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RIDGE-TOP TRENCHES AND RIFTS IN THE POLISH OUTER CARPATHIANS

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Abstract: In the Polish Outer Carpathians narrow and elongated depressions of various size occur on ridge crests and slopes, as well as on sandstone tors. They include ridge-top trenches with accompanying double ridges, rifts, as well as corridors and fissure caves. The distribution and geological setting of these forms suggest that they are genetically related to gravitational displacement of rock masses. Ridge trenches, rifts, and rock corridors frequently accompany large landslides and rock-slides, although occasionally they are the sole manifestations of mass movements.

Key words: Carpathians, ridge-top trenches, deep-seated creep.

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INTRODUCTION

In the mountain ranges, e.g. in the Alps and the Central Carpathians, reported are elongated narrow depressions, developed on the ridge crests. They run parallel to two or more secondary ridges and occasionally segment flattened crests. The origin of these forms has long been debated, any attributed to: deflation, suffosion, displacement of rock masses, and tectonic quakes (Klimaszewski, 1978).

The ridge-top trenches, rifts and double ridges have been described in detail by Nemčok (1982). He demonstrated a genetic link between these forms and gravitational movements on slopes. He distinguished surficial displacements of the rock masses and deep-seated creep. In the high mountains such phenomena are frequently observed and attain large dimensions. Numerous ridge-top trenches were found by Nemčok in the Central Carpathians, e.g. in the Tatra, Nízke Tatry, Velky Choč, Velka Fatra and Malá Fatra mountain ranges. These forms occur most frequently on crystalline rocks: gneisses, mica schists and granites but they are also encountered on Mesozoic limestones and dolomites.

Most of the trenches and rifts are located above the timberline. Similar forms have been observed and described from different regions as effect of large-scale rock creep on slopes (Radbruch-Hall, 1978).

In course of the present authors investigations, ridge-top trenches and double ridges have been found in the Outer Carpathians at several locations, either as single or as complex features. Besides these forms, one may distinguish elongated narrow steep-walled depressions previously mentioned by Flis (1958), K. Ziętara & T. Ziętara (1958) and T. Ziętara (1968), as well as fissure caves and expanded fissures in isolated sandstone cliffs and tors (Fig. 1). All the

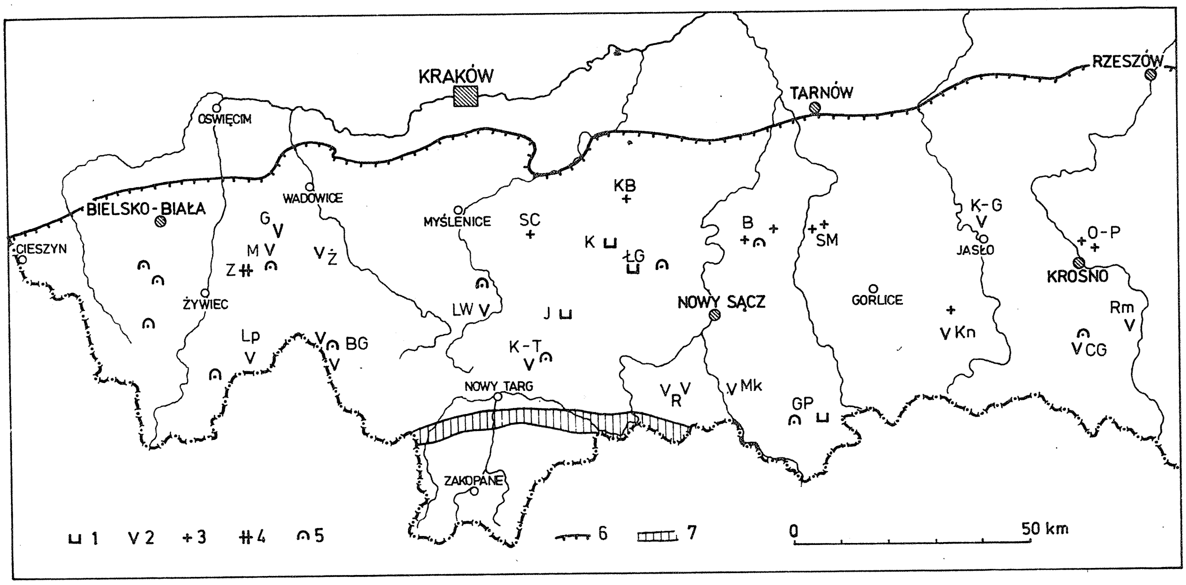

Fig. 1. Distribution of ridge-top trenches and rifts in the Polish Outer Carpathians. *1* — ridge-top trenches and double ridges; *2* — rifts; *3* — rock corridors; *4* — rock mazes; *5* — fissure caves; *6* — northern margin of the Carpathians; *7* — Pieniny Klippen Belt; *Z* — Zamczysko near Łysina; *G* — Gancarz; *M* — Madohora; *Ż* — Żurawnica; *Lp* — Lipowska; *BG* — Babia Góra; *LW* — Luboń Wielki; *K—T* — Kiczora-Turniska; *J* — Jasień; *SC* — Szczyrzyc; *KB* — Kamienie Brodzińskiego on Paprotna; *K* — Kamionna; *Ł G* — Łysa Góra; *R* — Radziejowa; *Mk* — Makowica; *GP* — Góra Parkowa; *B* — Bukowiec; *SM* — Skamieniałe Miasto near Ciężkowice; *Kn* — Kornuty; *K—G*—Krajowice-Golesz; *O—P*—Odrzykoń-Prządki; *CG* — Cergowa Góra; *Rm* — Rymanów

forms in question are genetically inter-related and they may be interpreted as resulting from gravity mass movements. Some of these forms accompany large landslides and constitute inherent elements of their morphology. The other forms, however, only indirectly suggest existence of displacement and subsidence of rock masses.

In the flysch part of the Polish Carpathians three types of the discussed forms can be distinguished (Fig. 2): (1) ridge-top trenches and related double ridges, (2) rifts within crests and on slopes (2a) and within colluvia (2b), as well as (3) rock corridors (3a), corridor systems — mazes (3b), and fissure caves (3c). Their occurrence reflects the process of degradation and dismemberment of the mountains. It should be noted that some of these forms were not regarded, so

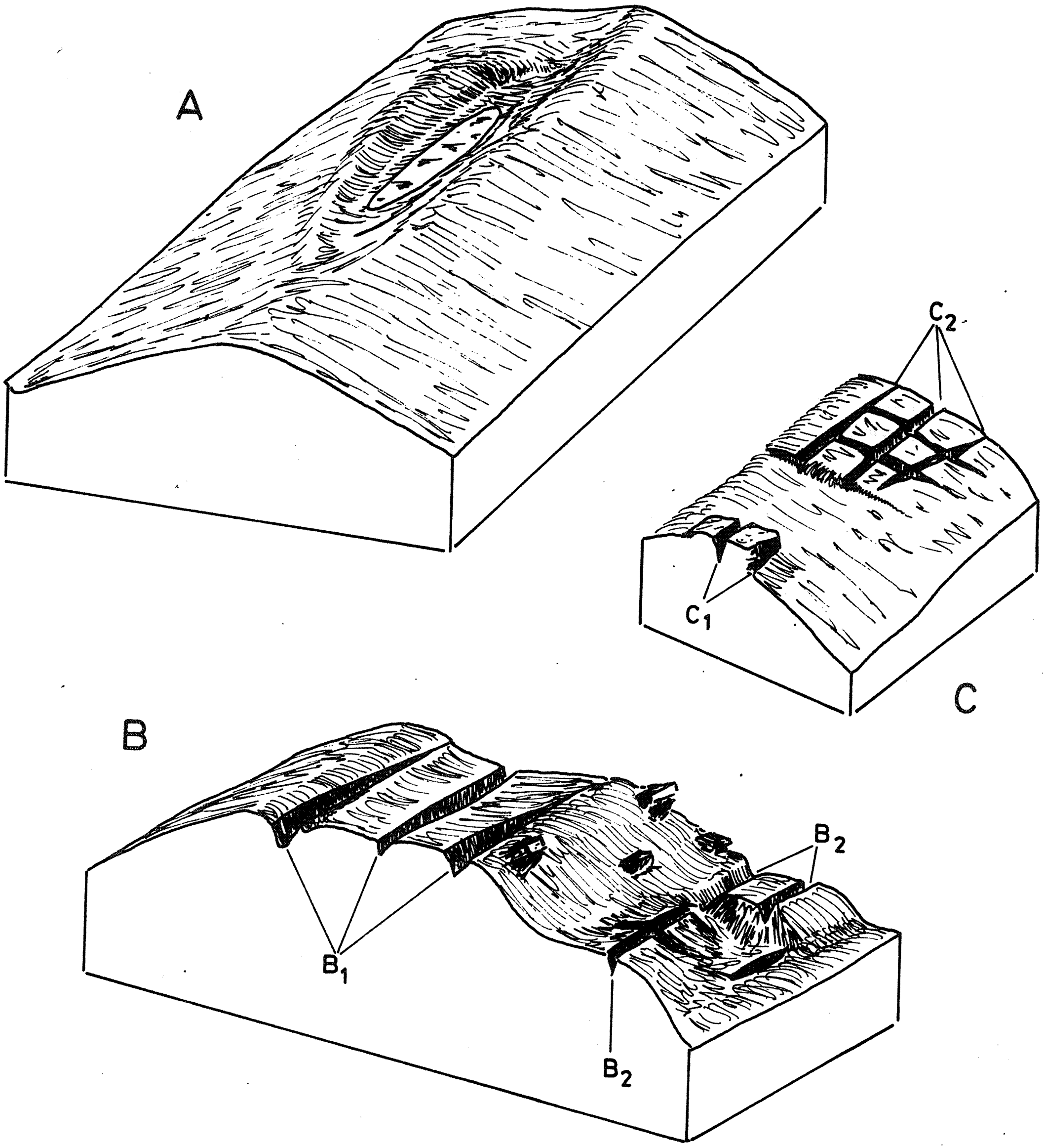

Fig. 2. Rift-type forms. *A* — ridge-top trench and double ridge; *B* — rifts: B_1 — rifts in the slump crown, B_2 — rifts within colluvium; *C* — rock corridors: C_1 — corridor in a tor, C_2 — rock maze

far, as indicative of rock-mass displacement. This primarily concerns ridge-top trenches and large rifts encountered outside of slides, which do not reveal direct relation to the slide-scarps and colluvia. In such cases, these forms can be regarded as the sole manifestations of the mass movements which invovle large portions of the slopes but reveal only small amplitudes of displacement. These latter forms exhibit similar relations to geological structures as typical landslides developed on the flysch rocks. Displacement of the rock masses takes place, as a rule, either conformably to the bedding (consequent structural forms) or along joints and dilated fissures (consequent fissure-type forms). The former case pertains to the ridge-top trenches and rock corridors, whereas the latter one, to all the three distinguished forms (Fig. 3).

The ridge-top trenches, rifts and rock corridors are being formed nowadays

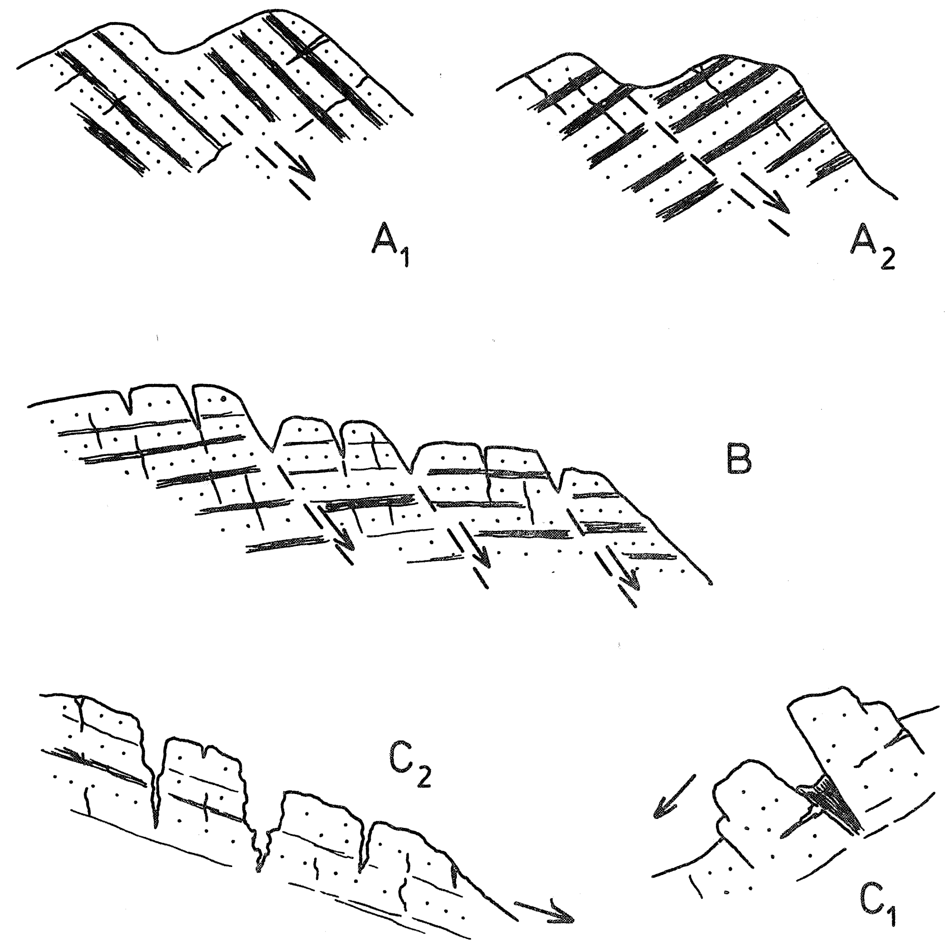

Fig. 3. Relations between the rift-type forms and geological structure. A_1 — ridge-top trench, consequent structural form; A_2 — ridge-top trench, consequent fissure-type form; B — rifts, consequent fissure-type form; C_1 — rock corridor, consequent fissure-type form; C_2 — rock maze, consequent structural form

but they have been forming also in the geological past. Depressions and expanded fissures filled with different sediments containing plant and animal remains, frequently in considerable concentrations, are favourable sites for preservation of these remains in the fossil form. Hence, these features may (analogously to some carst forms) be the subject of stratigraphical, paleontological and paleoecological investigations, especially those concerning the early Quaternary. In the Polish Carpathians there are known late-Quaternary malacofauna sites associated with rift-type forms (S. W. Alexandrowicz, 1985). The sediments filling marches within the discusses forms, are also promising for palynological studies of sediment sequences. Such studies have already been attempted in the Babia Góra range and may be extended on the newly described localities. The malacological and palynological analyses supplemented with radiometric datings may, in turn, be used to date the slumps and their relation to the particular climatic phases of the late Glacial and Holocene. This type of research, so far accomplished in a few sites only (Szymbark, Szczawnica, Czorsztyn, Piwniczna), is worth continuation.

RIDGE-TOP TRENCHES

Ridge-top trenches are found within crests. Where they occur, two ridges (the main and the accompanying ones) run alongside for some hundred metres. The main ridge continues beyond the extent of the trench, whereas the accompanying one bounds the depression and dies out gradually at its terminations. The crests may be symmetrical or asymmetrical. The main crest usually bounds the depression with a steep slope, while its outer slope is more gentle. The asymmetry of the accompanying crest is less pronounced. The heights of the crests are usually different, the accompanying crest being the higher. The depression separating the crests is elongated and narrow. The bottom of the trench is flat or concave, wet or boggy. The trench may be filled with water in ephemeral ponds richly overgrown with plants.

Good examples of the Western Carpathian ridge-top trenches are to be found on the Kamionna mountain near Żegocina and on the Parkowa Góra mountain in Krynica. Similar form was described by Flis (1958) on the Łysa Góra mountain near Limanowa. A small ridge trench occurs also on the Jasień mountain in the Beskid Wyspowy range.

RIDGE-TOP TRENCH ON THE KAMIONNA MOUNTAIN

The Kamionna mountain (805 m) in the Beskid Wyspowy range is located in the northern, marginal part of the Magura nappe. It is built of thick-bedded Magura Sandstone of the glauconite facies (Skoczylas-Ciszewska, 1960). Eastern slope of Kamionna descends abruptly to the deep Rozdziele Pass, while to the west from the summit there extends a ridge, some 1.5 km long, which passes into the neighbouring culmination of the Pasierbiecka Góra (769 m). Within the broad crest, at a distance of 0.5 km to the west from the summit of Kamionna, there occurs a ridge-top trench, 400 m long and more than 100 m wide. It is a consequent structural form developed on the northern limb of a meridionally trending syncline (Fig. 4). The main crest dips to the north at an angle 35–40°. Its southern slope forms a scarp of a varying height. In its central part it rises 2–3 m above the flat area at its foot, whereas at the eastern and western ends of the trench it is up to 7–10 m high. The flat area is 50 to 60 m wide and is occupied by a wet meadow, with a shallow pond in the centre some 50×100 m large. To the south, the trench is bounded by a secondary ridge facing the trench with an escarpment more than 20 m high. The escarpment lowers away from the centre and wanes in the southern slope of Kamionna. This slope is inclined at 25–30° but locally it is steeper.

The flat area at the top of Kamionna, bounded by the two discrete ridges, forms a typical ridge-top trench occupied by a wet meadow and marsh, and a permanent pond. The northern ridge is the main one and the southern ridge is

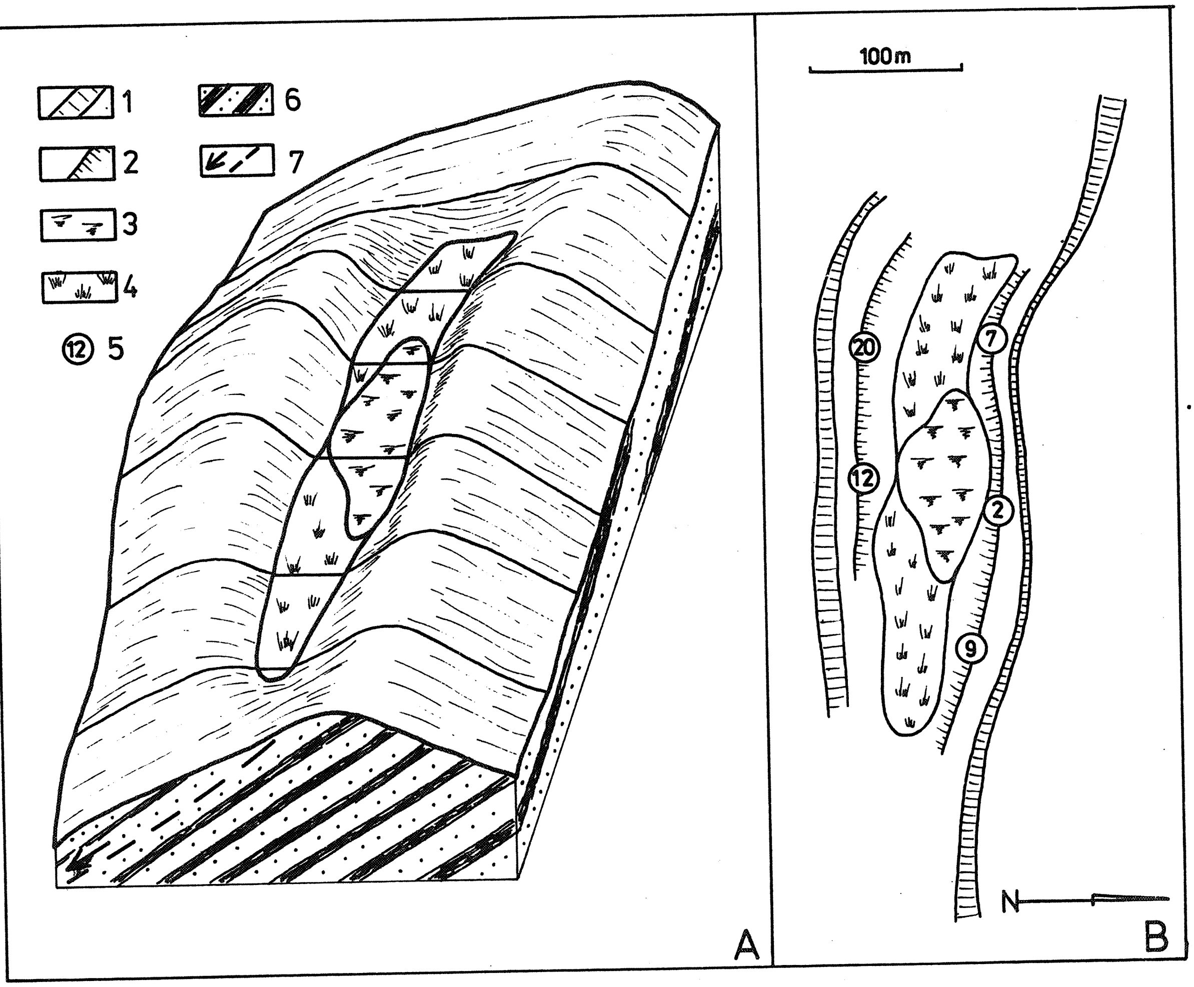

Fig. 4. Ridge-top trench on Kamionna near Żegocina. *A* — block diagram; *B* — sketch of the setting: *1* — ridges; *2* — scarps; *3* — pond within the ridge-top trench; *4* — waterlogged meadow in the ridge-top trench; *5* — height of the scarp in metres; *6* — Magura Sandstone; *7* — rupture surface

the accompanying one. The ridge-top trench wanes and eventually disappears in both directions. At its prolongation, however, there occurs a distinct depression of the crest in form of a minor pass.

RIDGE-TOP TRENCH ON THE GÓRA PARKOWA MOUNTAIN

The Góra Parkowa mountain (741 m) is built of thick-bedded sandstones with thin intercalations of shales and marls. According to Świdziński (1972), it is a sequence of the Magura Sandstone of the Sącz facies zone of the Magura nappe. The crest of the mountain extends in the NW–SE direction, and some 150 m from the cable-car station it passes down into a flat crest continuing to the east. The ridge is very narrow for 100 m; a flat-bottomed depression occurs on its southern side. It is occupied by a wet meadow with a pond 30 × 60 m large (Fig. 5). The extent and depth of the pond are limited by the lowest point

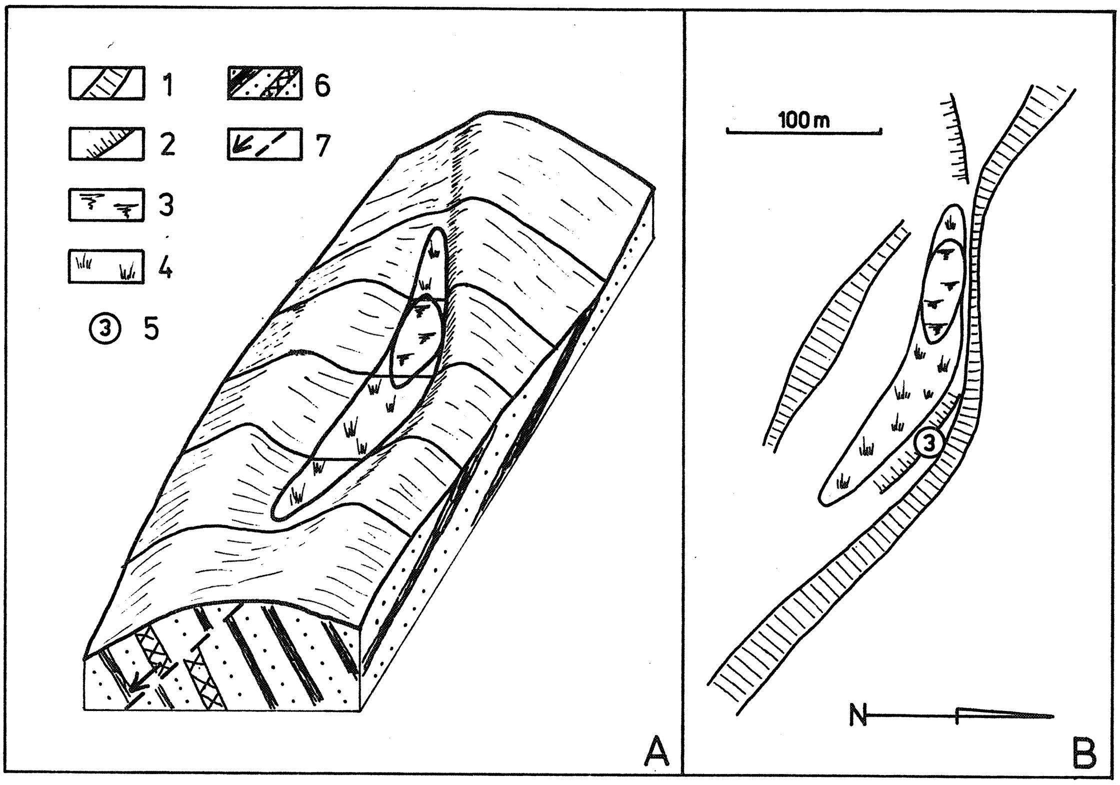

Fig. 5. Ridge-top trench of the Góra Parkowa near Krynica. Explanations as to Fig. 4

in the crest where water can overflow to the northern slope. The flat depression in the bottom of the ridge-top trench is 200 m long and up to 40 m wide. The main ridge which bounds the depression on the north, rises 2–3 m high. The ridge falls to the north with a steep slope of 35–40°. The accompanying ridge (the southern one) is 160 m long and in its culmination it is elevated 5–6 m above the trench bottom. The slope dips to the southwest at about 30°. It is uneven, rugged. Beyond the southeastern end of the ridge-top trench, the accompanying ridge declines and flattens. The trench dies away within a flat crest, 50–60 m wide. The form may be described as a structural fissure-type one (Fig. 5). A characteristic feature of this ridge-top trench is its curved shape manifest in the course of the main crest. On the western side, in the prolongation of the ridge there runs a steep escarpment which reveals features of a slump scarp deformed by creep.

FORMATION OF THE RIDGE-TOP TRENCHES

In the Polish geomorphological and geological literature, detailed descriptions of ridge-top trenches are confined to the occurrences in the Western Tatra Mountains (Młodziejowski, 1934; Jahn, 1964). The origin of these trenches was subject of vigorous dispute between Baumgart (1967, 1969) who favoured their formation due to suffosion and Jaroszewski (1965, 1969a, b) who assumed their gravitational origin. In the cited discussion, the concepts of various authors on the formation of ridge trenches and double ridges were presented and critically reviewed (Stiny, 1926; Paschinger, 1928; Aigner, 1933; Höhl, 1953; Mazúr, 1954). Almost all of the forms described by the cited authors occur in alpine-type mountains, mainly in the Alps and Carpathians, above the timberline. The same holds for the ridge trenches described or mentioned by Nemčok (1982).

In the Outer Carpathians, the forms discussed in the present study are found within the forested zone, at the altitudes not exceeding 1000 m, what considerably restricts a number of possible genetic interpretations. The forms were, so far, described only by Flis (1958) who demonstrated their relation to landslides.

The present authors suggest that the ridge-top trenches and double ridges have formed due to a very slow small-scale displacement of rock masses along moderately inclined deep-seated shear surfaces. The consolidation and structure of the relocated masses have not been affected, resulting in the lack of slope deformations characteristic of landslides. The sliding involved large fragments of the slopes including the ridge crest and the uppermost part of the opposite slope. Such position of the shear surface caused the displacement of a fragment of the ridge crest and its lowering.

The main ridge is situated at the intersection of the shear surface and the opposite slope, therefore it is narrow and bounded by a steep escarpment on the trench side. This is well visible in both the described examples. The crest is lowest in the central part of the trench length and rises at its ends, passing into the oriented undisturbed ridge.

The accompanying ridge represents the displaced and lowered fragment of the original crest. Both slopes of this crest reveal primary character resulting in asymmetry less distinct than in the main crest (Fig. 6*A*). The elevation difference between both crests indicates the maturity of the form. When the displacement is small the accompanying crest is higher and the ridge trench forms a closed depression, often filled with water (Kamionna, Góra Parkowa). In a more advanced stage the accompanying ridge is so lowered, that it becomes lower than the main one, and the ridge-top trench is usually drained along its axis (Fig. 6*A*, I–III). When the movement of the rock masses takes place along several parallel rupture surfaces, a system of parallel ridges and trenches forms on the crest. Examples of such forms were described, e.g. by Nemčok (1982) from the Slovak Central Carpathians.

Deep erosional cuts, deepening of the valleys and undercutting of the slopes by the erosional action of rivers and streams, may be considered the main agents causing the displacement of the rock masses on slopes and the formation of trenches on crests. In the Tatra Mountains the decisive role may be ascribed to glacial erosion (Jaroszewski, 1965). In the flysch Carpathians, the gravity movements are facilitated by the geological structure, in particular by the abundance of shales which reduce the slope stability. During the humid climatic stages, e.g. in the middle Holocene (Starkel, 1960), this factor might have played an important role.

One may infer that the conditions favouring disintegration of large rock masses and their very slow subsidence without distortion of the structure, existed in the Outer Carpathians during the degradation of the permafrost at the end of the last glaciation. At that time, ridge-top trenches could have formed in many mountain ranges.

Suffosion could participate in the formation and development of ridge trenches. Particularly favourable conditions for these processes existed in the

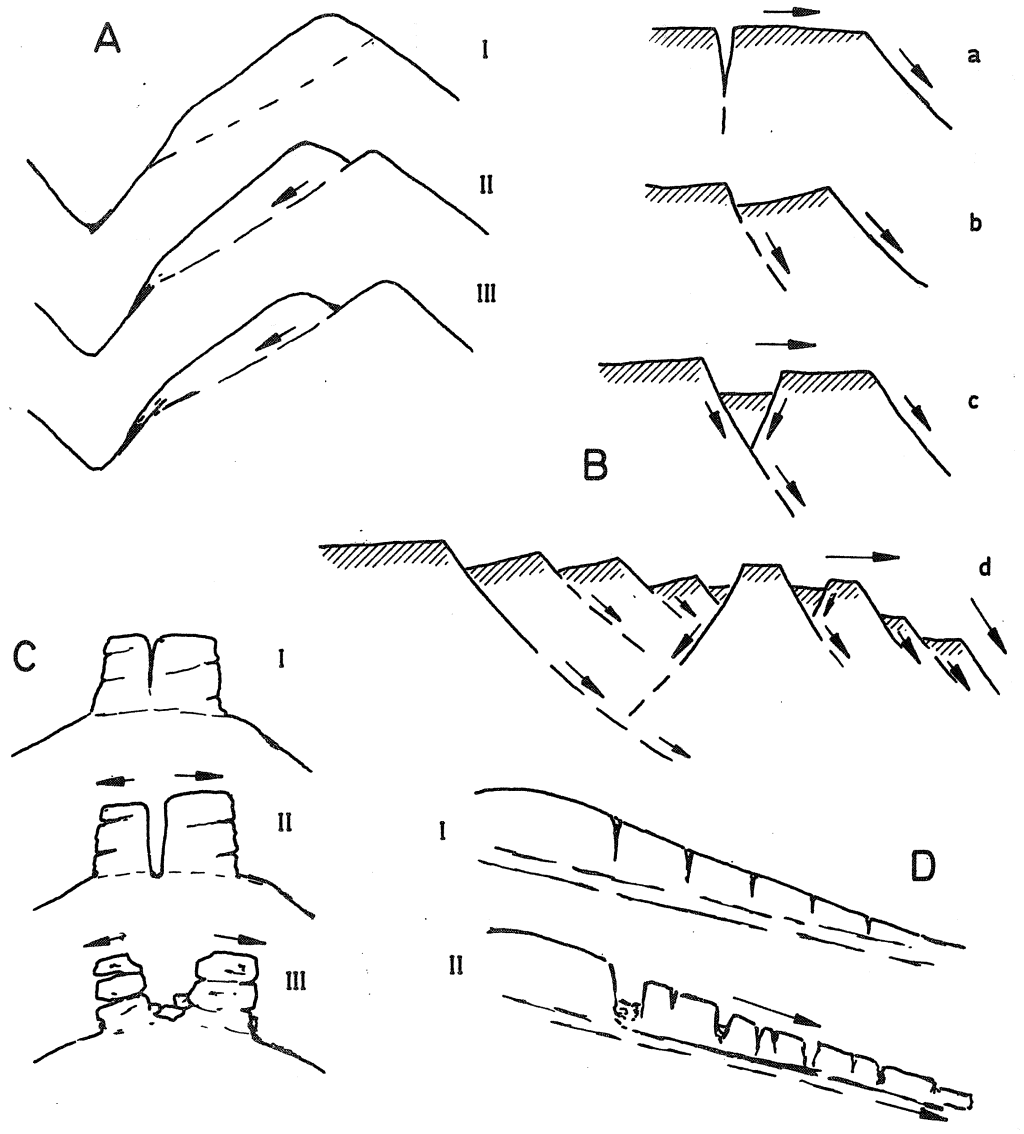

Fig. 6. Formation of the rift-type forms. *A* — stages of development of a ridge-top trench and double ridge (I—III); *B* — rift types described in the text (a—d); *C* — stages of formation of a rock corridor (I—III); *D* — formation of rock maze (I—II)

gravitionally loosened crystalline rocks as well as in limestones, dolomites and sandstones (Jahn, 1964). For numerous authors, e.g. Mazúr (1954) and Baumgart (1967), these were the processes responsible for the formation of ridge trenches and double ridges. In the flysch Carpathians, the abundance of shales and marls impedes groundwater circulation and thus hinders the development of the suffosion phenomena. Hence, these processes could only transform the existing trenches. The presence of wet meadows, marshes and even ponds in the trenches excludes suffosion as a cause for the ridge-trench formation.

RIFTS

The rifts are narrow, long hollows of various depths, situated on ridge tops and on the slopes involved in mass movements. The rift walls are usually steep (40° or more), often rocky, with outcrops of sandstone or shale and sandstone. A rift is symmetrical when both its walls are inclined alike. In asymmetrical rifts there is a steep wall, often rocky, and the opposite slope is gentle, less than 20°. Such forms were described by Nemčok (1982) as slid slopes, common in the Slovak Central Carphatians. Shallow forms, called also incipient rifts, are less than 2 m deep, while large forms may be deeper than 20 m. The narrow rifts, up to a few metres wide, reveal features of rock corridors if they are deep and their walls are steep. Large rifts are wider than 20 m. Asymmetrical forms are usually fairly wide and their limits on the gentle-slope side are indistinct.

The rifts may run in straight or zigzag course. In the latter case, their shape repeats the dominant directions of joints which usually intersect at right angles. The rifts most frequently follow the ridge, run parallel to the edge of the flattened crest, i.e. parallel to the strike of slope (subsequent rifts according to Flis, 1958). They may also run downslope (consequent rifts), perpendicularly or obliquely to the edge of the crest. The discussed forms concentrate above the landslide scarps or within large slumped blocks.

The rifts occurring above the slide scarps are similar to the widened slump fissures within the slope or crest. They are parallel to the scarp. Frequently they have large dimensions and diversified shapes. The bottoms are either overgrown or partly filled with rock debris. Occasionally one encounters there boggy depressions or even ephemeral water bodies.The best examples of such forms are known from the Magura Wątkowska mountain in the Beskid Niski range and from the Babia Góra mountain.

Rifts in colluvium are best developed in large slump slabs of only slightly disturbed structure. They are dilated fissures, even rock corridors, or trenches of crept walls. They run parallel or perpendicularly to the contours. Good examples of such fissures occur on the southern slopes of the Luboń Wielki mountain near Rabka and on the Golesz-castle hill in Krajowice near Jasło. Extensive slump with rifts occurs in Wzgórza Rymanowskie hills on the slopes of the Kopiec mountain.

KORNUTY IN THE MAGURA WĄTKOWSKA RANGE

Along the western edge of the ridge crest of the Kornuty mountain, a nature reserve in the Magura Wątkowska range, there occurs large group of tors built of thick-bedded Magura Sandstone (Świdziński, *fide* Sulma 1936). The tors are located along top of the main scarp of the slump that has descended toward the Bartne valley (Lach, 1970). Between the scarp and the ridge culmination there occur elongated depressions interpreted as rifts (Fig. 7). They are situated

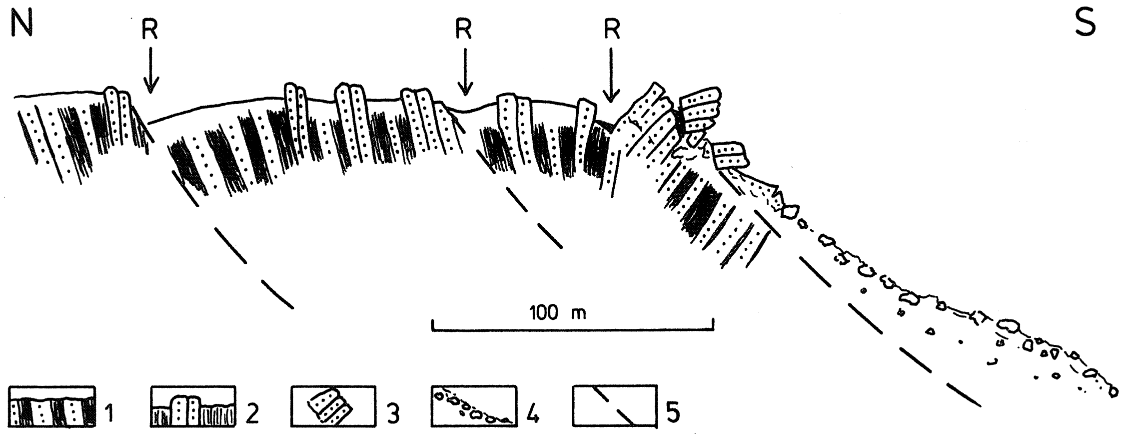

Fig. 7. Rifts on the Kornuty in the Magura Wątkowska range. *1* — Magura Sandstone; *2* — exposed sandstone beds; *3* — tors; *4* — slope debris; *5* — shear surface; *R* — rift

within the slightly lowered segment of the crest which forms a bench above the main scarp. The first rift is the best developed one, contouring the whole slump. It is an asymmetric trench several metres deep. Its eastern boundary is an escarpment rising 3.5 m above the bottom, inclined at 20—25°, rocky at places. Toward the west the bottom rises gradually. The subsequent, poorly developed rift runs parallel to the previous one at a distance of about 100 m. It is bounded by outcrops of the Magura Sandstone, dipping steeply to the south. The third depression accompanies the tors and it trends parallel to the crest edge at a distance of 20—40 m.

Rift trenches on the Kornuty mountain are shallow and filled with crept material. They follow the pattern of fissures in the crown of the large landslide, along which fissures a segment of the ridge crest subsided slightly in a stepwise fashion. The displacement of rock masses was accompanied by their rotation changing the dip angles of the sandstone beds. In the tors on the crest edge the fissures are open and individual blocks slide gravitationally down the slope, disintegrate and form vast piles of rock debris.

BABIA GÓRA RANGE

Typical and well developed rock rifts occur on the Babia Góra range (Babia Góra National Park) in the uppermost part of its northern slope. These features were described by K. Ziętara & T. Ziętara (1958) and S.W.

Alexandrowicz (1978). These are typical consequent fissure-type features formed by displacement of rock masses along a system of joints in gently dipping beds. The forms are best developed in the vicinity of the culmination Kępa and by Izdebczyska near the Brona pass (Fig. 8). In the first of the mentioned sites there are four narrow and shallow trenches separated by flat ridges. The highest ridge confines the whole group of features from the north. The rift accompanying it is 10—15 m deep. Its northern wall is up to 50° steep, at places rocky, whereas the southern slope is gentle and covered with weathering residuum. A little bog occurs at the bottom of this rift called Zimna Dolinka. The whole discussed assemblage of rifts and ridges, of total extent about 200 m, is delimited by a curved scarp. The subsidence and partitioning of a fragment of the ridge occurred along this very scarp, just above the main edge of the northern rock wall of Babia Góra (Fig. 8*A*).

Analogous set of features occurs at Izdebczyska. The lowered part of the ridge crest is here up to 250 m wide. The bounding scarp may be seen along the foot trail from Brona pass to the Diablak culmination. Five rifts separated by high rocky ridges can be distinguished here. The largest rift, called Zbójecka Dolinka, is up to 20—25 m deep and just as wide. On the walls of the adjoining ridges considerable expanding of jointing is visible as well as loosening of the Magura Sandstone beds. The successive ridges are gradually lower northwards, towards the edge of the ridge crest, which is the edge of the rocky northern face of Babia Góra (Fig. 8*B*).

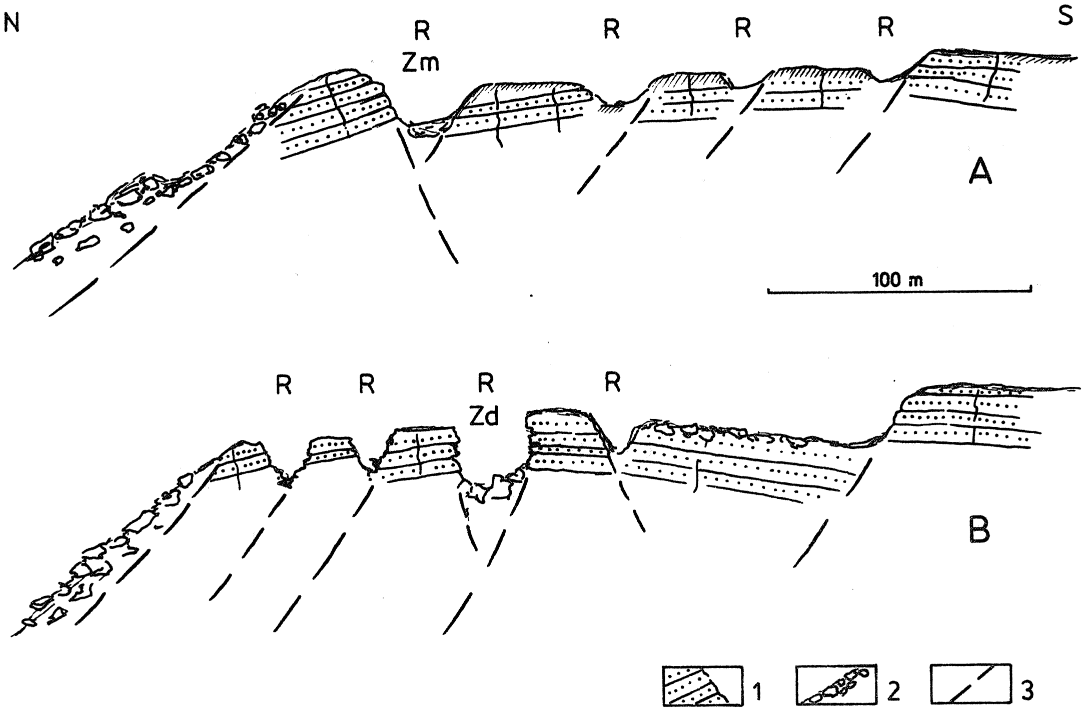

Fig. 8. Cross-section of the rifts on the Babia Góra ridge crest. *A* — rifts on the Kępa; *B* — rifts on the Izdebczyska; *1* — Magura Sandstone; *2* — scree field and slope debris; *3* — shear surface; *R* — rift; *Zm* — Zimna Dolinka; *Zd* — Złodziejska Dolinka

LUBOŃ WIELKI MOUNTAIN

A large set of morphological features including rifts, slump blocks and rock-block fields occur within the slide in the vicinity of the Luboń Wielki summit. The site is located in the nature reserve on the northern slope of the mountain (Starkel, 1960; Dubiel, 1977). The scarp of this landslide's niche attains 20 m in height and shows thick sandstone beds (Fig. 9). At its foot there is a rift, 20 m wide, filled with sandstone blocks. The adjoining rock ridge has a low northern slope, and the southern wall, 10 m high, falling steeply to the next deep rift filled with blocks. The next rocky ridge, up to 30 m wide, has sandstone outcrops on both sides and it is cut in the middle by a cleft 1 m wide. A steep slope beneath this ridge is covered by a block field built of Magura Sandstone. At its foot there occur other symmetrical rifts, whose southern walls are steep and rocky, while the northern ones are more gentle, covered with blocks and weathered rocks. Below, a steep forested slope begins.

The group of rifts on the southern slopes of Luboń Wielki represents features typical of large slides of more or less deep-seated ruptures in which the subsiding and sliding rock masses are not disintegrated but only fractured into ridges and huge rock-blocks. The rifts mark the shearing surfaces along which the rock movement took place, and the open fissures are the effect of these rock masses' separation. This separation occurred in part during the movement of colluvium, and partly after the movement has ceased, due to subsiding and relaxing of rock blocks. At the zones of disintegration of slump blocks, the moving debris and sandstone fragments have formed block fields.

GÓRA ZAMKOWA – GOLESZ

Characteristic rifts bounded by tors, rocky ridges and hillocks occur on the Góra Zamkowa hill in Krajowice at the foot of the Golesz castle (Fig. 10). They belong to the marginal zone of a large landslide. The landslide occurred within beds of Ciężkowice Sandstone intercalated with red clayey shales. North-western flank of this landslide is made by partly creeping scarp of the slide, at which place the tors have been modelled (Z. Alexandrowicz, 1987b). The first distinct rift, some 20 m wide, separates two groups of tors of which the upper one crowns the slide scarp, whereas the lower one forms a rocky crest of a slumped block. The second rift occurs in the lower block and in its lower part it passes into a large wall more than 10 m high. Within the next down slumped block, one may distinguish the third rift delimited by a rock ridge of walls partly covered with creeping slope sediments.

The described forms are arranged *en echelon* and were formed by sliding of the wide marginal zone of the large landslide. The whole zone built of thick-bedded Ciężkowice Sandstone forms a broad rock bench divided in several parts by the shear and slip surfaces marked on the surface as rifts.

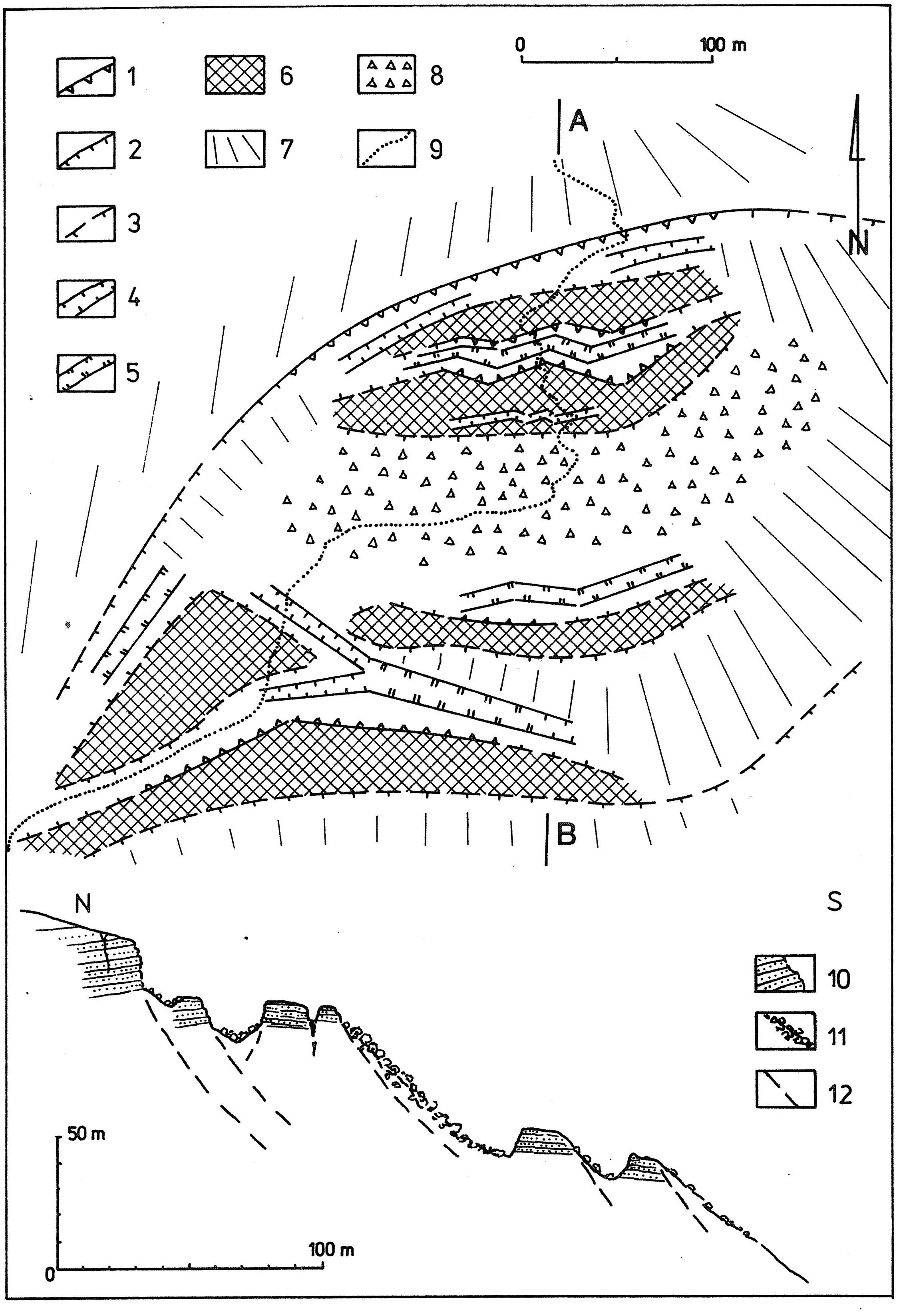

Fig. 9. Rift system on the Luboń Wielki. *A–B* — cross-section; *1* — niche and rock escarpments; *2* — slide niche with creeping walls; *3* — creeping escarpments; *4* — rifts of creeping walls; *5* — rifts of rocky walls; *6* — colluvial ridges; *7* — creeping slope; *8* — scree field; *9* — foot trail; *10* — Magura Sandstone; *11* — scree field and slope debris; *12* — rupture surface

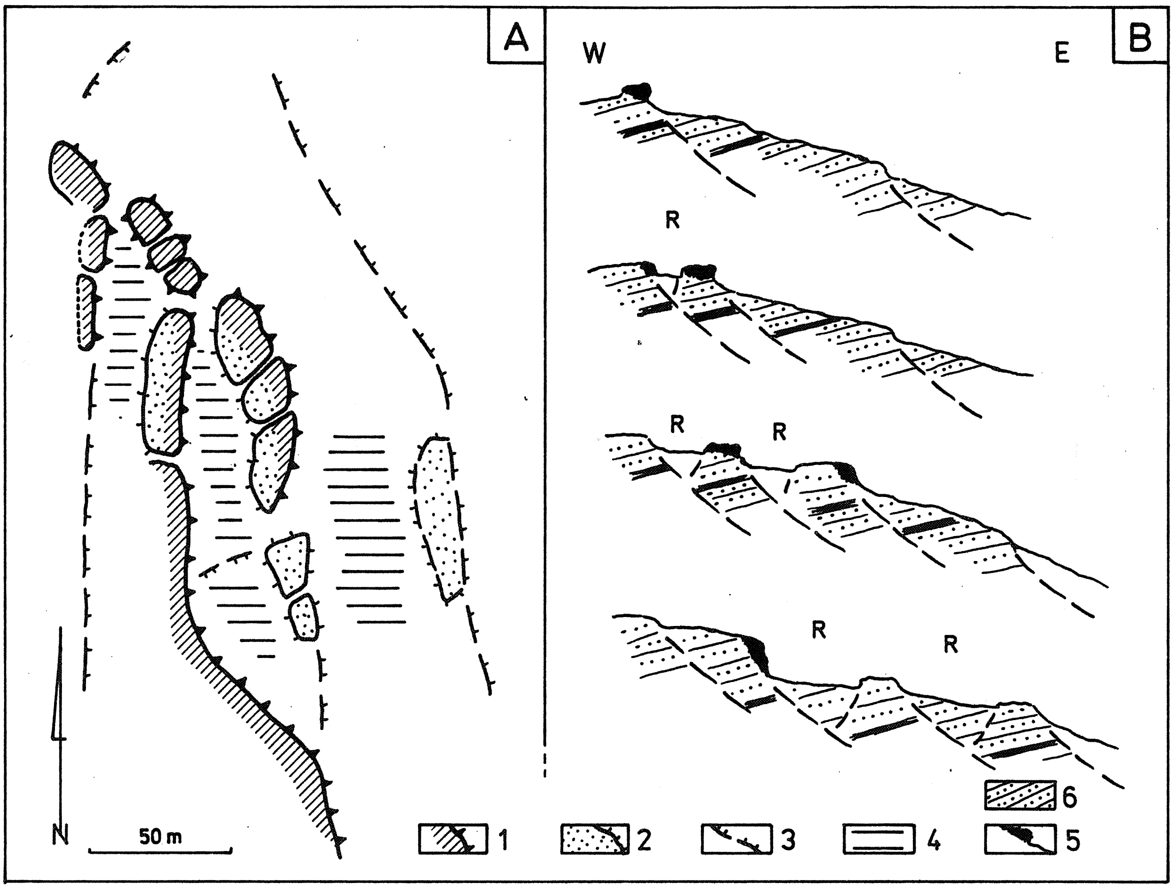

Fig. 10. Rift on the Góra Zamkowa — Golesz near Krajowice. *A* — sketch of the setting: *1* — rocky faces and tors within the landslide, *2* — colluvial ridges, *3* — creeping escarpments, *4* — flat rift bottoms; *B* — cross-sections of the rift system: *5* — sandstone tors, *6* — Ciężkowice Sandstone, *R* — rift

Gravitational movement of the slope took place slowly and had a small amplitude, hence the colluvium did not disintegrate but was divided into ridges and rifts, the latter forming a system of rock corridors.

ORIGIN OF RIFTS

Four types of rifts can be distinguished in the Western Carpathians. All of them reveal direct connection with landslides or slumps.

Expanded fissures situated above the edges of slide crowns in the zones not involved in the mass movement (Fig. 6*B a*). These are forms of various height, although usually shallow and narrow. Their walls are steep and covered with creeping weathered rocks. Occasionally they assume a form of widened trenches originating from the outward movement of a set of beds. The presence of open and permeable fissures facilitates transformation of these features by suffosion.

Rifts in the steplike sunken slide and slump blocks. They form on the shear and slide surfaces. The involved blocks may be rotated and cause asymmetry of a rift. In such case, one wall is made by the shear surface, and the other is the upper inclined surface of the slumped block (Fig. 6*B b*). Typical forms of that type occur, e.g., on Kornuty, where they are altered by suffosion.

Large rifts (rift trenches) and rift systems. They correspond with features referred to in the tectonic literature as antithetic trenches. They originate due to the separation of two slabs of rock along a slide surface accompanied by oblique secondary shear within the lowered rock slab. The resulting trench between the separated rock slabs is deep and wide (Fig. 6*B c*). Its walls are often steep or even rocky and the bottom is filled with large blocks of rock. The antithetic trenches and steplike slided slabs may compose complex systems of forms typified by the presence of numerous parallel rifts (Fig. 6*B d*). Typical examples of such features may be observed on the ridge crest of the Babia Góra range.

Subsequent and consequent rifts within slided blocks. They are usually small and short but may be deep and steep-walled. Such forms separate individual blocks or form system of trenches and corridors. They are observed e.g. on Luboń Wielki and Góra Zamkowa — Golesz.

The above-presented types of rifts are fairly common in the Outer Carpathians. Beside those described here, they occur also in the Beskid Śląski mountains (Ziętara, 1962), in the Pilsko range in the vicinity of the summit Skałka (Z. Alexandrowicz, 1978), on the Żurawnica hill near Sucha Beskidzka (Jakubska, 1978), on the Gancarz and Madohora in the Beskid Mały range (Starkel, 1960; Z. Alexandrowicz, 1978), in the group of tors Turniska near Kiczora in the Gorce range (Z. Alexandrowicz, 1982), on the Radziejowa and Jaworzyna Krynicka mountains (Flis, 1958; Bednarz, 1984) and on the Cergowa mountain near Dukla. Similar forms are described by Birkenmajer (1971) from Małe Pieniny Mts as gravitational deformations developed between blocks of limestones sinking gravitationally into underlying plastic clays and expanding along joints.

The listed rifts and complexes of the rift features reveal strong similarity with structures typical of the gravity fault tectonics. Applying classification accepted for such structures (Jaroszewski, 1974) one may distinguish: forms corresponding with step-fault systems, antithetic trenches and horsts, synthetic blocks etc.

ROCK CORRIDORS

Within individual, isolated sandstone tors, tor groups and sandstone massifs one commonly encounters fissures considerably widened due to sinking and lateral displacement of rock blocks. Such fissures are transformed into rock corridors with very steep, occasionally overhanging walls several metres or more high. The width of these forms is various. Within isolated tors, particularly those on ridge crests, usually one or two parallel corridors form, often widening upawards. In large groups of tors, the corridors intersect at an angle close to the right angle, reflecting the orthogonal joint system. Within the slumped blocks of rocks as well as in the fractured bare crown of the large scarps, there occur systems of expanded fissures reaching considerable depths, often concealed at top. One may distinguish three types of these features: (1) corridor systems (rock mazes), (2) single corridors, and (3) dilation or fissure caves.

The rock mazes are common, e.g. in the Upper Cretaceous sandstones in the Sudetes and the Bohemian Massif (Czeppe, 1952; Balatka *et al.*, 1969; Vítek, 1979). They occur in the mariginal zones of sandstone massifs in the vicinity of high scarps. The factors controlling their formation are: relaxation of the rock mass, settling of the massifs into soft marls and shales, and separation of the sandstone blocks along joints (Pulinowa, 1972). Similar phenomena have been observed on the Małe Pieniny (Birkenmajer, 1971), the Western Tatra Mountains (Lefeld, 1965), as well as in other massifs of the Central Carpathians (Nemčok, 1982).

In the flysch Carpathians rocks mazes are rare. An example may be found on the Zamczysko summit in the Beskid Mały mountains (Z. Alexandrowicz, 1978), Ściszków Groń range, to the west of its culmination. A system of rock corridors and rock cliffs occurs here, occupying an area of nearly 1 ha. They formed in thick-bedded, coarse-grained sandstones and conglomerates of the Lower Istebna Beds which are cut by orthogonal system of joints, striking predominantly at 20° and 110° (NNW – SSE and WNW – ESE). The discussed features are confined from the north by a steep rock wall more than 10 m high. A wide corridor runs along this wall. In the middle of the maze the corridors are 1 – 3 m wide and up to 5 m deep; to the south they are shallower. The whole complex of features is confined by a small cliff, partly covered with slope sediments. A depression accompanying this scarp passes into slope inclined at about 25°. Blocks, finer debris and sandy weathered material accumulate on the bottom of the corridors. The maze is formed by shallow rupturing of a series of thick beds of the Istebna Sandstone and their slight gravitational displacement over the slope. During this process large sandstone blocks split along joints.

Individual rock corridors occur within most of the isolated sandstone tors in the Carpathians (Klimaszewski, 1947; Z. Alexandrowicz, 1978). Sandstone blocks in the tors on the ridge tops often separate simultaneously in opposite directions, so that the corridors widen upwards. In the slope tors, mostly the fissures parallel to the slope contours are expanded. Instructive examples of corridors occur in the group of tors Prządki near Krosno (Świdziński, 1933; Z. Alexandrowicz, 1987a), in the tor Borsuk (in the group of tors Skamieniałe Miasto) near Ciężkowice (Z. Alexandrowicz, 1970), in the tor Diabli Kamień near Folusz (Z. Alexandrowicz, 1987b), in the tor Kamień near Szczyrzyc, in the group of tors Kamienie Brodzińskiego near Lipnica Murowana, and on the Wieprzyk Las hill near Siekierczyna (Z. Alexandrowicz, 1978). All these features are manifestations of slow subsidence and gravitational movement of sandstone blocks down the slope.

Fissure caves were reported from the Carpathians by Kowalski (1954), K. Ziętara & T. Ziętara (1958), and some other authors. The caves occur in several places, and the best known caves are in the Klimczok mountain, Malinów in the Beskid Śląski range, the Babia Góra range, the Szczebel and Jaworze mountains in the Beskid Wyspowy range, Turbacz mountain in the Gorce range, Jaworzyna Krynicka in the Beskid Sądecki range, in the group of tors Bukowiec on Diable Skały in Pogórze Rożnowskie hills, as well as in the Cergowa Góra mountain near Dukla (Fig. 1). Nearly all the mentioned forms are related to landslides and rock falls. They form during gravitational displacement of fractured sandstone and conglomerate beds. They are frequently accompanied on the surface by suffosion features marking the zones of strongly loosened rocks.

CONCLUSIONS

Our studies provide base for a classification and explanation of the origin of features of a trench or rift type, which form due to gravitational movement of the rock masses of the Carpathian flysch (Figs. 2, 3, 6). The main results of the present investigations may be set up in the following conclusions.

1. Ridge-top trenches, rifts, corridors, rock mazes and fissure caves occurring in the Polish Outer Carpathians belong to landslide-related forms of relief.

2. The ridge-top trenches and the double ridges related to them are formed due to gravity mass movements along deep ruptures, where the movement involves not only one of the slopes but also a fragment of the crest. The main ridge of a double ridge forms at the intersection of the rupture surface with the opposite slope, and the accompanying ridge is a displaced and lowered part of the original crest (Fig. 2*A*). Ridge-top trenches related to creep along a deep rupture have been described among others by Nemčok (1982).

3. Rifts on slopes and ridge tops are interpreted as expanded slide fissures. In slump crowns they result from relaxation of the rock mass following the landslide or they mark cracks opening beyond the main scarp (Fig. 2*B*). Rifts within slump blocks form due to opening of fissures in the moving rock masses which have lost their coherence (Fig. 2*B*).

4. Rock mazes may be considered as systems of rifts developed in slightly displaced rock blocks, due to expansion of joints (Fig. 2*C*).

5. Rock corridors are typical feature of isolated rock tors and are formed by widening of fissures during settling or slight lateral movement of the tors (Fig. 2*C*).

6. The expanded underground fissures form fissure caves in the rock mass extended during mass movements. They are encountered both, above the

slump scarps and within slump blocks. They are associated with rock corridors and rifts.

7. The described forms, genetically related to landslides and rock slumps, are modified by exogenic processes: weathering, deflation, ablation, rock fall-down, rain wash and creep of slope cover. A particular role is played by suffosion which operates selectively within the parts of the rock loosened due to the mass movements. However, suffosion can not be accepted as the main process in the formation of the trenches, rifts and corridors.

8. In the Polish Outer Carpathians, similarly as in other mountains and highlands, the mass movements are manifested not only in landslides, slumps, rock-falls etc., but also in the features described in this paper. The presence of ridge-top trenches, rifts, corridors, and other depressions of that type indicates gravitational processes even though the displacements of rock masses do not result in slide scarps, colluvial masses of characteristic relief and structure.

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Streszczenie

ROWY GRZBIETOWE I ROZPADLINY W POLSKICH KARPATACH FLISZOWYCH

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W polskich Karpatach fliszowych na grzbietach górskich i stokach w wielu miejscach występują wąskie, wydłużone, bezodpływowe zagłębienia określane jako rowy grzbietowe i rozpadliny. Są one związane genetycznie z grawitacyjnymi ruchami mas skalnych. Do tego typu form należą również korytarze rozwinięte w obrębie wyizolowanych skałek piaskowcowych oraz groty szczelinowe (dylatacyjne) (Fig. 1 i 2). Rowy grzbietowe i towarzyszące im grzbiety podwójne występują w obrębie wierzchowin górskich. Tworzą się one wtedy, gdy powierzchnia ścięcia, wzdłuż której nastąpiło nieznaczne przemieszczenie mas skalnych, przebiega głęboko w górotworze, a ruch masowy obejmuje nie tylko stok, ale fragment grzbietu lub wierzchowiny. Grzbiet główny stanowi wówczas krawędź przecięcia powierzchni poślizgu i przeciwległego zbocza, a towarzyszący jest przesuniętą i obniżoną częścią dawnego grzbietu góry (Fig. *2A, 6A*). Pomiędzy nimi rozciąga się obniżenie zabagnione lub nawet wypełnione wodą. Najlepsze przykłady takich form zostały znalezione na Kamionnej w Beskidzie Wyspowym (Fig. 4) i na Górze Parkowej w Krynicy (Fig. 5). Rozpadliny występujące na stokach lub wierzchowinach grzbietowych można uznać za rozszerzone szczeliny osuwiskowe. Tworzą się one ponad krawędziami nisz osuwiskowych na skutek odprężenia górotworu lub są śladami płaszczyzn odspojenia powstających poza główną powierzchnią poślizgu osuwiska (Fig. *2B* i *6B*). Rozpadliny takie występują w Kornutach w paśmie Magury Wątkowskiej (Fig. 7) oraz na Babiej Górze (Fig. 8). Inny, pospolicie spotykany typ rozpadlin obejmuje rozszerzone szczeliny w obrębie mas koluwialnych, które nie uległy rozdrobnieniu (Fig. 2B i 6B). Formy takie znane są m.in. z Lubonia Wielkiego i Góry Zamkowej – Golesz koło Jasła (Fig. 9 i 10). Korytarze skalne są typową cechą form skałkowych. Powstają one przez rozszerzanie szczelin w czasie osiadania lub nieznacznego, grawitacyjnego przemieszczania się skałek (Fig. *2C* i *6C*). Mogą one niekiedy tworzyć labirynty skalne, czego przykładem jest Zamczysko na Łysinie w Beskidzie Małym (Fig. *2C* i *6D*). W górotworze rozluźnionym w wyniku ruchów masowych zarówno ponad krawędziami nisz osuwiskowych, jak też w obrębie skib i osuniętych

pakietów skalnych tworzą się często groty szczelinowe (dylatacyjne), towarzyszące rozpadlinom i korytarzom skalnym. Wszystkie opisane typy form związane genetycznie z osuwiskami i zerwami skalnymi są przemodelowywane przez czynniki zewnętrzne przy współudziale deflacji, ablacji, odpadania fragmentów skalnych i pełznięcia zwietrzeliny. Szczególną rolę odgrywa tu sufozja działająca selektywnie w obrębie górotworu rozluźnionego przez ruchy masowe.