide) geological structure with two physically and mechanically different complexes. The upper complex of slidy slopes is composed of coarse-clastic unconsolidated lacustrine, glacial, fluvial and stream deposits (gravels, sands with intercalations of clays, muds and loams), travertines unsorted material of alluvial cones; the lower complex is represented by flysch (predominantly shaly) Paleogene sequences, marine and lacustrine Neogene suites (clays, marls, sands, clay to sandy tuffites).

The mentioned geological structure on slopes of the inner Carpathian basins originated by a combination of formation of various age. We cannot describe all cases, only some of the most typical:

on the Paleogene and Miocene filling of the majority of basins lays the Pliocene gravel formation named by several local names — Diviaky beds, Hron, Poltár, Košice, Pozdišov gravel formations etc. Originally continued cover was cut and furrowed by valleys and recently the Pliocene formations occur only in the form of denudation remains covering the tops and ridges of highlands and tabulae in basins. The margins of the Pliocene gravel covers under an influence of weathering are disintegrated and on slopes the thick loamy and gravel mantle rocks accumulate. They lay on the plastic ground and under the affect of both surface and subsurface waters and lateral erosion they slide. Locally, the original Pliocene mantle was fully destructed. In the present time we may find it only as a constituent of the slope sliding or not sliding Quaternary deposits. Instances of such slides we may find in the Ilava, Bánovce, Nováky—Handlová, Ipeľ, Lučenec, Rimava, Košice, Turiec, Bystrica, Brezno, Polom, Žiar and Zvolen basins.

On the Paleogene and Neogene fillings of basins lay Pleistocene covers of fluvioglacial gravels, river terraces, alluvial cones and stony cones (near the tectonic contact of the Paleogene and Neogene with older rocky formations at the margins of basins) etc. Denudation remains of fluvioglacial material were preserved on the slopes of Liptov and Poprad basins, remains of gravel terraces and old alluvial cones we may find in each inner Carpathian basin.

A considerable part of landslides is restricted to disintegrating margins of the Pleistocene deposits lying on the plastic Neogene and Paleogene substratum. There are also suitable conditions for the origin of thick surface rocks — loamy gravel and loamy stony debrises, which under certain conditions (hydrogeological regime undermining, sapping etc.), slide. On the slopes made of these formations, the essential part of landslides originates in the Žilina (Dolný Hričov, Lietavská Lúčka), Turiec (Kľačany, Horné Záturčie—Priekopa, Košúty—Sučany), Liptov (Liptovská Mara, Okoličné, Závažná Poruba, the vicinity of Konská near Smrečany) and Poprad basins. Planar and current landslides predominate in the inner Carpathian basins, sometimes we may see landslides along rotary sliding planes.

Landslide areas in the Neogene lowlands of Moravia and southern Slovakia

Lowlands are formed by the Neogene marine sediments of the fore deep (Dyje—Svratka, Vyškov and Horná Morava lowlands, Ostrava and Opava regions), sediments of the Vienna basin (Záhorie and Dolná Morava lowlands) and Pannonian basin (Dunaj and Trnava lowlands, further Nitra, Hron and Ipeľ uplands and Tisa lowlands). These sediments are represented mainly by clay, marls, muds, sands with intercalations of gravels and organoclastic limestones. However, the Neogene substratum is mostly covered by the Quaternary eolic sands, loesses and fluvial deposits.

A typical lowland-like tabular and flattened upland relief was modelated on the mentioned rocks. More sheer slopes originated only at the margins of tabulae. Sliding of slopes is connected almost exclusively with lateral erosion of rivers and incorrectly made cuts and other engineering constructions mainly for roads. In other cases we never find landslides in the lowland relief. Instances: block, planar and current landslides caused by a lateral erosion of the river Váh at the left slope between Hlohovec and Sereď, landslides in the cut of railway road near Vaďovce (Myjava—Nové Mesto) near Neverice and Žírany (Kozárovce—Zbehy etc.).

Conclusions

Finally, I have to point out that the principal condition for the origin of landslides by natural way is certain arrangement of layer complexes on a slope. This arrangement is so, that the upper part of a slope is composed of hard, rigid complex and the lower one by soft, plastic rock complexes. As this structure represents a primary condition, together with which act or on which depend further factors and causes of a sliding of slopes, we may name it as l a n d s l i d e g e o l o g i c a l s t r u c t u r e o f a s l o p e. The upper complex may be composed of hard extrusive, sedimentary and metamorphosed rocks, rocks in the facies of coarse and coarse-rhythmical flysch, further unconsolidated medium- or coarse-detritic sediments. The lower complex usually is composed of hard shaly rocks, hard rocks in the facies of fine-rhythmical flysch and unconsolidated fine-detritic and clayey rocks.

Many of the slopes with the mentioned composition and structure were exposed to the action of geomorphological factors contemporaneously with elevating of the Carpathians after recession of seas and lakes in the time of formation of rivers and river erosion began. Further slopes with similar construction were exposed later by gradual downward cutting in older geological structures. A river erosion denuded and denudes both stratigraphical and tectonical borders of formations and very frequently there are denuded hard rigid complexes lying in stratigraphical or tectonical superposition on soft plastic complexes on the valley slopes.

In the Carpathians, the most frequent are stratigraphical borders between sediments of deeper or shallower seas, between basal transgressive sequences and their underlying beds, between marine and fresh-water, resp. fresh-water — volcanic sediments and between volcanic traps and underlying beds, between Quaternary deposits and their underlying beds etc.

Tectonic borders are represented by overthrust planes of thrusts, overthrusts, nappes and normal faults, along which the yonger beds are connected with older ones directly on the relief plane. On the valley and basin slopes, older hard rocks occur in superposition on yonger ones, frequently unconsolidated. For instance fault zone at the margins of the Carpathian basins, along which the Paleogene — Neogene filling is connected with hard rocks of the crystalline, Mesozoic etc., further overthrust planes of the Križná and Choč nappes, denuded by valleys and tectonic planes between klippens and klippen mantle etc.

A river erosion and long-termed slope modelation denudes the mentioned structures in relief, which are modelated further by a short-time landslide action. Naturally, the landslide action accelerates destruction of these structures and leads finally to their extinction and a balance and a long-termed slope modelation again takes a part. In the field we may see various stadia of such development of landslide action.

The upper, rigid complex on a whole has another reaction to the geomorphological factors than the lower — plastic one. A different mode of weathering of these two complexes was expressed mainly during the periglacial clima, in which the Carpathian region was exposed to the weathering during the glacial which continues also recently by an action of moderate clima.

The greater are differences in physical and mechanical features of the mentioned two complexes, the more distinct are differences in the form of weathering, which leads finally to the origin of extreme thicknesses of the surface rocks, and in the lower part of slopes to the origin of distinct landslide relief.

A hydrogeological régime in the majority of lanslide regions has predominantly the character as follows: sliding loamy — stony debrises are feeded and wet by subsurface and rainfall water. The subsurface water, which is very frequently an immediate cause of landslide or its activation, flows to the surface rocks or sliding masses from the border of the mentioned two complexes. It flows through the upper complex of the volcanic traps, which are usually permeable, it accumulates at the base of the last and at the border of underlying impermeable rocks it flows to the surface rocks or in the form of spring on the surface.

A rainfall water, which is very frequently an immediate reason of the origin of landslide or its activation, comparatively easily penetrates in stony and loamy-stony debrises lying on a slope in situ or making a fossil, resp. consolidated landslide; such a water also makes them wet and saturated them. This water accumulates in the mentioned debrises, mainly in their central and upper parts where they are not mixed with fine, for water impermeable deposits and where predominate coarse fractions of deposits. On the basis of results of pump attempts placed along a profile of the Handlová catastrophical landslide it is well known, that ends of the landslide had in comparison with segregating and central parts very small content of water. Under such conditions, as very intensive factor of sliding, also a gravitation force of the subsurface water, accumulated in the surface rocks, acts.

An accumulation of the rainfall water on slopes in fossil and consolidated landslides is facilitated also by landslides relief with numerous hollows and close depresions.

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Arnold Nemčok

GEOLOGICKÁ STAVBA SVAHOV A JEJ VPLYV NA VZNIK A ROZŠÍRENIE ZOSUVOV V ZÁPADNÝCH KARPATOCH

Základným predpokladom pre tvorbu zosuvov prírodnou cestou je určité usporiadanie vrstevných komplexov vo svahu. Je to usporiadanie vrstiev hornín v tom zmysle, že hornú časť svahu buduje tvrdý — rigidný komplex, spodnú časť mäkký — plastický komplex hornín. Pretože je táto štruktúra prvotným základom, s ktorým spolupôsobia, alebo od neho závisia ďalšie faktory a príčiny zosúvania svahov, nazveme ju zosuvnou geologickou štruktúrou svahu. Horný komplex môžu zastupovať skalné, vyvrelé, sedimentárne, metamorfované horniny, skalné i poloskalné horniny vo vývoji hrubého a hruborytmického flyšu, ďalej nespevnené strednodetritické a hrubodetritické sedimenty. Spodný komplex obyčajne zastupujú skalné bridličnaté horniny, skalné i poloskalné horniny vo vývoji drobnorytmického flyšu a nespevnené jemnodetritické a ílovité horniny.

Mnohé svahy s touto stavbou boli k dispozícii geomorfologickým činiteľom už hneď po vyzdvihnutí Karpát, po ústupe morí a jazier, čiže v čase, keď sa začala vytvárať riečna sieť a pôsobiť riečna erózia. Ďalšie svahy s podobnou stavbou sa odkryli až neskoršie, postupným prehlbovaním a zarezávaním sa údolí do starších geologických štruktúr. Riečna erózia odkrývala a odkrýva tak stratigrafické, ako aj tektonické rozhrania útvarov a mnohokrát sa teda vo svahoch údolí a panví odkryjú tvrdé rigidné komplexy, ležiace či už v stratigrafickej, alebo tektonickej superpozícii nad mäkkými plastickými komplexami.

V Karpatoch to najčastejšie bývajú stratigrafické rozhrania medzi sedimentami hlbších a plytších morí, medzi bazálnymi transgresívnymi súvrstviami a ich podložím, medzi morskými a sladkovodnými, resp. sladkovodno-vulkanickými sedimentami, medzi vulkanickými príkrovmi a ich podložím, medzi kvartérnymi uloženinami a ich podložím a pod.

Tektonické rozhrania reprezentujú presunové plochy zdvihov, poklesov, prešmykov, príkrovov, pozdĺž ktorých sa na ploche reliéfu priamo stýkajú mladšie útvary so staršími. Vo svahoch údolí a kotlín sa tak často vyskytnú v superpozícii staršie skalné horniny nad mladšími, slabo alebo vôbec nespevnenými sedimentami. Napr. zlomové pásma na okrajoch karpatských kotlín, pozdĺž ktorých sa stýka paleogénno-neogénna výplň so skalnými horninami kryštalinika, mezozoika, alebo údoliami obnažené presunové plochy križňanského a chočského príkrovu, tektonické plochy medzi bradlami a bradlovým obalom a pod.

Postupujúca riečna erózia a dlhodobá svahová modelácia odkrýva v reliéfe uvedené štruktúry, ktoré sa ďalej modelujú krátkodobou, zosuvnou činnosťou. Je prirodzené, že zosuvná činnosť urýchli deštrukciu týchto štruktúr a spôsobí v konečnej fáze ich zánik, a teda znova nastolí vládu dlhodobej svahovej modelácie. V teréne môžeme pozorovať rôzne štádiá tohto vývoja.

Horný rigidný komplex ako celok reaguje na pôsobenie geomorfologických činiteľov celkom inakšie ako spodný — plastický. Rozdielny spôsob zvetrávania dvoch komplexov sa výrazne prejavil najmä počas periglaciálnej klímy, ktorej bola oblasť Karpát vystavená v dobách zaľadnenia, a pokračuje prirodzene i za pôsobenia dnešnej miernej klímy.

Čím väčšie rozdiely existujú vo fyzikálno-mechanických vlastnostiach uvedených dvoch komplexov, tým výraznejšie sa prejaví rozdielny spôsob zvetrávania, čo vedie v konečnom dôsledku k vytvoreniu extrémnych hrúbok pokryvných útvarov v dolnej polovici svahov a k vytvoreniu výrazného zosuvného reliéfu.

Hydrologický režim u väčšiny zosuvných svahov má prevažne takýto charakter: zosúvajúce sa hlinito-kamenité sutiny napája a prevlhčuje podzemná i zrážková voda. Podzemná voda, ktorá býva často bezprostrednou príčinou zosunu alebo jeho aktívizácie, vyteká do pokryvných útvarov alebo zosuvných más z rozhrania už spomínaných dvoch komplexov. Cez vrchný komplex, ktorý býva priepustný, prúdi, na jeho báze sa hromadí a na rozhraní s podložnými, pre vodu nepriepustnými útvarmi vyteká do pokryvných útvarov alebo na povrch vo forme prameňov.

Zrážková voda, ktorá býva ešte častejšie bezprostrednou príčinou vzniku zosunu alebo jeho aktivizácie, pomerne ľahko preniká do kamenitých a hlinito-kamenitých sutín ležiacich na svahu in situ alebo tvoriacich fosilný, resp. upokojený zosun; tiež ich nasycuje a prevlhčuje. Koncentruje sa v nich najmä v hornej a v strednej časti svahu, tam kde prevládajú hrubé frakcie uložením, kde sú ešte nie tak dokonale premiešané s jemnejšími, pre vodu nepriepustnými frakciami svahových hlín a pod. Je známe podľa výsledkov čerpacích pokusov umiestnených v pozdĺžnom profile handlovského katastrofálneho zosunu, že koncové časti zosunov boli takmer bez podzemnej vody. Za takýchto okolností pôsobí ako intenzívny činiteľ zosúvanie, gravitačná sila podzemnej vody nahromadenej v pokryvných útvaroch.

Zadržiavanie zrážkovej vody na svahoch pri fosilných a upokojených zosunoch podporuje aj zosuvný reliéf s početnými vpadlinami a bezodtokovými depresiami.