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PRESENT-DAY PROCESSES AND MICRO-LANDFORMS EVALUATION; CASE STUDY OF KOPSKÉ SEDLO, THE TATRA MTS, SLOVAKIA

The depression of Kopské sedlo (wide about 400 m) originated in one of the most important faults of the Eastern Tatra Mts. It forms the geological and geomorphological border between the Belianske Tatra Mts and the High Tatra Mts as well as a border between the Zadné and Predné Med'odoly valleys. In principle it is a wide depression (Phot. 1), that defines two cols — passes Kopské sedlo (1776 m a.s.l.) and Med'odolské sedlo (1749 m a.s.l.), common called as Kopské sedlo col (Fig. 1, Phot. 2).

Phot. 1. Broad depression of Kopské sedlo col (pass) separating the High Tatra (behind) from the Belianske Tatra (in front of white interrupted line)

Fot. 1. Szerokie obniżenie Przełęczy pod Kopą oddzielające Tatry Wysokie (z tyłu) od Tatr Bielskich (przed linią przerywaną)

Phot. 2. Bottom of Kopské sedlo with view of many erosion and accumulation microlandforms
Fot. 2. Centralna część Przełęczy pod Kopą z widocznym mikroreliefem form erozyjnych i akumulacyjnych

GEOLOGICAL SETTING OF THE STUDY AREA

The geological construction of this area is very complicated, because from the viewpoint of the stratigraphy of Mesozoic series there are many rocks of Triassic, Jurassic and Cretaceous Systems (Fusán *et al.* 1963). In the wider area of Kopské sedlo from the south there start to form Lower Trias quartzites with in some parts of conglomerates and also slates. In the northern direction this belt of 200–300 m is conterminous to a belt of gay slates of almost equal wide (150–300 m), going from the southern slope of Mt Belianska kopa (1832 m) to the end of the Zadné Med'odoly valley. Precisely in this gay slates the most typical destructive micro-forms of relief are created at the present in the Kopské sedlo (Fig. 2).

Dark limestones, dolomite limestones and dolomites from the Middle Triassic border only a small area on the south-eastern part of Kopské sedlo, in the Zadné Med'odoly valley they cover most of the area as to the Javorová dolina valley. From the Middle Triassic ascend also dolomites from the period of Ladinian-Karnian on the north-western side from Med'odolské

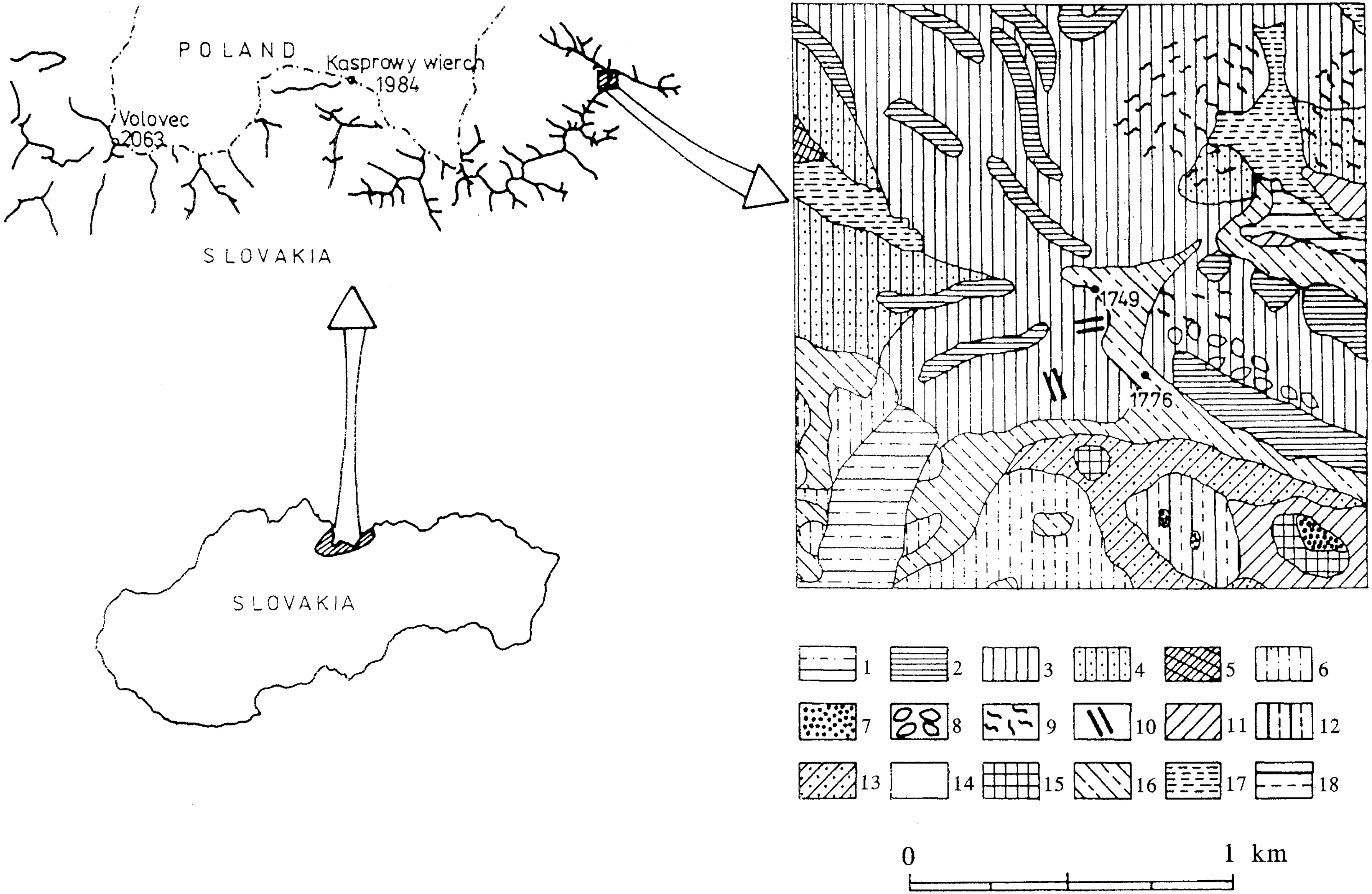


Fig. 1. Location map of study area and fragment of geomorphological map of Kopské sedlo depression in the Tatra Mountains (according to Lukniš 1973, slightly modified). 1 — cliff relief on granodiorite, 2 — cliff relief on a stabile Mesozoic bedrock, 3 — smooth relief on Mesozoic bedrock in periglacial processes area, 4 — smooth relief on Mesozoic bedrock out of periglacial processes, 5 — smooth denuded relief with erratic boulders, 6 — rundhöcker, 7 — erosive lake basin, 8 — rugged ridge and frost scar, 9 — solifluction, 10 — non-sorted stripes, 11–13 — Late Würm moraines, 14 — firn moraine, 15 — basin filled by washing, 16 — blocks of fault space, 17 — debris flow/alluvial cone, 18 — fan and terrace (Würm)

Ryc. 1. Lokalizacja terenu badań i fragment mapy geomorfologicznej Przełęczy pod Kopą (wg Lukniš 1973, nieco zmienione). 1 — ściana skalna na granodiorytach, 2 — ściana skalna na stabilnym mezozoicznym podłożu, 3 — wygładzona rzeźba na podłożu mezozoicznym w strefie oddziaływania procesów peryglacjalnych, 4 — wygładzona rzeźba na podłożu mezozoicznym poza oddziaływaniem procesów peryglacjalnych, 5 — gładki zdenudowany relief z eratykami, 6 — barańce, 7 — erozyjne zagłębienia jeziorne, 8 — nierówne grzbiety i krawędzie mrozowe, 9 — formy soliflukcyjne, 10 — pasy kamieniste, niesortowane, 11–13 — moreny późnowistuliańskie, 14 — morena firnowa, 15 — zapłynięte zagłębienia terenowe, 16 — bloki w strefach uskoków, 17 — spływy gruzowe i stożki napływowe, 18 — stożki i terasy wistuliańskie

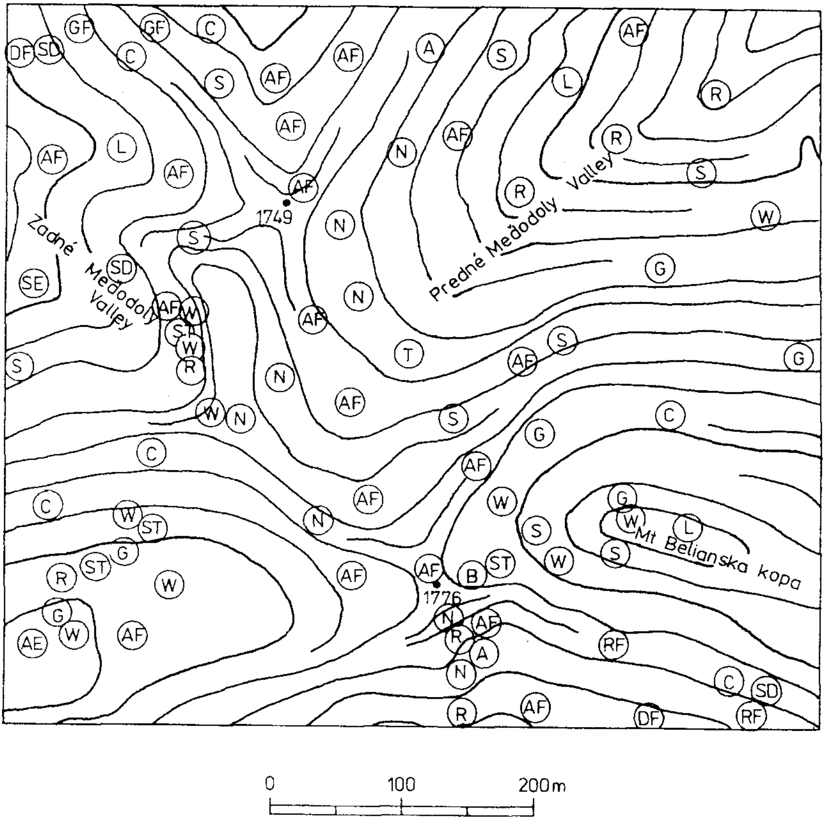


Fig. 2. Contour lines of Kopské sedlo pass. Symbols of morphogenetic phenomena and/or microlandforms with location of their occurrence. A — avalanches, AE — areal rainfall erosion, AF — anthropogenic forms of soil mantle destruction, B — bald spot soils, C — creeping, DF — debris flow, G — garlands, GF — gravel formation from rockfall, L — landslides, N — nivation, R — rills and gullies, RF — rockfall, S — solifluction, SD — slip of debris, SE — stream erosion (fluvial), ST — stripes, T — thufurs, W — wind erosion

Ryc. 2. Układ poziomic na Przełęczy pod Kopą. Symbole oznaczają procesy lub mikroformy z lokalizacją ich występowania. A — lawiny, AE — spłukiwanie powierzchniowe, AF — formy antropogeniczne i zniszczenia pokrywy glebowej, B — miejsca pozbawione gleby, C — spełzywanie, DF — spływy gruzowe, G — wieńce kamieniste, GF — formowanie hałd z odpadania, L — osuwiska, N — niwacja, R — żłobiny i rynny, RF — odpadanie, S — soliflukcja, SD — pełznięcie gruzu, SE — erozja fluwialna, ST — pasy kamieniste, T — tufury, W — erozja wiatrowa

sedlo beneath Mt Hlúpy vrch (2060 m), Mt Ždiarska vidla (2146 m), Mt Havran (2151 m) to Mt Muráň (1889 m). Although the Upper-Triassic belt from the period Norian-Carpathian Keuper covers a smaller area, geomorphologically seen it is more important. This belt is formed by gay slates, quartzites sandstones and interstratified beds of dolomites. It is reaches Kopské sedlo from the east and in it lies not only the northern part of Mt Belianska kopa, but also the end of the Predné Med'odoly valley under Mt

Hlúpy vrch. This part is also formed by Jurassic dark slates, sandy limestones, sandstones and quartzites. Merlites and limestones from the Lotharing-Toarcian period in the depression of Kopské sedlo (100-300 m deep) was eroded already formerly.

It concerns a very divers mixture of rocks, often with contradictionary resistence against the effect of relief-forming processes. This is reflected also in the diversity of meso- and especially micro-landforms in this area.

GEOMORPHIC SETTING

From the geomorphological map (Fig. 1) of Lukniš (1973) results that:

— in the depression a smooth, and on adjoining slopes also cliff, relief was formed as well as talus cones and block landslides (about their inclination towards their arising especially on loamy weathering products of Keuper in the Belianske Tatra Mts also writes Andrusov 1959);

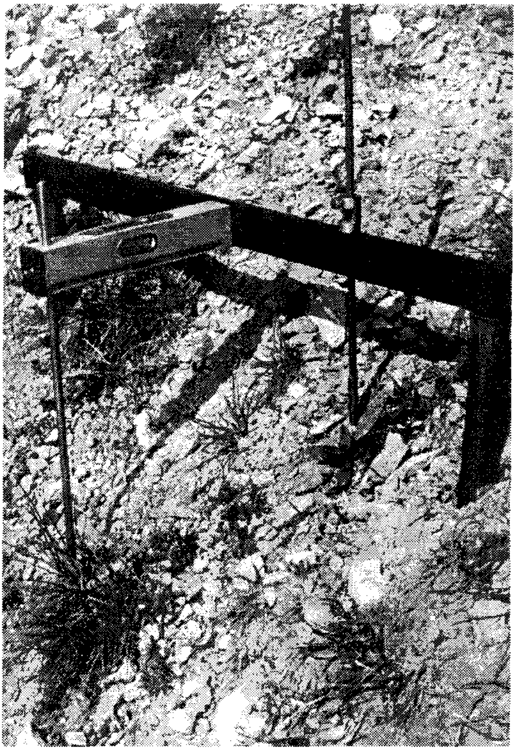
— on Mt Belianska kopa it concerns also gravitation deformation and on its side towards the col from microforms it concerns stripes patterned grounds and solifluction terraces.

Especially in the micro-relief of Kopské sedlo depression and its surroundings a much richer pallet of landforms is found, that is typical for the present development of the surface (Fig. 2) This is described more detailed in other author's papers (Midriak 1972a, b). The forms are a result of water-erosion, gravitation, eolian, nivation, cryogenic, organogenic and especially anthropogenic processes, speed up by intensive destruction through water, wind, snow and frost. The next part of the paper deals with these processes in quantification and/or rate. It is necessary to stress, however, that most of the processes occur in mutual combination.

RESEARCH METHODS

In the last 30 years we established an amount of permanent and temporary plots in Kopské sedlo and its surroundings for research and monitoring of the present-day morphogenetic processes and their resulting forms.

We applicated micro-levelling (Phot. 3), translocal, volumetrical, weighing, deluometrical, deflametrical, pedological, geomorphological, mapping, cartometrical, geological, hydrological, microclimatical, vegetation, fotogrammetrical and historical methods. Some of them are original, developed during research, others are described by several authors (especially Rapp 1962, Gerlach 1964, Kotarba 1970, Washburn 1979, Zachar 1982, Midriak 1983 and others).



Phot. 3. Micro-levelling gauge for measurement of a surface change due to erosion or/and accumulation

Fot. 3. Instalacja do pomiaru zmian powierzchni gruntu wskutek erozji i akumulacji

PRESENT-DAY GEOMORPHIC PROCESSES IN THE AREA OF KOPSKÉ SEDLO

WATER PROCESSES

In spite of the fact, that the higher part of the Belianske Tatra Mts belongs to the cryonival belt with plentiful cryogenic processes, water processes are the most important for the recent development of the surface in this area. The niveopluvial and the pluvial climatical-morphogenetical period (according to Kłapa 1975), when there can theoretically be surface runoff effects, lasts around 43% of the days yearly (159 days). In spite of that the above mentioned author assumes washing only during 42 days a year (also in the pluvio-nival period). In our opinion this is too few.

The larger part of Kopské sedlo depression is threatened by the 5th (according to classification of Zachar 1982) level of potential erosion due to surface runoff with a very strong soil losses of 5 to 15 mm a year, and a smaller part of the flat bottom is threatened by the 4th level, with strong potential soil losses of 1.5 do 5 $mm.yr^{-1}$. If we look more detailed, there are places (on very steep slopes) where the surface is threatened even catastrophically, with possible soil losses of more than 15 $mm.yr^{-1}$.

On the naked surface of the SW slope (inclination of 35°) of Mt Belianska kopa, with dolomite crumbles in the wider rill, there is an annual loss of surface water of 343 $m^3.ha^{-1}$. This leads to a lowering of the slope through denudation of a layer of 2.6 to 5.6 mm (with an average of 3.58 $mm.yr^{-1}$). Under Mt Jahňací štít on stripped loamy soils there is a runoff of 861 $m^3.ha^{-1}.yr^{-1}$ on slopes of 27° and soil losses of 1.9 to 2.2 $mm.yr^{-1}$. In the middle of Med'odolské sedlo col in stripped rills on gay slates and sandstones (on a slope of 30°) we measured an average surface runoff of 679 $m^3.ha^{-1}.yr^{-1}$ and a lowering of bottom of 0.7 to 2.8 mm (on an average 1.67 $mm.yr^{-1}$).

In years with heavy downpours (on the average around once in 6 to 15 years) there are temperately created 3 to 20 cm deep cascade rills with sedimentation sections on the bottom of col gully cut in Kopské sedlo. These linear phenomena disappear fast, because they are buried by material which is moved by gravitation and solifluction processes from gully walls.

During snow melting or heavy rainfall a turbidity of the surface runing water amounts to 0.12 to 7.28 $g.l^{-1}$! Water processes have to be attributed special importance at surface morphogenesis, because they have an overall effect and through transport they remove also free weathering material, that was temporary placed under the influence of other destructive processes (weathering, eolian, gravitational, nivational, cryogenic and anthropogenic processes).

GRAVITATION PROCESSES

This group of processes is very spreaded in the area of Kopské sedlo (especially landslides, rock falls, creeping, slip of debris, debris flows, avalanches etc.).

Through the fall of dolomite and dolomite-limestone litter on the SSW-SW slopes of Mt Belianska kopa and at the end of the Zadné Med'odoly valley we found a retreat of rock walls with an average rate of 0.003–0.019 $mm.yr^{-1}$ (in single years even 0.23–0.43 $mm.yr^{-1}$ and for instance from 1977 until 1980 no weathered particles fell at all). Among the rock litters prevail fractions with a diameter above 80 mm (56%) and above 50 mm (28%). Grains under 1 mm were represented only by 0.25%.

Slip of debris in gullies is often combined and spatial overlaps with debris flows, but in times when these very fast mass movements don't empty the gullies from the debris there also occurs frost creeping or frost slip of the superficial material.

In gullies on SW slopes of 35°–45° the rock debris with diameter from 3–5 to 15–20 cm were moved on the average distance of 0.59 m to 0.66 m per annum. Only 30% of rock debris stayed in their place.

Through scour of the surface, which is formed by weathered dolomite (with diameter of 0.5–1.5 cm) on the bottom of shallow gully with inclination of 35° we found out, that the lowering of the surface by moving snow is up to 42 mm a year!

The rate of creeping, that takes place on smooth slopes is similar to such which was measured by Kotarba (1976) on the Polish side of Czerwone Wierchy (1970 m a.s.l., WNW-slope with inclination of 30–43°) where an average movement of turf downslope amounts to 1.8 mm (max. 1.7 cm) per annum.

EOLIAN PROCESSES

For wind erosion processes are very favourable morphological conditions in the depression of Kopské sedlo where the anemo-morphological system (Jeník 1958) is formed. It concerns not only an occurrence of vegetation formations, but also eolian corrasion and deflation.

The both geomorphic processes are more expressively manifested especially in tangential parts of the relief (edges, the bottom of col, tourist paths etc.). By the activity of the processes (along with cryogenic ones) non-sorted stripes were formed (in front of Phot. 2) on the weathering material of dolomite-limestones. Their surface at maturity stage (inclination of 0 to 3°) is lowering on an average 0.50 to 2.22 $mm.yr^{-1}$.

Other form of eolian processes are eolian niches in the walls of col gullies. A rate of their lateral increase amounts to 1.86 to 4.74 cm yearly, on an average 2.35 $cm.yr^{-1}$. A grow lengthwise by a retrogradation of the col gully amounts to 6.1 cm (from 9 to 26 cm) per annum.

NIVATION PROCESSES

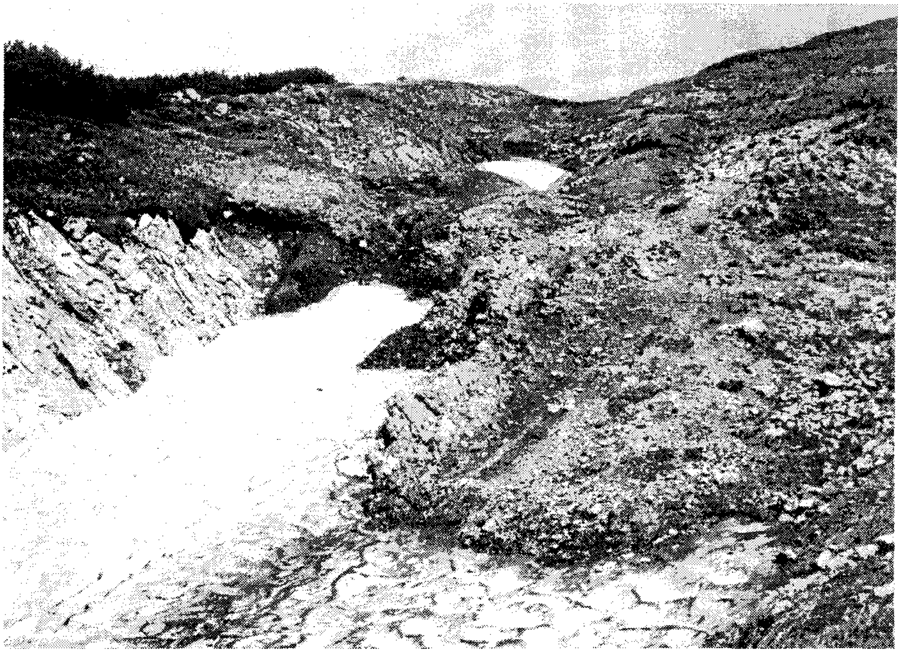
During winter snow drifts are formed behind of edge of Kopské sedlo depression. Their height amounts to up 10 m. The floor of nivation hollows wide of 50–80 m is plunged recently into bedrock about 0.5 to 1 m, on the slates up to 2 m.

An average vertical rate of plunging of the col gully beneath Kopské sedlo (Phot. 4) by nivation mostly during whole the Holocene amounts to about 1 $mm.yr^{-1}$. A contemporaneous rate of denudation of weathering products, however, is rather higher and it amounts to 3.12 to 39.52 $mm.yr^{-1}$ at smooth slopes of loamy erosive rests or 0.32 to 6.37 mm per annum (on an average 2.5 $mm.yr^{-1}$) such as nivation scratch of a smooth N-slope of Mt Belianska kopa on a dolomite-limestones and sandstones.

CRYOGENIC PROCESSES

A congelifraction of dolomite-limestone part of slopes in the surroundings Kopské sedlo col results a retreat of rock walls with rate of 0.003 to 0.019 mm yearly.

The freezing of soil with its heaving was observed up to 30 cm of depth (the Kopské sedlo depression on the side of Predné Med'odoly valley). A maximal heave of topsoil layer amounts to 39 mm and a maximal amplitude of



Phot. 4. Nivation landforms on the bottom of the gully in Kopské sedlo

Fot. 4. Formy niwacyjne w obrębie rynny wyciętej w Przełęczy pod Kopą

vertical movements up to 53 mm. These movements result both the soil cryoturbation and cryoplanation.

By combination of both needle ice solifluction and gelisaltation denuded walls of gullies were retreated about 17.86 to 29.85 mm yearly. Those are enormous amounts, but also fluvial activity, snow and wind have a part to play in transporting the material produced by frost action. On the wall of a tourist path beneath Kopské sedlo we have measured a retreat with soil losses of 3.64 mm. Needle ice as a destructive factor has formed three-layer formation there and loamy soil was removed during one-rotation regelation cycle (in this place there is an average of 111 regelation days yearly!).

Also a thufur field originated as a result of cryogenic morphogenesis in the wet part of Kopské sedlo depression during Sub-Atlantic period. Diameter of thufurs amounts to 1 m, their height during freezing is 0.7 m otherwise up to 0.6 m. Thufurs are inactive in the present. Gerlach (1972) on the Polish side of the Tatra Mts have measured vertical movements of the earth hummocks during freezing and thawing in range 45 mm.

ANTHROPOGENIC PROCESSES

Among these processes above all tourist paths are dominant in Kopské sedlo depression. Destruction of their surface is dependent on frequency of tourists. Tourist path spacing was increased of 10.4% during 10 years (1967–1976), an average increase of a wide of the paths amounts to 0.61 m and the enlargement of a total bare surface area amounts to 5.4% yearly. Lowering of the path surface amounts to 0.5 mm per annum.

COMPREHENSIVE EVALUATION OF THE GEOMORPHOLOGICAL DEVELOPMENT OF THE AREA OF KOPSKÉ SEDLO AND ITS SURROUNDINGS — DISCUSSION

The global evaluation of present-day geomorphic processes in the study area, and especially their comparison with the rate of the processes in the geological past longer ago, is a very complex task. This mainly, because the high montain landscape in the area of the Western Carpathians is of the fossil landscape structure type, that arose in the Pleistocene under different climatical conditions. This was not only the case with the basic relief forms, but also with slope deposits and soils, whose age is much higher then until not long ago was assummed (Šály 1986). That is why processes, that operate at the moment, intensively change the surface of this landscape. Its homeostatic ability is quite small (Mazúr 1979).

The area of Kopské sedlo col as a whole was developed under periglacial conditions, although the southern slope of Mt Belianska kopa, today a mighty gully beneath Kopské sedlo into Biely potok valley, and Predné Med'odoly valley were unconditionally influenced by the Würm glaciation (see also the map in Lukniš 1973). This stimulated a different disposition of bedrocks or weathering material for further destructive processes.

Another difficulty, that prevents unambigious definition of separate present-day morphogenetic processes as the most important of the whole set of processes, resides in the fact, that separate exogenetic factors don't act only succesively, but also parallel (water–snow, snow–ice–wind etc.) at one place. At exact research of the rate of present-day relief-forming processes most of all the problem of separation of singular processes, that with the until now used methods can not be secured, stands out.

Thus reliable data from direct measurements are only those, that are usually presenting the integrated rate of several processes, which result the lowering of the surface or retreat of rock walls.

In the case of cliff relief, created in the surroundings of Kopské sedlo mainly on dolomite limestones and dolomites the average retreat of rock walls vary from several thousands to several tenths of mm a year, (these data are similar to those from the Polish side of the Tatra Mts, although an average rate is a higher according to Kotarba 1976). The result of these processes are mainly found in the creation of debris, that are moveable, and thus the growth processes of the vegetation on the surface (usually from marginal lines) don't have a high enough intensity to stabilize.

In the area of Kopské sedlo the local bare areas in gullies and rills are very intensively lowered and also on the bottom of nivation depressions, where the lowering takes place with a rate of some milimetres to some centimetres a year. The result of the processes is gradual vertical of the mentioned landforms, weakening of the stability of its slopes and edges, from which material falls and is transported by water and wind.

If we take into account the processes connected with erosion activities of surface runoff, than the rate of lowering of the surface by water erosion (0.7–5.6 $mm.yr^{-1}$) convince us of the very high anti-erosion effect of herbaceous vegetation. The erosion threat in the depression of Kopské sedlo is 5 to 15 mm and in a smaller part (about 15–20%) 1.5 to 5 $mm.yr^{-1}$. This is the potential erosion, which would occur, when the surface would not be protected by any vegetation nor by anti-erosion measures. According to the measured real soil losses through water erosion on areas with permanent grass lands there is an average lowering of 0.01 to 0.03 $mm.yr^{-1}$ under similar conditions (Midriak 1983). This means, that the amount of soil losses through runoff is only 0.1 to 1.3% of the potential erosion in this places.

Anthropogenic processes we can count among the most dangerous forms from the viewpoint of relief development (in case of Kopské sedlo mainly tourist paths). The danger lies in the fact, that the effect of the anthropogenic factor in the form of direct destruction of the surface does not have to last during the whole period of destruction unlike the other destructive factors. It can give the impulse for the beginning of destructive processes or its speeding up and be absent in the next period of relief development, when primary factors (water, wind, frost and snow) continue the process. It can also lead to the origine of waste lands (Midriak 1983).

CONCLUSION

The area of Kopské sedlo has a complex geological construction, with tectonical movements and recent geomorphic development in a periglacial climate and at the present it is a very convenient object to study changes — rate and dynamics of morphogenesis. After long term monitoring of separate morphogenetical processes or their groups, it can form an important key to knowledge and/or creation of models of further development of the landforms under the influence of a combination of natural and anthropogenic factors in the high mountain environment.

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STRESZCZENIE

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WSPÓŁCZESNE PROCESY MORFOGENETYCZNE I CHARAKTERYSTYKA MIKRORZEŹBY PRZEŁĘCZY KOPSKÉ SEDLO (PRZEŁĘCZ POD KOPĄ) W TATRACH, SŁOWACJA

Przełęcz pod Kopą (1749–1776 m n.p.m.) rozdzielająca Tatry Bielskie i Tatry Wysokie jest założona w strefie uskoków tektonicznych. Posiada złożoną strukturę geologiczną. Budują ją głównie łupki i wapienie dolomityczne. Za współczesną morfologię przełęczy są odpowiedzialne procesy krioniwalne. W przedstawionej pracy analizowane są zespoły współczesnych procesów morfogenetycznych (procesy erozji wodnej, grawitacyjne, eoliczne, niwacyjne, kriogeniczne i antropogeniczne) zarówno pod względem jakościowym, jak i ilościowym. Dane zaprezentowane w pracy zebrano przy zastosowaniu różnych metod, a w szczególności bezpośrednich pomiarów w terenie oraz pomiarów stereofotogrametrycznych.

Dla skonstruowania geomorfologicznego modelu ewolucji form na przełęczy najważniejsze okazały się pomiary intensywności niektórych procesów. Stwierdzono, że średnie roczne wartości cofania ścian skalnych zbudowanych z dolomitów i wapieni dolomitycznych wynoszą 0,003–0,019 mm. Bardzo intensywnie przebiega proces obniżania powierzchni w żłobinach i rynnach rozcinających strefę przełęczy oraz w niszach niwacyjnych zwłaszcza założonych na łupkach. Denudacja w obrębie tych form wynosi od 0,5 do 42 mm w ciągu roku. Boczne cofanie zboczy rynien wynosi do 23,5 mm, a ich długość zwiększa się o 61 mm w ciągu roku.

Zagrożenie potencjalną erozją gleby przez spłukiwanie powierzchniowe wynosi od 5 do 15 mm/rok (tylko dla 15-20% powierzchni obliczono wartości rzędu 1,5 do 5mm/rok). Jednak rzeczywiste wartości usuniętej gleby wynoszą od 1,7 do 3,6 mm/rok na powierzchniach pozbawionych roślinności i 0,01 do 0,03 mm /rok na powierzchniach utrwalonych roślinnością murawową. Wartości rzeczywiste stanowią zaledwie 0,1 do 1,3% wskaźników erozji potencjalnej. Bardzo niebezpieczne dla stabilności środowiska wysokogórskiego są procesy degradacyjne związane z użytkowaniem turystycznym, a dawniej z pasterstwem.