Slope movements in Slovakia- geographic and geological characteristics

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Slope movements in Slovakia– geographic and geological characteristics

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Problems caused by slope movements are the most dangerous geodynamics phenomenon in the Slovak Republic. Primarily they destroy the utility values of the exposed areas, i.e. devastate grassy and forest vegetation, farmland fund and also destroy man–made constructions which are mainly roads, railways, buildings and other important installations constructions.

In this paper the slope movement processes in the Slovak Carpathian are described with the relation to geographic and geological subdivision. The regional engineering part and slope movement's parts are quoted from Matula, Pašek (1986) and Nemčok (1982), respectively.

INTRODUCTION

According to the last data (Liščák, Caudt, 1997) nearly 15,000 slope deformations are registered, which represent about 3.7% of the entire area of Slovakia. They cover about 1,820 km^2. In some areas, however slope deformations disturb more than 60% of the total territory surface (Petro, Polaščinová, Wagner, 1999).

Due to rapid development of the infrastructures, which requires utilization of the affected areas and also by increasing number of destructive landslides, systematic study and monitoring of the natural phenomena gave rise.

PHYSICO–GEOGRAPHICAL CONDITION

Slovakia is situated in Central Europe between the longitude of 16° 50' to 22° 34' east and the latitude of 47° 44' to 49° 37' north, and occupies mainly the Western Carpathian Mountains and the northern parts of the Pannonian basin. The total area is 49,036 km^2. The altitude above the sea level (*a.s.l.*) ranges from 95 m in Bodrog to 2,655 m in Gerlach, the highest peak of High Tatra Mts. The Danube drains practically from the whole area to the Black sea. Only a small part is drained to the Baltic Sea by tributaries of the Visla river.

The climate in Slovakia is continental, with four distinct seasons. Summers are typically hot and humid, while winters are cold and dry. The coldest month is January with average minimum temperature from −1 to −3 °C in the lowlands and −11 °C on the

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highest peaks of High Tatra Mts. The warmest month is July with average maximum temperature from 18 to 20 °C in the lowlands and about 3 °C at the peaks of High Tatra Mts.

Average annual precipitation in Slovakia is about 780 mm, which ranges from about 500 mm in the middle of Podunajská basin to more than 1500 mm on the highest peaks of High Tatra Mts.

GEOLOGICAL AND GEOMORPHOLOGIC DEVELOPMENT OF THE SLOVAK PART OF WEST CARPATHIANS

The principal structural features of the Slovak Carpathians are the results of Alpine mountain– forming process, which took place in the Cretaceous and Tertiary. These processes formed an arcuate mega–anticlinorium mountain range, folded on the northern border of the alpine geosyncline area. It is a typical zonal mountain range.

The West Carpathians are differentiated into two groups according to the stratigraphic criteria: Outer, non–alpine nappes and Inner, before Paleogene structures.

The fundamental geomorphic features of the Slovak Carpathians are the reflection of the Pliocene development phase during which individual ranges developed as macrorelief of geomorphologic unit. The geomorphological development during the Quaternary is connected with the Pliocene phase of development of the topography and is characterized by the formation of microrelief of smaller morphological forms.

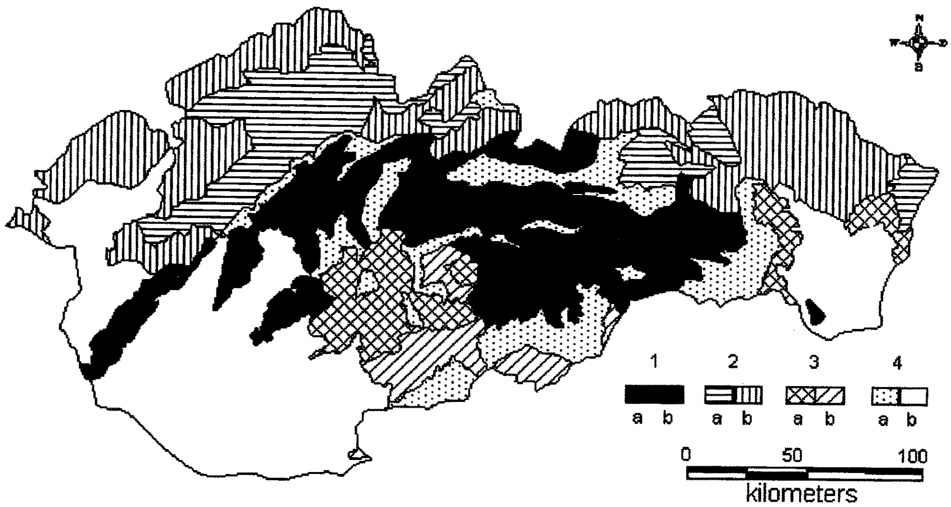

Fig. 1. Map of engineering–geological zones after Matula (1969) 1–REGION OF CORE MOUNTAINS: 1–a High Core Mountains, 1–b Middle Core Mountains. 2–REGION OF CARPATHIAN FLYSH: 2–a Flysh Highlands, 2–b Flysh Uplands, 3–REGION OF NEOGENE VOLCANITES: 3–a Neogene Volcanite Highlands, 3–b Neogene Volcanite Uplands, 4–REGION OF NEOGENE TECTONIC DEPRESSIONS: 4–a Intracarpathian Basins, 4–b Intramountain Basins.

Table 1. The geologic and the engineering geologic areas in the Slovak Carpathians

The Engineering Geologic Classification of the Slovak Carpathias by Matula (1969) Regions	Sub–regions	*The Geologic Classification of the Slovak Carpathias by Biely et al. (1996)*
Carpathian Flysh	Flysh Highlands Flysh Uplands	THE OUTER CARPATIANS Flysh Belt Klippen Belt
Core Mountain	High Core Mountains Middle Core Mountains	THE INNER CARPATIANS Tatricum, Veporicum, Fatricum, Zemplinicum, Hronicum, Gemericum, Meliaticum, Turnaicum, Silicicum
Neogenne Tectonic Depressions	Intracarpathian Basins Intramountain Basins Carpathian Foredeep Depression	Inner Carpathian Paleogene Neogene Basins
Neogene Volcanics	Neogene Volcanite Highlands Neogene Volcanite Uplands	Neogene Volcanics

The topography forming processes and slope movements have been developed in various geomorphic units and reflect the regional peculiarities of the various areas. Therefore it is necessary to link the types of slope movements with the areas that have similar geologic–tectonic structure and similar geomorphologic development.

Taking into account the criteria of homogeneity of geologic–tectonic structures and of macrorelief, Matula (1969) sub–divided the Slovak Carpathians into the four engineering–geological regions. The regions are further divided according to the criterion homogeneous macro– and meso– shapes of the surface and similarities of basic features of geomorphologic development into the nine engineering–geological sub–regions. A graphical illustration of the regions and the sub–regions are shown in Figure 1, and their comprehensive distribution with corresponding to geological areas are classified in Table 1.

SLOPE MOVEMENTS AND FACTORS OF THEIR DEVELOPMENT IN THE SLOVAK CARPATHIANS

According to Nemčok, Pašek and Rybář (1974) classification system, the slope movements depending on the type of movement, resulting failures and velocity of movement are divided into the four categories: creep, sliding, flow and fall. Landslides are the most common slope failures in Slovakia, rock falls and debris flows are also frequent. The slope failures have been developed abundantly in areas where sufficiently unfavorable properties of rocks, relief and river net as well as precipitation form in complex combination the optimum conditions for the slide causing factors. The intensity and distribution of the slope movements in the Slovak Carpathian are drawn in Figure 2.

Brunsden (1993) subdivided causes of different landslide types into three categories: preparatory, sustaining and triggering (Dikau *et al.*, 1996). According to this classification the most frequent preparatory mechanisms in Slovakia are: erosion–accumulation process, particularly river erosion, weathering of rock exposed in slopes, shocks and

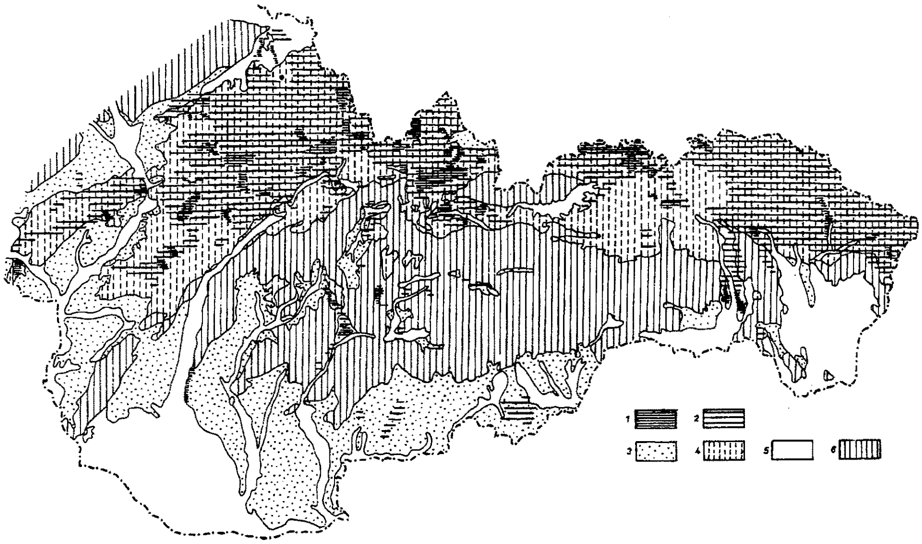

Fig. 2. Distribution and intensity of the slope movements in the Slovak Carpathians after Matula (1969): 1–heavily affected areas, 2–areas with considerable occurrence of the slope movements, 3–areas with favorable lithological conditions, unconsolidated cohesive soils, for development of the slope movement, 4–areas with suitable properties of rocks and geomorphological conditions, weak rocks and flysh types of rocks, for development of slope movements, 5–areas where properties of rocks, thicker strata of gravels and sands, and geomorphological conditions are not favorable for the development of the slope processes, 6–areas formed by hard rock and strongly consolidated shales.

vibrations caused from the ground destructions and also by seismic activity. The most common trigger mechanisms are: climatic factors of rainfall, snow melting and temperature anomalies, and geometrical changes of slopes like as surcharge on ridge and undercutting at foot.

CHARACTERIZATION OF THE SLOPE MOVEMENTS IN THE SLOVAK CARPATHIANS RELATED WITH THE ENGINEERING GEOLOGICAL REGIONS

Region of the Carpathian Flysh

The region of the Carpathian Flysh forms a continuous belt at the external margin of the West Carpathians so–called as Flysh and Klippen belts and reaches deep into the Central Carpathians. This region is generally known as the area of intensive development of slope movements. Although the flysh represents only 20% of the area of Slovakia, about 50% of the all slope failures were registered there (Malgot, Baliak, 1996a).

Lithological character is simple and monotonous, dominated are Mesozoic and Paleozoic rock complexes of the flysh formation, and most spread of them is typical

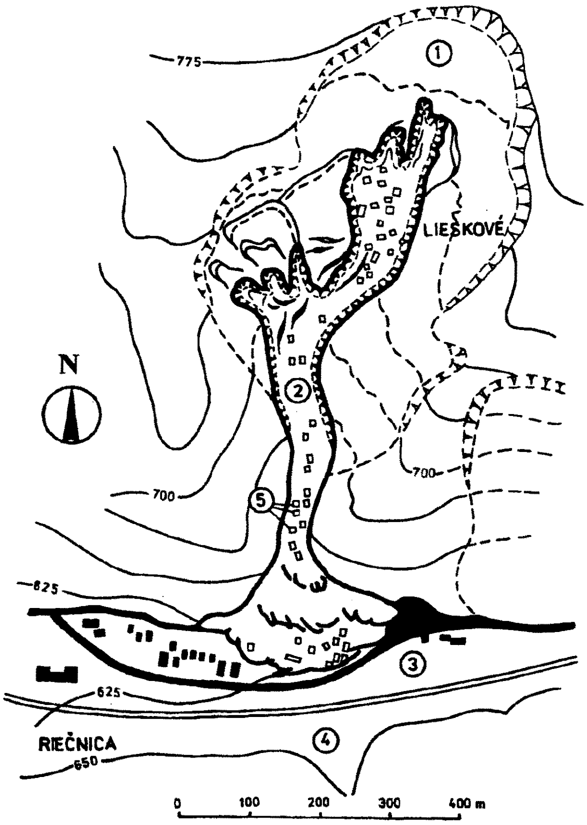

Fig. 3. A map of the catastrophic earthflow near Riečnica village (by Řepka in Nemčok 1982) 1–an old landslide of surface deposits on marly shales and sandstones, 2–the reactivated earthflow, 3–a lake, 4–a new riverbed, 5–scattered and deformed houses.

rhythmical structures of claystone and sandstone terrigenous flysh. The sub–region Klippen Belt has most complicated tectonic structure in West Carpathians.

Geomorphologic conditions

The Flysh Highlands are the most uplifted parts of the Carpathian Flysh as their top ridges raise the elevation of 1,000 to 1,200 m *a.s.l.* The flysh topography was formed during the Quaternary by stream erosion and periglacial activity. This process resulted in a dissected topography with relief energy of 150–500 m. The areas of Flysh Uplands are less uplifted and morphologically are foothills of Flysh Highlands or individual uplifts. Their relief ranging 500 to 1,200 m a.s.l. is very monotonous, characterized by gentle

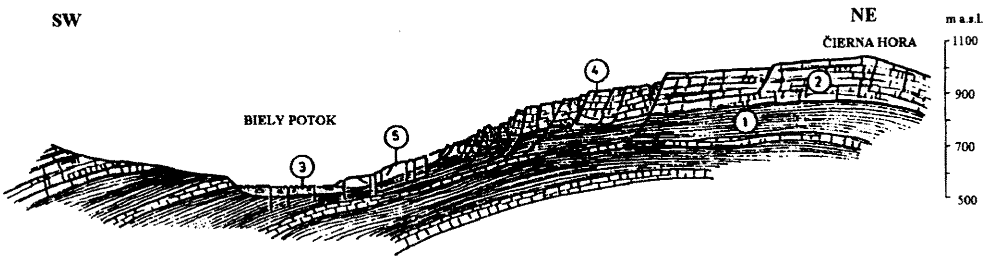

Fig. 4. A profile through the ridge of the Čierna hora Mt. near Tichý potok village (Nemčok, 1982). 1–claystones with interlayers of sandstones, 2–sandstones with interlayers of claystones, 3–fluvial deposits, 4–block rifts and a block field, 5–landslides, abbreviation m.n.m express meters above the sea level.

slopes and broad ridges. The local relief is lower here ranging 30–300 m relative.

According to Janova (2000) development of the slope failures in the region of Carpathian flysh depends much more on the degree of tectonic reworking and the presence of coarse deluvial sediments than the rock lithology and geomorphological setting.

Types of slope movements

Slope movements are the most typical exogenous geodynamic processes in the areas of Flysh Uplands, where various types of slope failures are abundant. Among them *creep, sliding and flow* of the surface, and near–surface layers prevail. At present also the old landslides are reactivated, that is mainly caused by deep erosion, gradual surcharge of slope, rainfall and temperature anomalies. For example, Figure 3 shows earthflow, which is approximately 1 km long, 35–150 m wide and maximum 15 m deep, and reactivated along an old landslide during the heavy rains in June 1962 near Riečnice village.

Slope failures occur rarely in the central ridges of the Flysh Highlands. A typical example of *deep–seated creep failure* with subsequent transformation to various types of slope deformations developed near Tichý potok village (Figure 4). An area of failure is approximately 2,900 m × 3,600 m and the maximum depth is 150–200 m.

Region of Neogene Volcanic

The region of Neogene volcanic is located mainly in central and eastern Slovakia. Volcanic activity occurred in several centers and in several phases with greatest intensity in the Tortonian and Sarmatian, and resulted in a system of stratovolcanes and independent lava bodies.

Various types of slope movements occur on the margins of volcanic ranges where rigid volcanic material, predominantly andesites and their pyroclastics, rhyolites, basalts lie on plastic strata, Paleogene pelitic and aleuric shales and weakly consolidated fine–grained strata of Neogene composed of clayey–silty–sand rocks.

In the Volcanic Uplands thick complexes of 200–300 m of volcanic tuffs and tuffities sub–horizontally lying in Old Miocene and Pliocene clayey–sandy sediments form the bedrock, and also in some places various andesite and basalt are ejected and distributed.

Geomorphologic conditions

Present relief of the Volcanic Highlands represents only the bottom parts of stratovolcanes with the maximum altitude of 900 to 1,460 m *a.s.l.* The relief was formed by neotectonic movements with uplift–subsidence, intensive erosion–denudation processes and slope movements.

The relief in the Volcanic Highlands is very young and intensively structured with energy of 150 to 600 m relative relief, while in the Volcanic Uplands is smooth modeled with lesser energy of 30 to 80 m in relative relief.

The greatest area and intensity of slope movements is in the margins of volcanic areas whose slopes face steeply into young, tectonically based, erosive–denudation depressions and valleys.

Types of slope movements

Various types of slope movements developed here, the most characteristics are *block types of failures* appear as block disintegration and block fields. The whole process is generally slow and long term last, but sometimes *sliding of blocks* may occur. *Sliding* and the resulting forms– *landslides* represent another type of mass movement occurring frequently in the margins of volcanic areas. Sliding develops from *surficial creep* failures as a result of climatic seasonal anomalies. Sliding often transfers into *flow*, and a combination of these processes is quite frequent in this area. Also *deep–seated creep* on the margins of the Volcanic Highlands is common and can transforms into *rockfall* in some areas.

Figure 5 shows a geological cross–section through Handlová basin, where the catastrophic landslide occurred (in the periods 1960–1961 and 1969–1970) and caused

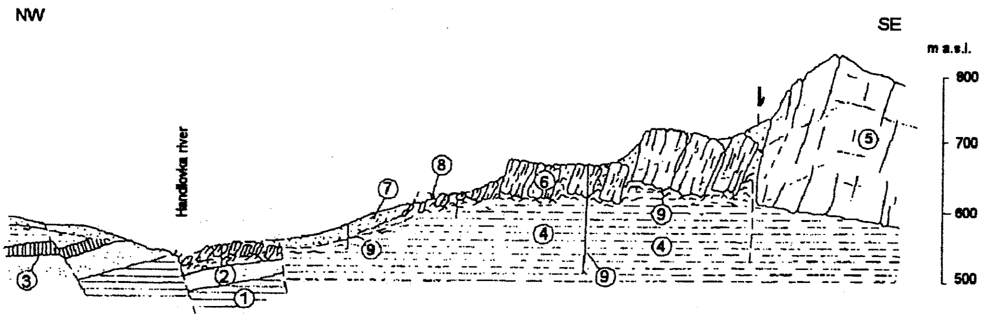

Fig. 5. Geological cross–section through Handlová basin (Rybár, Nemčok 1968). 1–clayey and marly shales, sandstones, 2–psamitic and psefitic tuffs, 3–coal bearing series, 4–claystones, 5–andesite, agglomerate tuffs, 6–block type deformation, 7–landslides, 8–creeping zone, 9–boreholes.

numerous damages. Hard and rigid volcanic rocks rest upon Paleogene and Neogene clayey rocks. The block type failures like block rifts, block fields and areal landslides are predominant, flow slides are less frequent (Malgot, Baliak, 1996b).

Region of Neogenne Tectonic Depressions

The mountain ranges of the Carpathian mega–anticlinorium are separated by Intramountain basins, which are the results of differential uplift during the Pleistocene and Quaternary periods. The basins are filled with Tertiary strata of flysh formation composed of sandstones, shales and conglomerates, with the Molasse formation of sandy–clayey sequences, gravels and tuffities etc. and Quaternary sediments. The beds lie horizontally or in flat folds and are dissected by longitudinal and transverse faults.

Areas of the Intracarpathian basins represent the northern points of extensive Neogene basins of subsidence, filled with Tertiary marine sediments which maximum thickness is about 5,000 m. Areas of the Carpathian foredeep depression are filled with molassoid sediments formed on the outer periphery of the West Carpathian.

Geomorphic conditions

The Intramountain basins are characterized by a hilly topography with flat and wide ridges and hills having moderate, sometimes step–like slopes. Local relief is 30–200 m relative relief. In the areas of the Intracarpathian basins, a considerably leveled relief was formed and further dissected by partly intensive erosion and periglacial solifluction. Differences in the local topography vary within 30 to 80 m. The relief of moderate uplands with flat hills and slopes were formed in the areas of the Carpathian foredeep depression.

Types of slope movements

Most of the geodynamics processes are localized in the areas of Intramountain basins, where slope failures have a great significance, because majority of the population, industries, communication networks are concentrated. Abundant existence of the slope failures is due to the geological structures characterized by two complexes with differences in the physico–mechanical properties that are the lower soft complex of Neogene clays or weathered Paleogene of the flysh substrata, and the upper harder complex of coarse lake–fluvial gravels and sands deposits or the material from the periglacial fans (Matula,

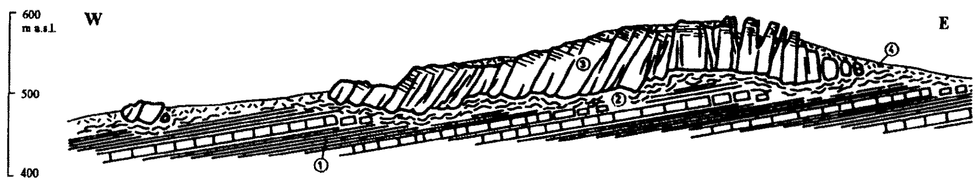

Fig. 6. A profile through the Dreveník Mt. (Nemčok, 1982). 1–sandstone and marly claystones of Central Carpathian Flysh, 2–fragments of sandstones and travertines and sandy loams–the shear zone, 3–block rifts and a block field from travertine blocks, 4–slope debris.

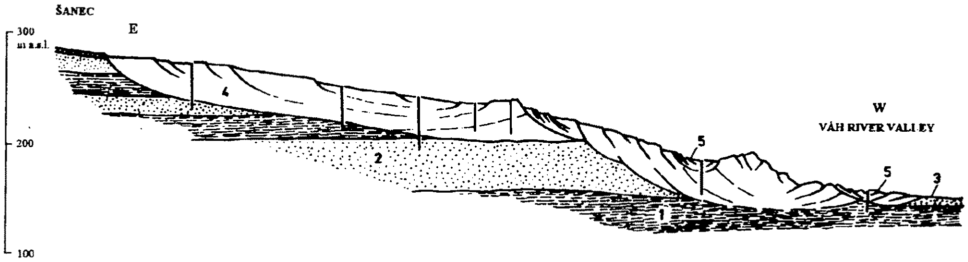

Fig. 7. A profile through a slope failure in the west slope of the Sanec Mt. near Hlohovec town (Otepka in Nemčok, 1982) 1–clays, 2–sands, 3–fluvial deposits, 4–intermittent landslide, 5–active landslides.

Pasek, 1986).

The most frequent types are *areal and stream–like landslides* caused by intensive deep and lateral stream erosion. A very typical phenomenon in the flat slope depressions filled with thick Quaternary loamy deposits is a *surficial creep.*

Deep–seated creep affecting the travertine mounds developed in Dreveník Mt. in Hornádska kotlina basin which profile is shown in Figure 6. In areas of the Intracarpathian basins the slopes of lowlands are rarely formed by slope movements. *Frontal landslides* are predominant types of the slope failure.

System of the slope failures between Hlohovec town and Sered' town is a unique landslide area in the sub–region of the Intramountain basins as shown in Figure 7. This large scale landslide area is composed of some individual landslides. Total width of the failure is 18 km with maximum length of individual landslides to 800 m. Predominate types are frontal landslides caused by a lateral erosion of the Váh river.

Region of the Core Mountains

The Core mountains are spatially most extensive mountain range in the Slovak Carpathians. They cover central parts of the area and are characterized by different rock complexes and complicated tectonic structure marked by various tectonical styles. The cores ranges are represented by Precambrian metamorphic rocks of gneisses, migmatites, phyllites, amphibolites and mica schists and Hercynian granites rocks, which are overlaying by Mesozoic and late Paleozoic sedimentary rocks of limestones, dolomites, quartzites and shales.

Geomorphologic conditions

In the sub–region of High Core mountains, high relief with steep slopes and deep valleys was formed by neotectonic uplift affected by glacial and fluvial erosion. The relative relief is up to 500– 850 m and more than 20 peaks reach over than 2,500 meters in elevation. Mountains glaciers eroded the highest ranges, where typical glacial forms are common, while in lower parts without mountain glaciers, flat and periglacial processes modeled rounded relief.

The Middle Core mountains differ from the sub–region of the High Core mountain by a lower relief of 150 to 550 m and relief structure. Beside young tectonic movements, the greatest part in the relief formation was' played by water erosion and spread karst processes.

Types of slope movements

Different forms of the slope failures were developed at the region of Core mountains according to the variety of geological units. The slope failures are common mainly in the areas of the High Core mountains, while they are rare in the areas of the Middle Core mountains.

Slope movements have a specific nature in this region. There is an example of *deep–seated creep* of rock massif, which cause slope failures to depth of 250–300 m and disintegration of mountain ridges. The ridge of Smerek in Tatra Mts. is an example. A length of the failure along the ridge is 1,700 m and a depth 200–250 m as shown in Figure 8.

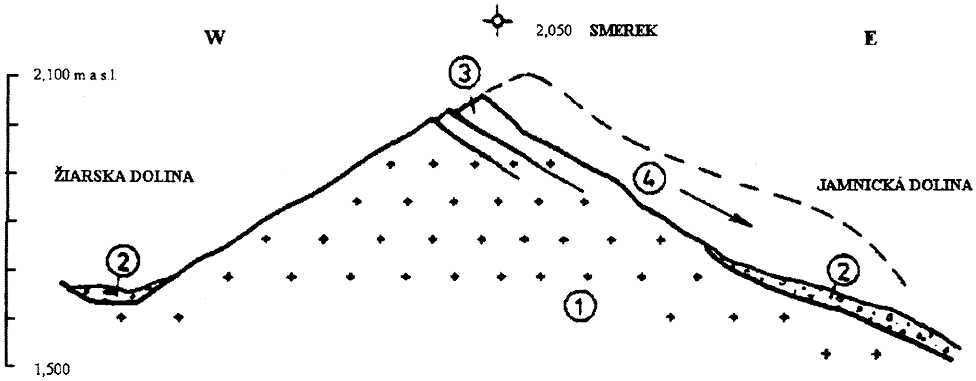

Fig. 8. A profile through the ridge of Smerek Mt. (by Nemčok, 1982). 1–paragneisses 2–glacial deposits, 3–remains of shifted blocks, 4–a shape of the past failure

The deep–seated creep, which is common particularly in the areas of metamorphic and granitic rocks, is accompanied with numerous *rockfalls* and *falling of fragments. The rock flows* are also frequent, which results in *stream–like deposits* typical of *debris flow*. *Rock glaciers* form conspicuous deposits and *surficial creeping of talus cones* below rock walls are frequent in areas of granites rocks. The largest rock glacier in Slovakia is in Roháčska valley in Tatras, its length is 1,950 m, average width 150 m in the upper parts and 350 m in the lower parts. At the areas of Mesozoic sedimentary rocks the slope movements developed in slopes and ridges where thick–bedded and massive complexes of limestones or dolomites rest in stratigraphic and tectonic superposition on plastic complexes composed of schistose beds.

FUTURE DIRECTION OF LANDSLIDE INVENTORY

At the beginning, problems of slope movements were studied only occasionally as a part of the process of basic geological, geomorphological studies and also related with some construction works. Systematic and methodically uniformly elaborated surveys of the slope movement have been carried out in Slovakia since 1962. Catastrophic Handlovà landslide was turning point in importance of study and understanding slope movements' phenomena. The first step of the systematic research was general registration of slope movements. That project was later gradually changed into evaluation of important landslide areas. An inventory of slope failures with continuous updating was done next in several stages. Subsequently a detailed study of selected slope deformation areas started and is continuing up to present (Wagner et al., 2000).

The investigation showed that extension of slope failures depend on the geologic structures predisposing to the origin and development of slope movement, geomorphologic, hydrological and climatic conditions and also in some areas by negative human interventions. Completion the slope failures inventory for the entire country is a long–term plan for landslide studies in Slovakia. (Wagner et al., 2000).

TERMINOLOGY

Areal shaped landslide is a type of landslide where its width and length are almost same.
Block type of failure, in Japanese literature type Hokusho, developed on the margins of volcanic tables, which are fractured and disintegrated into a mosaic of larger or smaller units, gradually still more separated and displaced from the main mass.
Creep is a slow and long–continued movement of a rock or soil caused by shearing forces due to gravitation and seasonal changes.
Deep–seated creep is a slow and long continuing slope movement affecting a rock mass of hundreds meters depths, developed exclusively by shear forces derived from gravitation.
Disintegration of mountain ridges is the result of deep–seated, plastic deformation in a rock mass, leading to extension at the surface, widespread in all the mountain ranges of the earth.
Fall is very rapid, expressed in m/s, gravitational movement of masses and single fragments on steep rock slopes.
Flow is a relatively rapid, expressed in meters per minute, gravitational movement of masses along a slope. The moving masses involve any kind of material, which is available and may be therefore divided into rockflow, debrisflow and soilflow which is earthflow or mudflow.
Frontal landslide is a landslide where its width is multiple times longer than a length.
Rock glaciers developed in high mountain areas with cold climates is a term for movement of stone fragments and boulders with a matrix interstitial ice. This process is a part of surficial creep.
Sliding is a relatively rapid, lasting some days to several months, gravitational movement of material on a slope, along a recognizable shear surface. The results of sliding are landslides.
Slope failures are the resulted forms of the slope movement process.

Slope movements are gravitational movements of masses from higher position to lower one with the exception of movement where the material is carried away by transporting media. The slope movement term is used to replace word landslide, as used in general sense.

Stream–like landslide is a landslide where its length is multiple times longer than a width.

Surficial creep is a slow uniform mass movement in the surface zone of a rock or soil mass, induced by shear forces derived partly from gravitation, partly from seasonal processes.

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