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THE LATE NEOGENE-QUATERNARY TECTONIC MOBILITY OF THE POLISH WEST CARPATHIANS A CASE STUDY OF THE DUNAJEC DRAINAGE BASIN

(Pl. I-V, Figs. 1-14)

Późnoneogeńsko-czwartorzędowa mobilność tektoniczna polskich Karpat Zachodnich na przykładzie dorzecza Dunajca

(Pl. I-V, Fig. 1-14)

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Abstract: The article deals with neotectonic movements which have been affecting the Dunajec drainage basin since the Sarmatian. The amount and intensity of these movements have been calculated and compared with the geological structure of the basin. It seems probable that the Plio-Pleistocene tectonics of the West Carpathians reflects tectonic mobility of the flysch substratum. This mobility may refer to the still continuing process of backward thrusting of the Easteuropean Platform under the Carpathians.

Key words: neotectonic movements, geomorphology, Neogene, Quaternary, Dunajec drainage basin, West Carpathians.

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Treść: Artykuł omawia ruchy neotektoniczne zachodzące w obrębie dorzecza Dunajca (polskie Karpaty Zachodnie), począwszy od sarmatu. Obliczone rozmiary i prędkości tych ruchów przeanalizowano na tle budowy geologicznej dorzecza. Plioceńsko-czwartorzędowa aktywność tektoniczna Karpat Zachodnich może odzwierciedlać mobilność podłoża fliszu, związaną z niezakończonym jeszcze procesem podsuwania się podłoża platformowego pod Karpaty.

INTRODUCTION

This article concerns neotectonic movements in the Dunajec drainage-basin (Polish West Carpathians). These movements started at the decline of the Sarmatian and continued during the Pliocene and Quaternary periods.

Geomorphic investigations were aimed at reconstructing the course of Late Neogene – Quaternary tectonic movements as well as their impact on the mountaineous topography. In order to enlighten the nature and intensity of these movements, a detailed geomorphological survey on the scale of 1:25000 was made (cf. Figs. 2, 3 and 4). The analyses of terrace forms and covers in their stratigraphic sequence, cross-sections and longitudinal profiles were carried out along the valleys of the Dunajec, Poprad and Kamienica Nowojowska rivers. Special attention was paid to the diversity of forms and facies within the given covers, to the interrelationship between fluvial and slope deposits and to the relations between accumulational covers and rock socles. All available aerial photographs were also used.

The age correlation of the terraces was enabled by sedimentological observations of fluvial deposits, their relation to solifluction and proluvial covers as well as by hitherto prepared ^{14}C datings and palynological analyses.

The investigated terrace system was compared with that of Slovakian and Alpine rivers.

GEOGRAPHIC SETTING

The investigated part of the Dunajec drainage-basin, comprising 32% of the Polish Carpathians area, is located within several geomorphic units which reveal different geologic and morphologic properties. These units are as follows: the eastern part of the Nowy Targ Basin, the Pieniny Klippen Belt, the Beskid Sądecki Mts., the Łącko – Podegrodzie Foothills, the Nowy Sącz Basin with the Stary Sącz Foothills, the eastern part of the Beskid Wyspowy Mts., the Grybów Mts. and the southern part of the Ciężkowice Foothills (Rożnów Plateau).

The highest elevations are characteristic of the Beskid Sądecki Mts. (1100 – 1265 m), the lowest ones occur within the Nowy Sącz Basin (310 – 270 m) and within the Ciężkowice Foothills (250 m).

GEOLOGIC SETTING

The substratum of flysch nappes within the Dunajec drainage basin occurs at different depths. Refraction geophysical profiles, running N – S and transversing the Nowy Sącz Basin, reveal the presence in the surroungings of the town Nowy Sącz, of a strong negative gravimetric anomaly (–40 mgal), which could refer to the southern limit of the Epivariscan Platform (Ślączka, 1975). This border zone seems to be thrown down to the south, beneath a depth of 14 km. To the north, however, the Carpathian basement rises, reaching near Zakliczyn a depth of 4 km.

The axis of regional gravimetric low extends here from Nowy Sącz to Nowy Targ. Some geologists believe that the northern margin of the regional gravimetric low is to be interpreted as a zone of deep faults, throwing down the peripheral parts of the platform basement, and separating the primary basement of geosynclinal sediments from the non-regenerated Epivariscan Platform. Sikora (1976) called this zone the "Pericarpathian Lineament".

Another deep-seated fault is believed to be located along the Pieniny Klippen Belt. According to Birkenmajer (1977), the Moho discontinuity is downthrown here to a depth of approximately 50 km.

The seismicity of the West Carpathians is comparable with that of the Eastern Alps (Zatopek, 1979). Seventy earthquakes were recorded on the territory of the

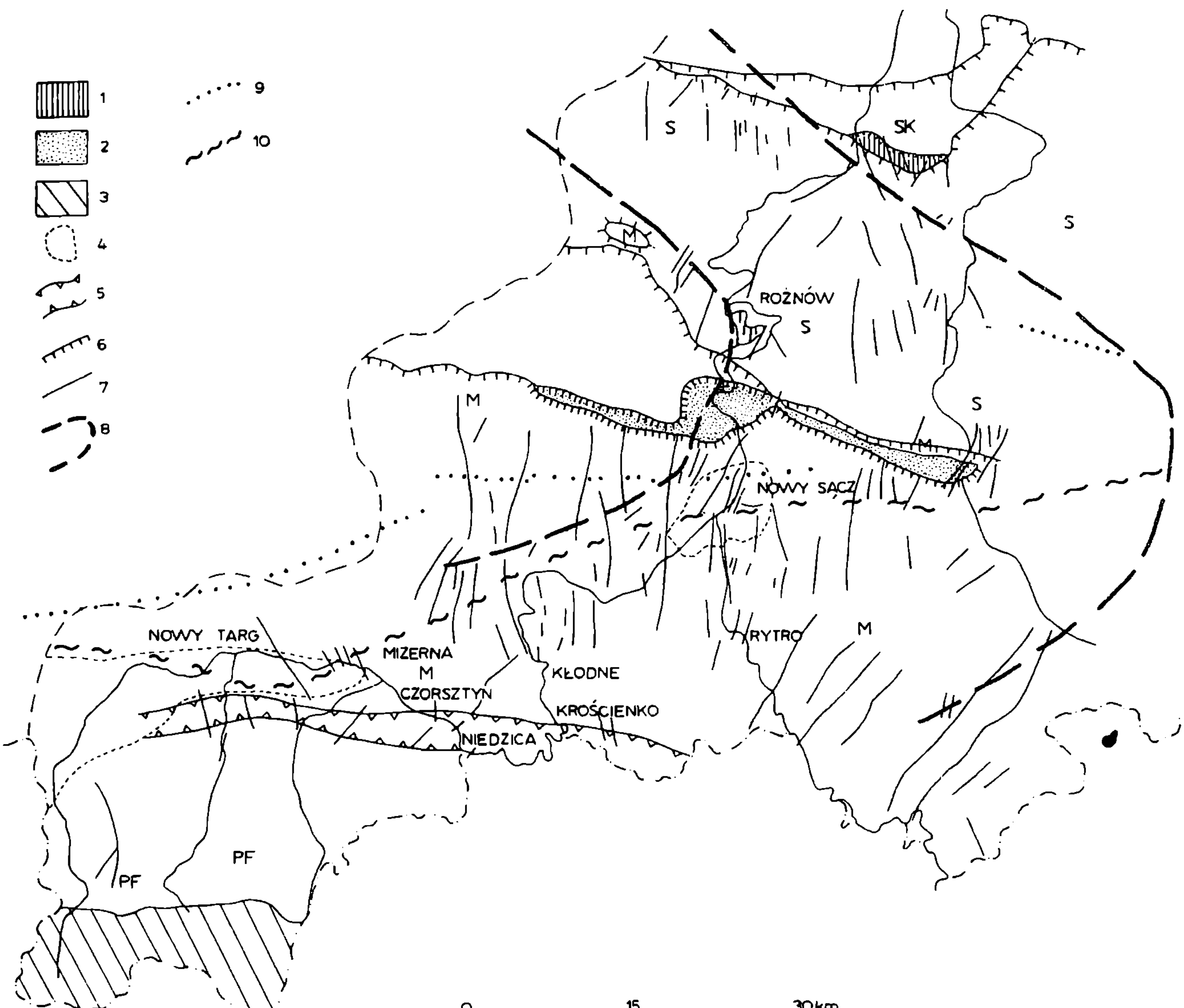


Fig. 1. Geological sketch of the investigated area (compiled after: Oszczypko 1973, Ślączka 1975). *1* – Sub-Silesian nappe, *2* – Grybów unit, *3* – Tatra units, *4* – Neogene molasses, *5* – Pieniny Klippen Belt, *6* – overthrusts, *7* – faults, *8* – axes of positive magnetic anomalies, *9* – supposed southern boundary of the Epivariscan Platform, *10* – axis of regional gravimetric low. *M* – Magura nappe, *SK* – Skole nappe, *S* – Silesian nappe, *PF* – Podhale Flysch

Fig. 1. Szkic geologiczny obszaru badań. *1* – płaszczowina podśląska, *2* – jednostka grybowska, *3* – jednostki tatrzańskie, *4* – molasy neogeńskie, *5* – pieniński pas skałkowy, *6* – nasunięcia, *7* – uskoki, *8* – osie dodatnich anomalii magnetycznych, *9* – przypuszczalna południowa granica platformy epiwaryscyjskiej, *10* – oś regionalnego minimum grawimetrycznego. *M* – płaszczowina magurska, *SK* – płaszczowina skolska, *S* – płaszczowina śląska, *PF* – flisz podhalański


0
1
2 km
Łeżowa
Glinki
ŁACKO
Dunajec
Zabrzeż
Zarzecze
BOCZÓW
Ochotnica Dl.
Rzeka
ŁĘG DUN.
Sobel
TYLMANOWA

Dunajec drainage-basin in the period of 1000–1966. 14 epicentres were situated within the basin itself. Most frequently, earthquakes occurred in the Pieniny Mts. (5) and the High Tatra Mts. (4), rarely – in the Beskid Sądecki Mts. (3), in the Podhale (2) and in the Orawa Basin (2). The epicentres are situated on the inner side of the Peripieninian Lineament (Pagaczewski, 1972). Focal depths in the Pieniny Mts. reach 23 km. The nature of seismic events, reviewed by the author, enables to expect the magnitude of earthquakes equal to 5–7° MCS in the Pieniny Mts. and 2–4° MCS in the Beskid Sądecki Mts.

The area under study (cf. Fig. 1) falls into a number of tectonic units of various orders. The 1st order units are: the Pieniny Klippen Belt, the Magura nappe, the Grybów unit and the Silesian nappe. Upon these units two superimposed intermontane depressions are developed: the Nowy Targ Basin, formed

Fig. 2. Geomorphological sketch of the northern part of the Dunajec gorge within the Beskid Sądecki Mts. Fragments of planation surfaces: *1* – Beskidy level, *2* – intermontane level, *3* – foothills level. Ridges formed by intersection of valley-sides: *4* – narrow and rounded, *5* – broad and rounded. Summits: *6* – rounded, *7* – domal, *8* – conical ; *9* – passes (cols), *10* – hard-rock ridges built up from sandstones, *11* – block fields (felsenmeer). Scars of rock-slides: *12* – old, *13* – fresh. Scars of landslides, -slips and -slumps: *14* – old, *15* – fresh; *16* – small landslides, -slips and -slumps, *17* – creepbuilt (colluvial) fan plains, *18* – land-slide, -slip tongues, *19* – scree heaps below scars of rockfalls, *20* – solifluction-built plains, *21* – compact, silty loams. Scarps of river terraces and alluvial fans of relative altitudes: *22* – below 3 m, *23* – 3–6 m, *24* – 6–12 m, *25* – above 12 m. Rock and erosion-accumulational terrace plains: *26* – Biber, *27* – Donau, *28* – Günz, 29 – Mindel, *30* – Riss. Erosion-accumulational and fill top terraces: *31* – Würm (W – Würm, LG – Late Glacial), *32* – Holocene; *33* – alluvial fans. River beds cut in solid rock: *34* – medium, *35* – small; *36* – river beds cut in alluvial and colluvia. Abandoned loops cut in alluvia: *37* – fresh and holding water, *38* – old and dry. Rapids in river beds: *39* – medium, *40* – small rivers; *41* – plunge pools, eversion channels, *42* – hanging valley steps, *43* – chutes, *44* – valley-heads and saucer-shaped valleys. River-cliffs: *45* – 6–12 m, *46* – above 12 m; *47* – outcrops of Early Quaternary conglomerates

Fig. 2. Szkic geomorfologiczny północnej części przełomu Dunajca przez Beskid Sądecki. Fragmenty powierzchni częściowego zrównania: *1* – poziom beskidzki, *2* – poziom śródgórski, *3* – poziom pogórski. Grzbiety utworzone na przecięciu zboczy dolinnych: *4* – wąskie i zaokrąglone, *5* – szerokie i zaokrąglone. Wierzchołki: *6* – kopiaste, *7* – kopulaste, *8* – stożkowe; *9* – przełęcze, *10* – grzbiety twardzielcowe zbudowane z piaskowców, *11* – blokowiska. Nisze lub tylne progi osuwisk skalnych: *12* – utrwalone, *13* – świeże. Nisze lub tylne progi osuwisk ziemnych: *14* – utrwalone, *15* – świeże; *16* – drobne osuwiska i zerwy, *17* – powierzchnie osuwiskowo-złaziskowe, *18* – jęzory osuwiskowe, *19* – zwały obrywu, *20* – równiny akumulacji soliflukcyjnej, *21* – scementowane gliny pylaste. Krawędzie teras rzecznych i stożków napływowych o wysokości względnej: *22* – poniżej 3 m, *23* – 3–6 m, *24* – 6–12 m, *25* – ponad 12 m. Równiny teras skalnych i skalisto-osadowych: *26* – Biber, *27* – Donau, *28* – Günz, *29* – Mindel, *30* – Riss. Terasy skalisto-osadowe i osadowe włożone: *31* – Würm (*W* – Würm, *LG* – późny glacjał), *32* – holoceńskie; *33* – stożki napływowe. Koryta rzeczne wycięte w skałach podłoża: *34* – średnie, *35* – małe; *36* – koryta rzeczne wycięte w aluwiach i koluwiach. Koryta starorzeczy wycięte w aluwiach: *37* – świeże, głębokie, z wodą, *38* – stare, płytkie, suche. Progi skalne w korytach rzek: *39* – średnich, *40* – małych; *41* – kotły i rynny eworsyjne; *42* – progi u wylotów dolin zawieszonych, *43* – żleby, *44* – leje źródłowe i doliny nieckowate. Podcięcia erozyjne o wysokości względnej: *45* – 6–12 m, *46* – ponad 12 m; *47* – wychodnie dolnoczwartorzędowych zlepieńców

Fig. 3. Geomorphological sketch of the Nowy Sącz Basin and its margin. For explanation – see Fig. 2.

Fig. 3. Szkic geomorfologiczny Kotliny Sądeckiej i jej obrzeżenia. Objaśnienia jak na figurze 2

Fig. 4. Geomorphological sketch of the Dunajec valley within the Beskid Wyspowy Mts. and the Rożnów Plateau. For explanation – see Fig. 2.

Fig. 4. Szkic geomorfologiczny doliny Dunajca w obrębie Beskidu Wyspowego oraz Płaskowyżu Rożnowskiego. Objaśnienia jak na figurze 2

on the Magura nappe and the Pieniny Klippen Belt and, the Nowy Sącz Basin, lying on the Magura flysch. Both depressions are filled by freshwater Neogene deposits, several hundred metres thick.

Ostaficzuk and Pszczółkowski (1978) and Ostaficzuk (1978), by the use of LANDSAT-2 images, have distinguished several "photolineaments", transversing the territory of the Dunajec drainage-basin. These lines strike SW – NE, W – E, N – S and, in the northern part of the basin, NNW – SSE. The majority of lineaments neither coincide with the course of overthrusts nor with faults. The Pieniny Klippen Belt, the northern margin of the Nowy Sącz Basin and the Rożnów Plateau are the only exceptions.

LATE NEOGENE PALAEOGEOGRAPHY OF THE MIDDLE PART OF THE DUNAJEC DRAINAGE-BASIN

The results of investigations on planation surfaces in the southern part of the Dunajec drainage-basin are included in one of the author's previous papers (Zuchiewicz, 1980). This chapter gives a brief account of these investigations.

The oldest Carpathian planation surface, the so called "Beskidy level" (Starkel, 1969; Mazúr and Činčura, 1975; Baumgart-Kotarba, Gilewska and Starkel, 1976), was formed during the Sarmatian. This level can be seen in the form of smoothed, flat-topped crests of the Lubań and Radzieiowa Ranges (cf. Table 1). It was strongly disturbed in the Moldavian phase (Early Pannonian).

In the Late Miocene and Early Pliocene periods, the Pieniny Klippen Belt represented a range dissected by small streams. According to Birkenmajer (1979), the northern slopes of the Pieniny Mts. were drained by the "Nowy Sącz's Dunajec system" at that time. During the Pliocene a strong subsidence is known to have taken place within the Orawa – Nowy Targ Depression. The zone of the most intensive subsidence followed the northern margin of the Pieniny Klippen Belt (Watycha, 1976). The Gubałówka Foothills, as well as the Tatra region underwent slight uplift, hence the Tatra Mts. constituted an upland at that time (Klimaszewski, 1965).

During the Pannonian, warm and dry climatic conditions enabled intensive planation processes. The "intermontane level" (Klimaszewski, 1937; Starkel, 1969; Mazúr and Činčura, 1975) is believed to have been formed then.

Comparing the altitudes of the intermontane level within various mountain groups around the Pieniny region, one can notice the specific character of the Lubań Range. It is characterized by the highest absolute altitudes (770 – 1190 m above sea level), as well as by their distinct differentiation. These features are evidence of differential uplift tendencies of the axial part of this range.

During the Middle Pliocene, uplifting movements affected the Lubań – Radziejowa Ranges, whereas the Krośnica catchment area underwent subsidence. These movements can be confined to the Attican and Rhone orogenic phases. The amplitude of tectonic movements is evidenced by differences in heights between preserved remnants of the intermontane and foothills levels (Table 1, 2). They vary from 170 – 430 m (Lubań Range) to 115 – 150 m (Spiš Pieniny Mts.) and to 100 – 150 m (Pieniny Mts.).

Table – Tabela 1

Altitudes of planation surfaces within the middle part of the Dunajec drainage-basin

Wysokości powierzchni częściowego zrównania w obrębie środkowej części dorzecza Dunajca

Mountain range		Beskidy level	Intermontane level	Foothills level	Riverside level
Spiš Pieniny Mts.		–	805 (295)	690 – 760 (150 – 210)	625 – 640 (120 – 135)
Pieniny Mts.	Polish part	–	750 – 800 (330 – 340)	650 – 710 (170 – 240)	600 – 640 (120 – 150)
	Slovak part	–	700 – 880 (270 – 440)	590 – 680 (150 – 190)	560 – 610 (100 – 150)
Lubań Range		?	770 – 1190 (265 – 560)	600 – 760 (155 – 240)	520 – 650 (90 – 150)
Radziejowa Range	W	905 – 1195 (530 – 875)	635 – 830 (300 – 495)	495 – 690 (175 – 290)	450 – 525 (145 – 165)
	E	850 – 1050 (520 – 690)	650 – 815 (310 – 475)	515 – 620 (190 – 270)	410 – 515 (95 – 155)
Jaworzyna Krynicka Range	W	885 – 1075 (545 – 760)	640 – 830 (300 – 480)	475 – 590 (170 – 260)	435 – 505 (110 – 155)
	E	–	660 – 930 (300 – 480)	520 – 725 (170 – 260)	475 – 600 (100 – 155)
Łącko – Podegrodzie Foothills		–	605 – 685 (260 – 290)	495 – 610 (165 – 215)	435 – 605 (125 – 155)
Grybów Mts.		–	540 – 800 (270 – 380)	435 – 690 (160 – 250)	370 – 580 (100 – 155)
Beskid Wyspowy Mts.	W	–	585 – 645 (305 – 350)	450 – 590 (180 – 230)	355 – 450 (90 – 135)
	E	–	525 – 575 (270 – 315)	415 – 515 (155 – 240)	

Altitudes in brackets – in metres above valley-floors.

Simultaneously with the formation of the "intermontane level", clayey-silty deposits are known to have developed within depressions and flood-plains of the ancient Dunajec. These deposits interfinger with slope deposits, derived from the southern slopes of the Lubań Range (Mizerna, Kluszkowce, Grywałd, Dziadowe Kąty and Potoczki). Bakker (1965) stated that floristic remains found in Pliocene deposits from the Mizerna locality can be used as indicators of tropical "sula". Such a kind of tropical waterfalls occurs within mountains with thick weathering covers. The thickness of the weathering covers in the Tatra region could have reached 20 – 30 m in the Middle Pliocene times.

The Pliocene deposits filling the Dębno – Frydman Graben are composed of clays with intercalations of sands and fine-grained gravels, and are 21 – 26 m thick (Niedzielski, 1971). These deposits occur about 100 m beneath the base of the Sarmatian deposits from Huba, situated on the northern margin of the graben. Clay and clayey-sandy deposits of Middle to Upper Pliocene age crop out at Mizerna. According to Środoń (1973) they were re-deposited by Pleistocene solifluction processes, from previously higher situated sites. Similar deposits occur at Grywałd, Dziadowe Kąty and Potoczki (Klimaszewski, 1948a; Birkenmajer, 1958). Their thickness does not exceed 9 – 16 m. They reveal a remarkable variability of frequently wedging-out beds as well as the presence of gravel and clay lenses within sands, a large amount of angular rock debris and the dip of sedimentary complexes up to 6°. All these features seem to indicate a solifluctional, post-sedimentary redeposition. The age of floristic remains found in the clays from Dziadowe Kąty and Potoczki localities is thought to be Lower (Szafer, 1954) or Middle (Birkenmajer, 1958; Oszast, 1973) Pliocene.

During the Rhone and Valachian orogenic phases, the forementioned deposits were redeposited due to lowering movements which affected southern slopes of the Lubań Range (Fig. 5). The intermontane level was then dissected and slightly tilted (Starkel, 1972).

In the Romanian, the topography of the Pieniny Klippen Belt was characteriz-

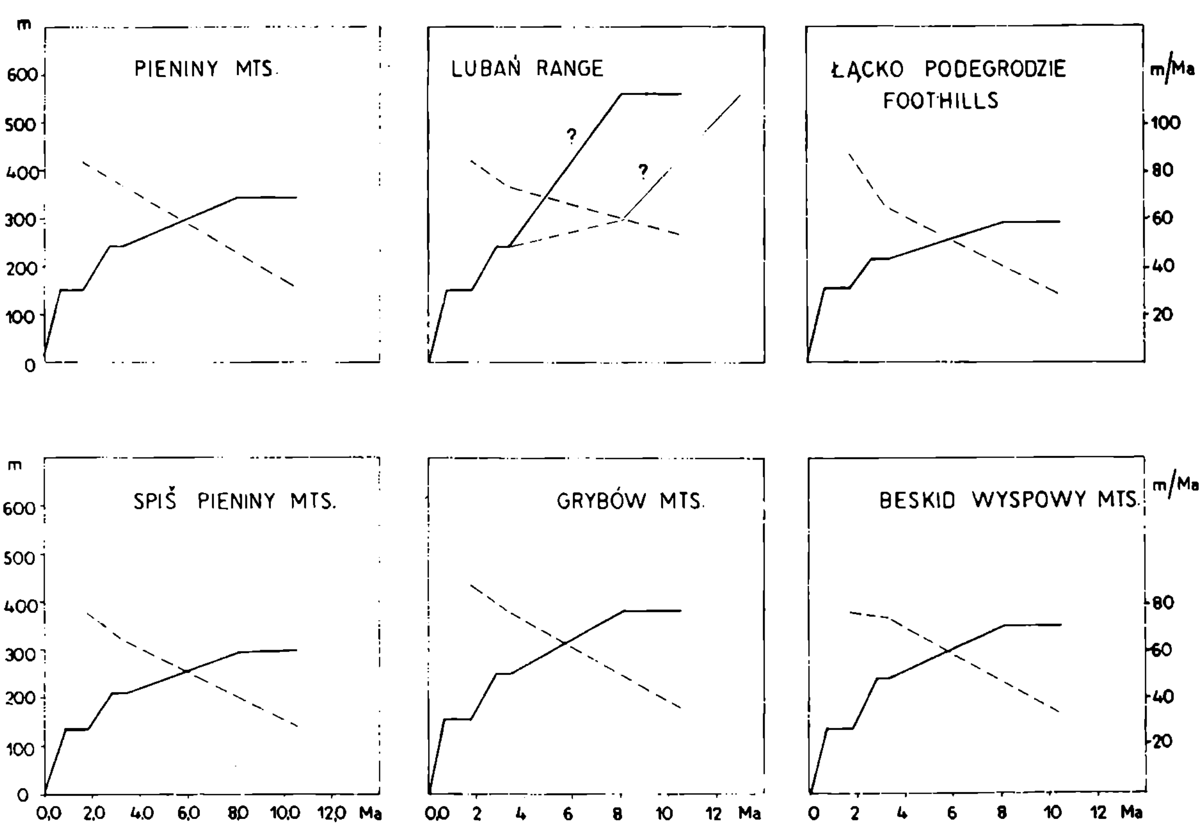


Fig. 5. Bubnoff diagrams plotting uplift against time for the selected mountain ranges during the Neogene. Dotted lines – cumulative uplift rates in Bubnoff units (metres per million years)

Fig. 5. Diagramy Bubnoffa obrazujące rozmiary wypiętrzania wybranych masywów górskich w neogenie. Linia przerywana – krzywa kumulacyjna tempa wypiętrzania w jednostkach Bubnoffa (metry/mln lat)

ed by the presence of broad valleys and large flat crests. The foothills level began to develop at that time. It truncates flysch deposits of various resistance. Starkel (1975) and Baumgart – Kotarba, Gilewska and Starkel (1976) applied the Late Pliocene age for this level, but Henkiel (1969) thought it to be formed during the Middle Pliocene. Around the Lubań Range this level represents a glacis-type planation surface, but within the other areas, however, it resembles a surface formed due to lateral river erosion.

The higher situated remnants of this level are clearly visible within the Radziejowa Range (175 – 290 m), the Jaworzyna Krynicka Range (170 – 260 m) and in the Grybów Mts. (160 – 250 m).

When comparing the altitudes of preserved fragments of the Late Pliocene (Romanian) foothills level to the Lower Quaternary level, one can estimate the amount of uplift in various parts of the Dunajec drainage-basin. This upheaval took place during the Valachian phase (cf. Table 2). The total amount

Table – Tabela 2

The amount of uplift of the middle part of the Dunajec drainage-basin during consecutive Neogene and Quaternary orogenic phases (in metres)

Rozmiary podniesienia środkowej części dorzecza Dunajca w poszczególnych fazach tektonicznych neogenu i czwartorzędu (w metrach)

Mountain group – phase		Moldavian	Attic and Rhone	Valachian	Pasadenian
		Pannonian	Pontian-Dacian Dacian-Romanian	Romanian--Donau	Cromerian--Mindel 1
Spis Pieniny Mts.		–	85 – 145	27 – 75	45 – 50
Pieniny Mts.	Polish part	–	100 – 160	50 – 90	50 – 95
	Slovak part	–	120 – 250	40 – 50	15 – 65
Lubań Range		?	110 – 320	65 – 90	15 – 70
Radziejowa Range	W	230 – 380	125 – 205	30 – 125	70 – 90
	E	210 – 225	120 – 205	95 – 115	35 – 95
Jaworzyna Krynicka Range	W	245 – 280	130 – 220	60 – 105	60 – 95
	E	–	130 – 220	70 – 105	–
Łącko – Podegrodzie Foothills		–	75 – 95	40 – 60	80 – 85
Grybów Mts.		–	110 – 130	60 – 105	60 – 85
Beskid Wyspowy Mts.	W	–	120 – 125	90 – 95	40 – 80
	E	–	75 – 115	65 – 105	–

Age of orogenic phases – according to: Vass, Bagdasarjan and Slavik (1974), Vass (1975) and Van Eysinga (1975).

of Neogene subsidence of the Nowy Targ Basin was estimated by Watycha (1976) to be 900–1600 m. The accompanying uplift of the Lubań Range reached a value of 200–600 m. The approximate magnitudes and rates of uplift during Pliocene and Early Quaternary times are shown in Table 2. These values should be treated very cautiously, so as they represent only a rough estimation.

At the decline of the Pliocene intensive weathering processes occurred. They resulted in the formation of the weathering cover which developed on the Magura, Jazowsko and Lower Łącko Beds. These deposits underlie Early Quaternary terrace covers, the patches of which remained at Kadcza, Płusy and Falkowa.

At the Płusy site, SE of Podegrodzie village, there occur laminated, clayey-sandy deposits which include a horizon of carbonate concretions and calcareous sandstones. It can be suggested that this cover was formed at the decline of the Pliocene and/or in the earliest Quaternary. The mechanism of its formation could have resembled the process that leads to the formation of "caliche". The source of calcium carbonate were sandstones of the Lower Łącko Beds. The thickness of the horizon, rich in carbonate concretions as well as calcareous detritus, does not exceed a value of 1 to 10 cm. There also occur fragments of highly calcified sandstones. Carbonate concretions are usually oval or sub-spherical in shape. They contain 50% $CaCO_3$, as well as sand and quartzitic silt.

ORIGIN OF THE DUNAJEC AND POPRAD WATER-GAPS

There exist various concepts about the origin and age of the Dunajec water-gaps within the Pieniny Mts. A list of main ideas is given in the author's previous work (Zuchiewicz, 1980).

The age of the Dunajec water-gap can be estimated on the basis of several facts, namely: on the occurrence of planation surfaces in the Pieniny Mts. and on the distribution and age of the Pliocene deposits which outcrop in the eastern part of the Nowy Targ Basin as well as in the Krośnica catchment area.

It can be suggested that the first phase of the water-gap's formation started in the Middle Pliocene, but the Early Quaternary seems to be abetter estimation. This is proved by the fact that within the Dunajec gorge only the Lower Quaternary level remained. A reconstruction of the original position of the freshwater Pliocene deposits on the southern slopes of the Lubań Range (above 650 m above sea level) calls for the re-examination of Gadomski's (1934) and Żytko's (1963) concepts, concerning the Pliocene course of the Dunajec within the Krośnica and Grajcarek valleys.

The main factors that have influenced the formation of the Niedzica and Pieniny water-gaps are: differences in rock resistance, Pliocene-Early Pleistocene block-type crustal movements, the Plio-Quaternary activity of the Peripieninian deep-seated fault, as well as large depressions of the Pieniny Klippen Belt and north-south striking fault zones. These factors have determined the formation of incised meanders within the Pieniny gorge.

The results of the author's investigations in the Dunajec gorge in the Beskid

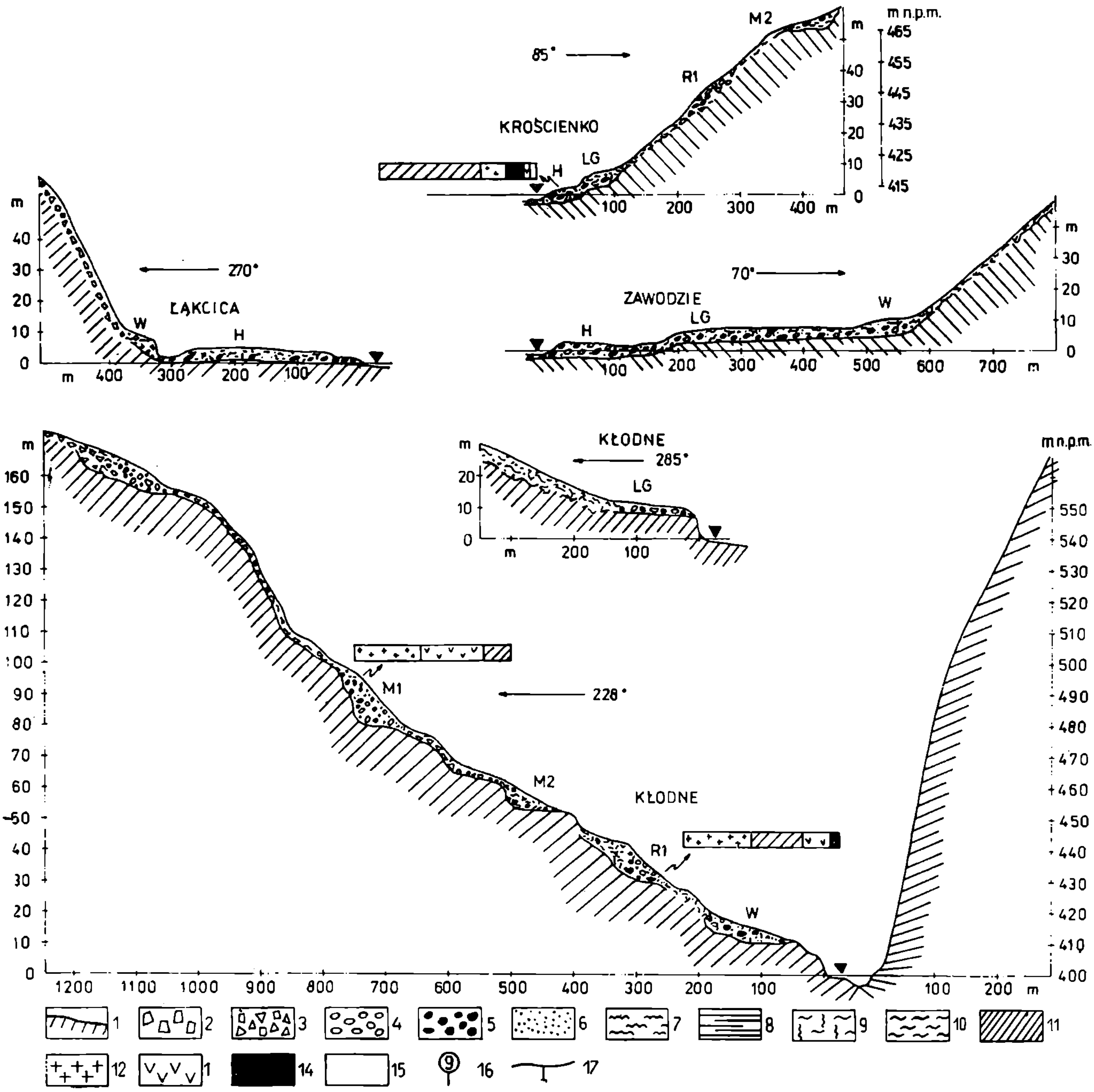


Fig. 6. Geomorphological cross-sections of the Dunajec valley within the Beskid Sądecki Mts. *1* – outcrops of solid rocks, *2* – blocks, *3* – debris, *4* – gravels and pebbles derived from flysch, *5* – gravels and pebbles of the Tatra rocks, *6* – sands, *7* – silts, *8* – clays, *9* – loess-like loams, *10* – loams. Diagrams of petrographic composition: *11* – sandstones, *12* – granites, *13* – quartzites, *14* – limestones, *15* – other rocks; *16* – borings made by Geological Institute, *17* – wells

Fig. 6. Przekroje geomorfologiczne przez dolinę Dunajca w Beskidzie Sądeckim. *1* – cokół skalny, *2* – głazy, *3* – rumosz ostrokrawędzisty, *4* – żwiry i otoczaki materiału fliszowego, *5* – żwiry i otoczaki materiału tatrzańskiego, *6* – piaski, *7* – pyły, *8* – iły, *9* – gliny lessopodobne, *10* – gliny. Diagramy składu petrograficznego: *11* – piaskowce, *12* – granity, *13* – kwarcyty, *14* – wapienie, *15* – pozostałe skały; *16* – wiercenia Instytutu Geologicznego, *17* – studnie

Sądecki Mts. seem to prove hitherto proposed hypotheses about its antecedent origin (Sawicki, 1911; Smoleński, 1937; Klimaszewski, 1937, 1948b; Starkel, 1972; Zuchiewicz, 1978). The oldest deposits including the Tatra gravels are fluvial covers, found in the vicinity of Kłodne (Fig. 6). They are believed to have been deposited during the Biber "glaciation". It can be stated that the gorge itself was formed during the Early Quaternary, but its present shape is due to consecutive deepening in the Pleistocene.

It is also necessary to revise Klimaszewski's (1961) view concerning the overflow of a Pliocene lake from the Krościenko Basin to the north. This lake – if it existed – was too small to give origin to the Dunajec valley.

The origin of the Poprad water-gap within the Beskid Sądecki Mts. has not yet been explained. Rehman (1895) pointed to the role of tectonic movements, Sawicki (1909) applied the antecedent theory, and Gadomski (1934) suggested capture. The author inclines to accept the last concept.

QUATERNARY EVOLUTION OF THE DUNAJEC DRAINAGE-BASIN

At the beginning of the Quaternary period the general upheaval of the Central West Carpathians is believed to have taken place (Harčar, 1975; Kvitkovič and Vanko, 1971). It was accompanied by subsidence of intermountain depressions and neighbouring lowlands (Baňacký, 1978). These movements led to the formation of deep tectonic troughs in the pre-Quaternary basement, along the northern and NW margin of the Carpathian arc.

Between 1.5 and 0.86 M.y., the third volcanic subphase in the Jesenik Mts. took place (Šibrava and Havliček, 1980). This subphase is associated with the Drahany tectonic phase which occurred at the lower boundary of the Middle Quaternary, i.e. before the first continental glaciation (Šibrava, 1979). Tectonic activity reached its maximum immediately before the Matuyama-Brunhes boundary, i.e. 0.69 M.Y. BP (Šibrava and Havliček, 1980).

During the Early Quaternary the Tatra streams were captured by the Biały Dunajec and, the Biała Woda stream was captured by the Białka river system (Halicki, 1930; Watycha, 1976). Changes in the channel network were closely associated with the tectonic mobility of the Podhale and Tatra regions. In the same period (Biber-Günz?), the Dębno – Frydman Graben was formed, and reached a depth of 130 m (Niedzielski, 1971). The Early Pleistocene was also the period when river terraces were developing. These terrace levels were hitherto believed to represent remnants of the "river-side planation surface", formed under cold and dry climatic conditions (Szafer, 1954; Činčura, 1967; Dżułyński et al., 1968).

ANALYSIS OF QUATERNARY RIVER TERRACES OF THE DUNAJEC, POPRAD AND KAMIENICA NAWOJOWSKA VALLEYS

In the Dunajec, Poprad and Kamienica Nawojowska valleys there remained several benches of rock, erosion-accumulational and fill top terraces. Their number and age have been studied by many authors (cf. Smoleński, 1918; Klimaszewski, 1937, 1948b, 1967; Starkel, 1972; Oszczypko, 1973; Zuchiewicz, 1978, 1980).

BIBER

Within the Beskid Sądecki Mts., at the Kłodne and Wietrznica localities, there occur patches of the oldest fluvial deposits. They cover rock socles (cf. Figs. 2 and 6) having a relative height of 150 – 155 m above the valley-floor. These covers contain poorly rounded pebbles derived from flysch and, to a lesser extent, the Tatra gravels. Early Pleistocene age of these deposits can be assumed on the basis of their high position on the valley sides, as well as their petrographic composition and degree of weathering.

In the Podegrodzie Foothills, a number of patches of strongly weathered sandstone pebbles were found. They are 0.4 – 2 cm in diameter and are mixed with angular debris in a matrix of sandy clays. Two distinct terrace levels can be distinguished there: 146 – 150 m and 155 – 160 m.

Similar deposits cover a flat-topped crest of Sokolica, south-west of the town Stary Sącz, at an altitude of 112 – 118 m above the Dunajec's flood-plain.

All these gravels rest on erosional flats, representing fragments of the so called "river-side level". Altitudes of this level vary from 123 – 134 m in the Spiš Pieniny Mts. and up to 100 – 150 m in the Pieniny Mts. (cf. Zuchiewicz, 1980).

To the north of the town Nowy Sącz, as well as in the Poprad and Kamienica Nawojowska valleys, the discussed terrace level is an erosional landform, which occurs at an altitude of 160 – 120 m above the river-beds.

It is impossible to give a precise age estimation of these terrace covers, except for morphostratigraphic criteria. The author suggests that they could have been laid down during the Biber "glaciation".

BIBER – DONAU

On the NW margin of the Nowy Sącz Basin there occur deposits classified as Pliocene or Lower Quaternary in age (Oszczypko, 1973). They consist of conglomerates, composed of pebbles of fine-grained sandstones and marlstones, 10 – 30 (50) cm in diameter, containing intercalations of grey, marly mudstones and fine-grained sandstones, with illite-calcareous cement. Pebble imbrication indicates the direction of transport as from north and NNW. These deposits crop out (cf. Fig. 3) at an altitude of 23 – 140 m above the river-bed. They are underlain partly by flysch and partly by clayey-sandy Badenian deposits. Oszczypko (1973) associated the conglomerates with deposits of the Domański Wierch (Orawa Basin), but Oszczypko and Wójcik (in print) ascribed their formation to the period that followed the Pasadenian orogenic phase. They are by all means older than the overlying gravelly-sandy cover from the Mindel Glacial and younger than the level covered by the Biber and Donau alluvia.

The presence of coarse-grained deposits of alluvial fans, deposited under high-energy conditions, seems to indicate an increase in tectonic activity along transversal faults cutting the Nowy Sącz and Krynica subunits' contact. This activity increased after the Biber stage.

The amount of dissection of rock socles of the Biber terrace in the Dunajec valley is from 53 to 24 m. Higher values are characteristic of the Poprad (62 m) and Kamienica Nawojowska (60 m) valleys.

DONAU

Fluvial deposits, younger than those of the Biber stage, have been preserved almost exclusively on southern slopes of the Łącko – Podegrodzie Foothills. These rest on erosional flats, 90 – 110 m above the river-beds and have a thickness of 2 – 8 (15) m. The gravels which crop out at Maszkowice, Jazowsko, Kadcza, Naszacowice and Stary Sącz, consist of highly weathered sandstone (80%), quartzite (7%) and granite (3%) pebbles, 2 – 15 cm in diameter, mixed with angular rock debris and/or strongly cemented grey, sandy clays.

To the north of Nowy Sącz, in the Poprad valley and within the Kamienica Nawojowska valley (cf. Figs. 2 and 3), the described terrace is almost exclusively a rock one. In the Dunajec valley, the longitudinal profile of this terrace reveals some disturbances. A number of upwards can be seen there (Figs. 10 and 11), especially in the vicinity of Jazowsko, Rdziostów and Znamirowice. Between Chełmiec and Znamirowice, the rock socle splits into two levels: 103 – 98 m and 120 – 115 m above the valley-floor.

Considering the position of the preserved covers on valley sides, beneath the oldest Quaternary deposits and above the gravels of the Günz stage, they can be associated with the Danube (Donau) stage.

DONAU – GÜNZ

Between 1.51 and 1.3 N.Y. BP, on the NW margin of the Carpathians, there occurred a phase of increased volcanic activity, accompanied by a phase of intensive tectonic movements (Šibrava and Havliček, 1980). These led to the dissection of alluvial covers and underlying basement rocks.

The depth of dissection increased in the Beskid Sądecki Mts. from west to east. Highest values are characteristic of the Dunajec valley course between Jazowsko and Kadcza (33 – 25 m). In the Poprad valley the amount of river erosion increased to the north, from 10 to 18 m. Within the Grybów and Beskid Wyspowy Mts. the values considered varied from 15 – 25 m in Roszkowice to 30 – 40 m in Rdziostów and 27 – 42 m to the south of Rożnów (cf. Fig. 13).

A period of intensive tectonic activity seems to be associated with tectonic movements of the Pasadenian orogenic phase. These movements caused several disturbances in terrace profiles of the Žitava river in Slovakia (Harčar, 1975).

Interglacial deposits, formed under moderate-warm climatic conditions are preserved at Szaflary, Falsztyn and Mizerna. In the Szaflary quarry they are represented by a 0.1 – 3 m thick regolith that underlies clays, dated back as far as the Cromerian (Birkenmajer and Stuchlik, 1975). Similar regolith-like solis remained on weathered limestones to the west of Falsztyn, in the Pieniny Mts. (Guzik and Łydka, 1969). At the foot of the Lubań Range, an accumulation of clayey and clayey-sandy deposits took place (Mizerna).

Altitudes of the Dunajec river terraces within the Beskid Sądecki Mts.,
r – right side, l – left side, in brackets
Wysokości teras Dunajca w obrębie Beskidu Sądeckiego, Pogórza
r – strona prawa, l – strona lewa,

Cross-section	Krościenko	Kłodne	Wietrznica	Boczów	Łącko	Jazowsko
Region		Beskid Sądecki Mts.			Łącko – Podegrodzie	
Distance from Nowy Targ, km	50 – 51	55	63	65	70 – 71	76
Biber	–	154 – 161 (154) l	150 – 155 (150) l	–	–	–
Donau	–	–	–	–	104 (98) l	113 – 117 (110) l
Günz	–	–	–	–	95(85) 84(83) l	92 – 93 (81) l 77 – 82 (77) r
Mindel 1	–	78 – 96 (78) l	75 – 85 (75) l	–	70 – 74 (56) l	56 – 63 (56) l
Mindel 2	52.5 – 56 (52.5) r	51.5 – 55 (51.5) l	47.5 – 65 (47.5) l	55 – 68 45 – 52 (45) l	50 – 58 44 – 45 (38 – 43) l	48 – 51 (44) r
Riss 1	26 – 32 (26) r	29 – 41 (29) l	21 – 26 (21) l	25 – 28 (25) l	23 (21) l	22 – 30 (13 – 14) l
Riss 2	–	20 – 31 (20) r	–	11 – 24 (11) r	16 – 17 (12) l	–
Würm	9 – 11.5 (4) r	16 – 18 (10) l	14 – 16.5 (11) l 7 – 8 (5.5) l	8 – 10 (3) l	10 – 13 (– 5) l	9 – 121
LG	5.5 – 7 r	10 – 11 (10) l	–	6 – 91	5 – 7 (– 4) l	5 1
Holocene	1 – 2 (– 3) r	3.5 – 5 (0) r 1.5(0) r	2 – 3 (0) l 1(0) r	2 – 5 (– 5) l 1 lr	4(– 4) l 3,2 l	3 – 4 l 4 – 5(0) r

Table – Tabela 3

the Łącko – Podegrodzie Foothills and the Nowy Sącz Basin (in metres)
– altitudes of rock socles in metres
Łącko-Podegrodzkiego oraz w Kotlinie Sądeckiej (w metrach)
w nawiasach – wysokości cokołu skalnego, w metrach

Kadcza	Naszacowice	Podegrodzie	Brzezna	Biegonice	Gaj	Biczyce Dolne
Foothills			Nowy Sącz Basin			
78	82	85	89	90	92	96
–	–	146 – 149 l	–	–	–	(150) l
105 – 106 (96 – 104) l	109 – 110 (90) l	96 – 105 l 88 r	–	–	–	–
77 – 83 (77) l	88 (71) l	–	–	–	71 – 88 (71) l	–
65 – 68 (65) l 62 – 65 (62) l	68 – 74 (56) l 53 – 64 (53) l	57 – 72 l	53 – 61 l 47 – 51 l	55 – 80 (55) r	59 – 72 (59) r	
36 – 44 (36) r	48 (38) l	48 – 50 32 – 38 l	29 – 33 l	41 – 48 (41) r	–	–
22 – 24 (19) r	26 (14) l	22 – 24 l (12 – 13) l	12 – 23 (11 – 12) l	25 – 28 (10) r	20 – 24 (16 – 20) r	21 – 22 l
12 – 14 (10) r	–	15 – 16 (12 – 13) l	–	13 – 20 (10) r	12 – 22 (3 – 10) r	10 – 15 l
8 – 9 r 9 – 12 (1.5) l 7 – 8(0) l	8 – 9 l	10 l 8 – 14 (– 2.5) r	7 – 10 l 6 – 9 r	10 – 11 r	–	9(– 4) r 5 – 12 (– 4) l
4 – 5 (1.5) l	4 – 5 l	5 – 6 l	5 – 6 l	5 – 7 r	4 – 5 r	4 – 5(– 4) l
1.5 – 2 r 0.5 – 1 r	3 – 3.5 l 1 – 2(0) l	3.5 – 4 l 4 – 4.5 r 2 – 3 l r	3 – 4 l 1 r 1 – 2 l	3.5 – 4 r	2 r	2.5 l 0.5 l

At the decline of the interglacial and in the anaglacial phase of the following glacial stage, an intensive deposition of fluvial deposits began. Cold and wet climatic conditions prevailed (Szafer, 1954).

GÜNZ

The river terraces formed in this period can be traced in the Beskid Sądecki Mts. (Fig. 6), within the Łącko-Podegrodzie Foothills and on the western margin of the Nowy Sącz Basin. They represent a number of flats covered by fluvial gravels and sands, 3 – 4 m (Kadcza, Dąbrówka Polska) to 9 – 17 m (Gaj) thick. These gravels consist of sandstone, quartzite and granite pebbles, 4 – 6 to 8 – 10 cm in diameter, located within clayey sands and covered by silty-sandy clays.

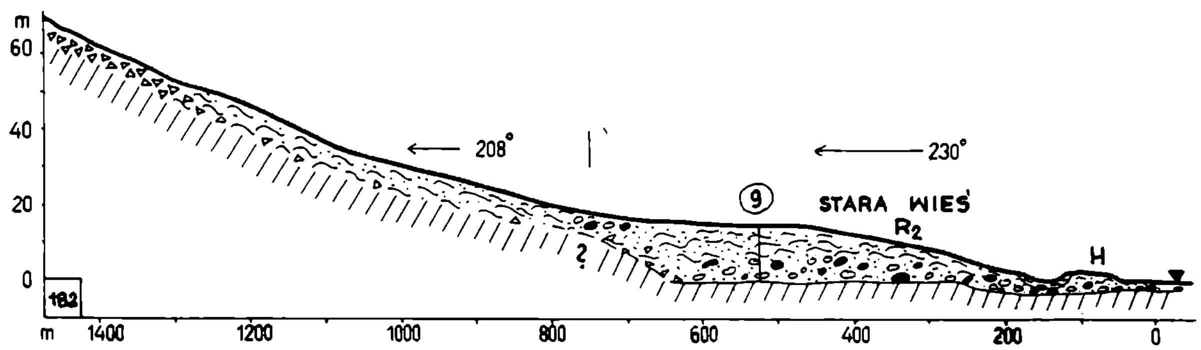


Fig. 7. Geomorphological cross-section of the Dunajec valley within the Beskid Wyspowy Mts. For explanation – see Fig. 6

Fig. 7. Przekrój geomorfologiczny przez dolinę Dunajca w Beskidzie Wyspowym. Objaśnienia jak na figurze 6

Fluvial deposits rest on rock socles, gently sloping from 84 to 71 m above the valley-floors. To the north of the Nowy Sącz Basin, rock socle's altitudes rise to 80 – 93 m (Fig. 7).

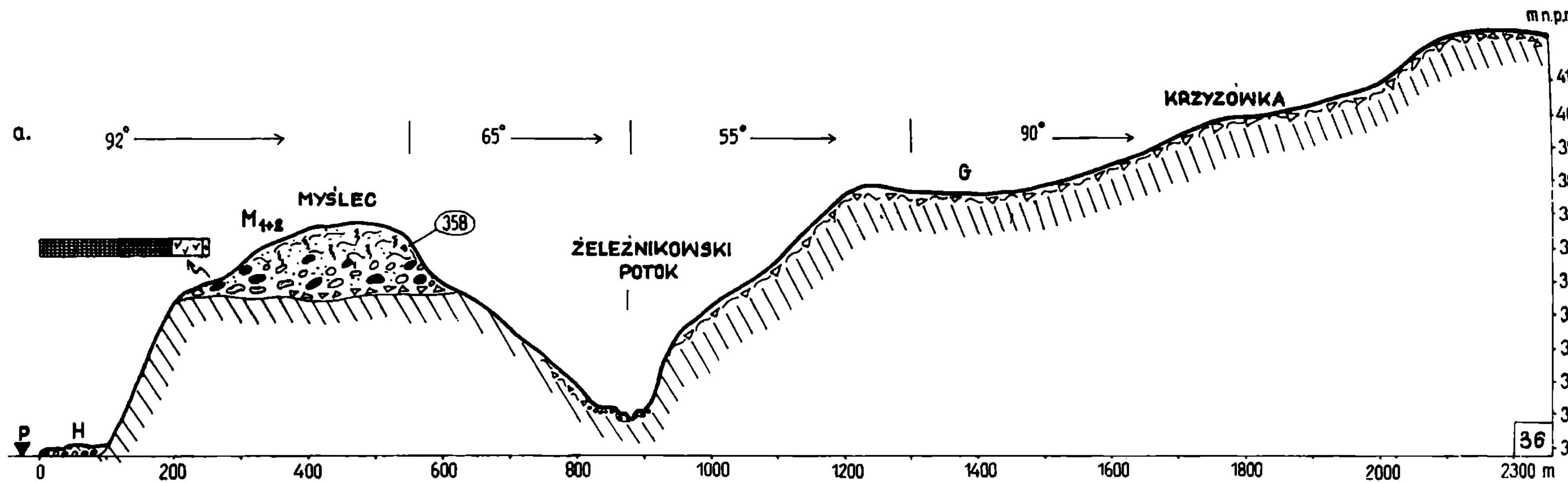
Disturbances in longitudinal profiles of the rock socles can be seen to the east of Jazowsko (Fig. 10), as well as in the vicinity of Rożnów and Tęgoborze.

On the Poprad valley-sides (Figs. 3 and 8), poorly preserved fragments of gravel covers remained, being composed of quartzite and sandstone pebbles. They rest on flat, erosional shelves, 80 m high (Popowice, Szczerbiniec, Zagórze Myśleckie). To the north of Myślec, the substratum of alluvial covers descends to a height of 74 m (Fig. 8).

In the Kamienica Nawojowska valley, altitudes of rock socles do not exceed 52 – 57 m (cf. Figs. 9 and 12).

GÜNZ – MINDEL

The erosional dissection of rock socles which started at the decline of the Günz stage, reached its maximum intensity during the Cromerian interglacial. Rates of dissection were higher in the vicinity of Maszkowice (28 – 30 m) and Jazowsko (21 – 24 m), but they decreased eastwards, up to 15 m in the Nowy Sącz Basin. A stronger erosional activity was observed in the Grybów Mts. (35 m).



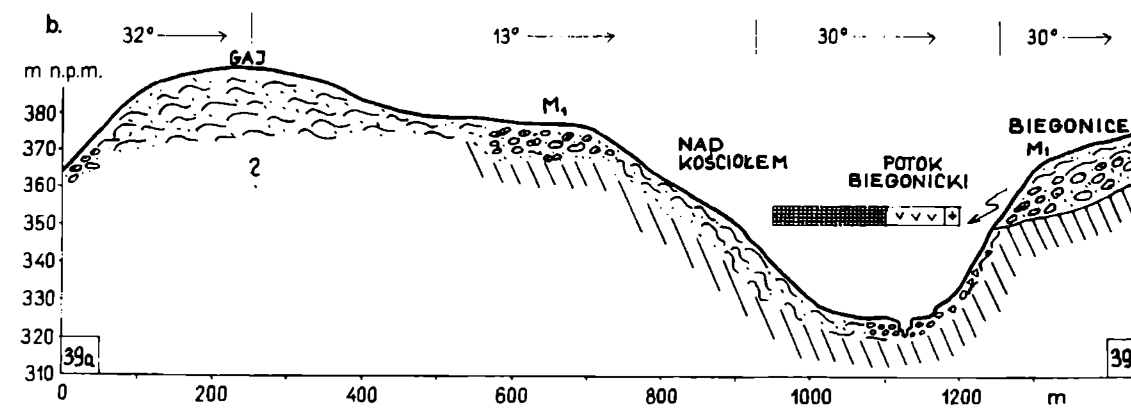
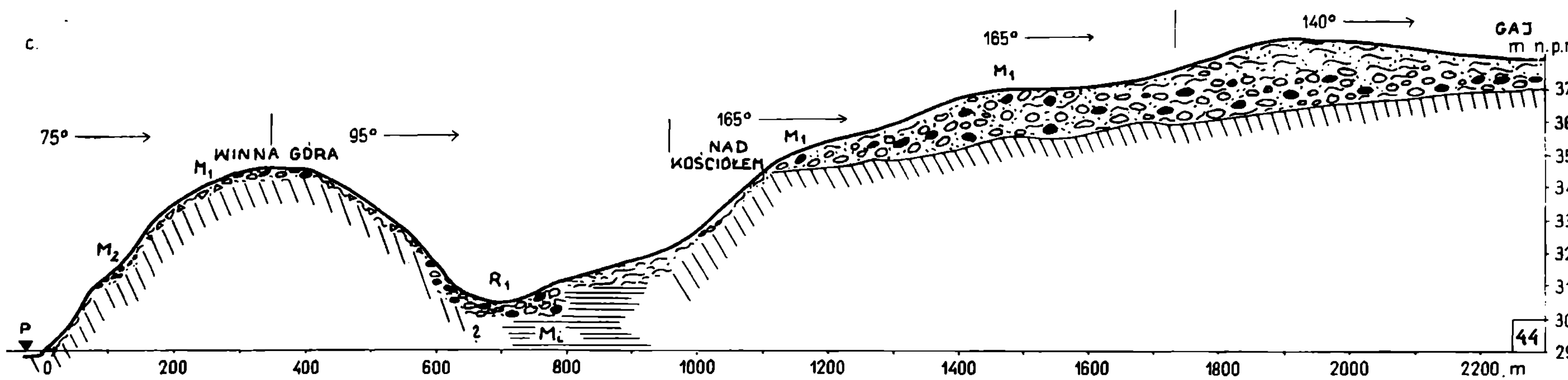
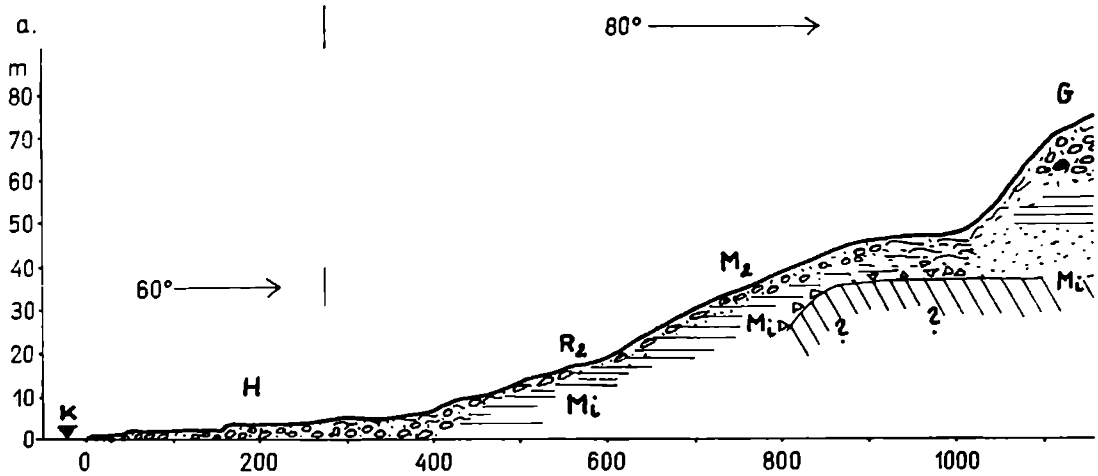


Fig. 8a, b, c. Geomorphological cross-sections of the Poprad valley. For explanation – see Fig. 6

Fig. 8a, b, c. Przekroje geomorfologiczne przez dolinę Popradu. Objaśnienia jak na figurze 6

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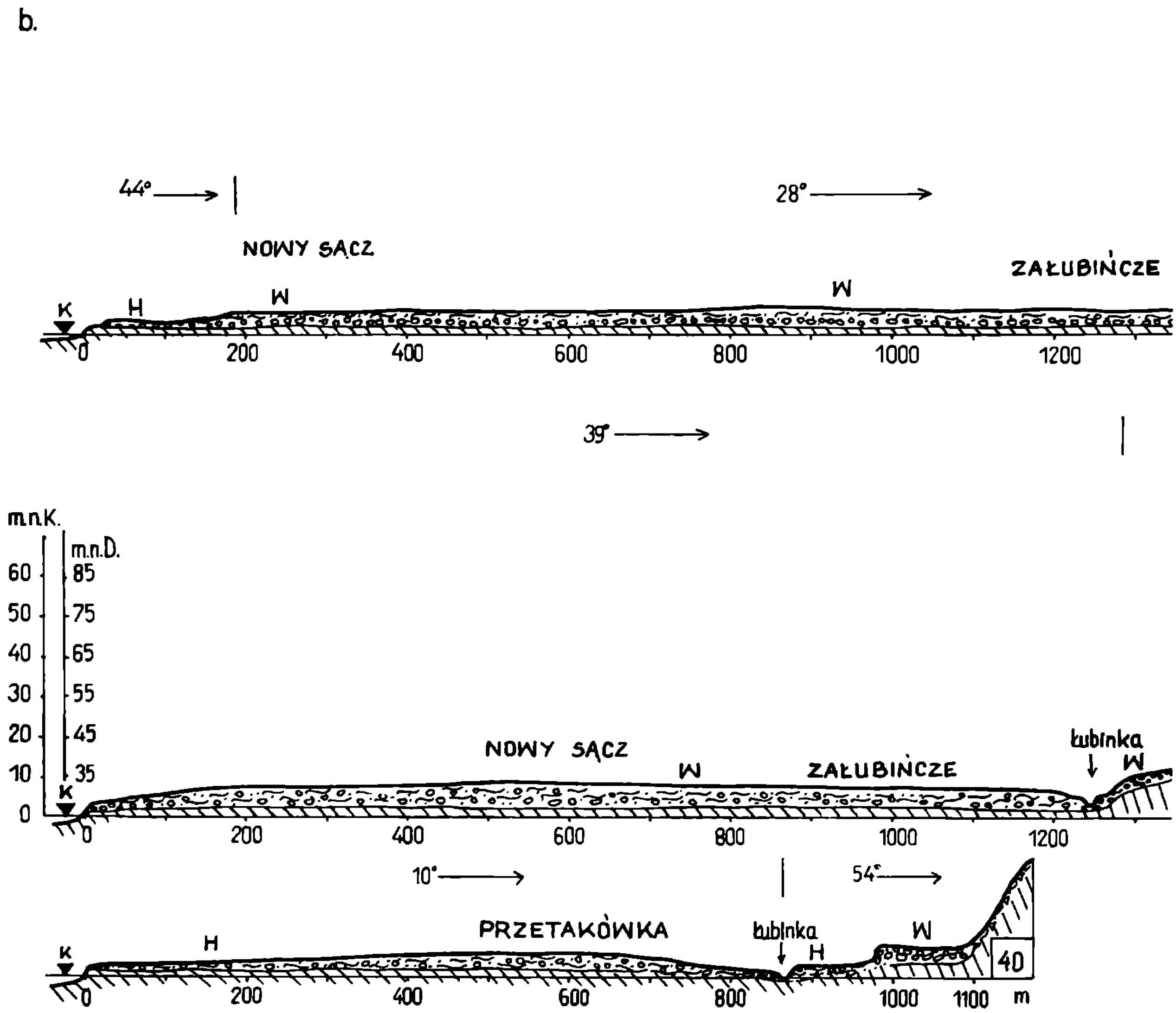
b.
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39°
m.n.K.
m.n.D.
60
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85
75
65
55
45
35
NOWY SĄCZ
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ZAŁUBIŃCZE
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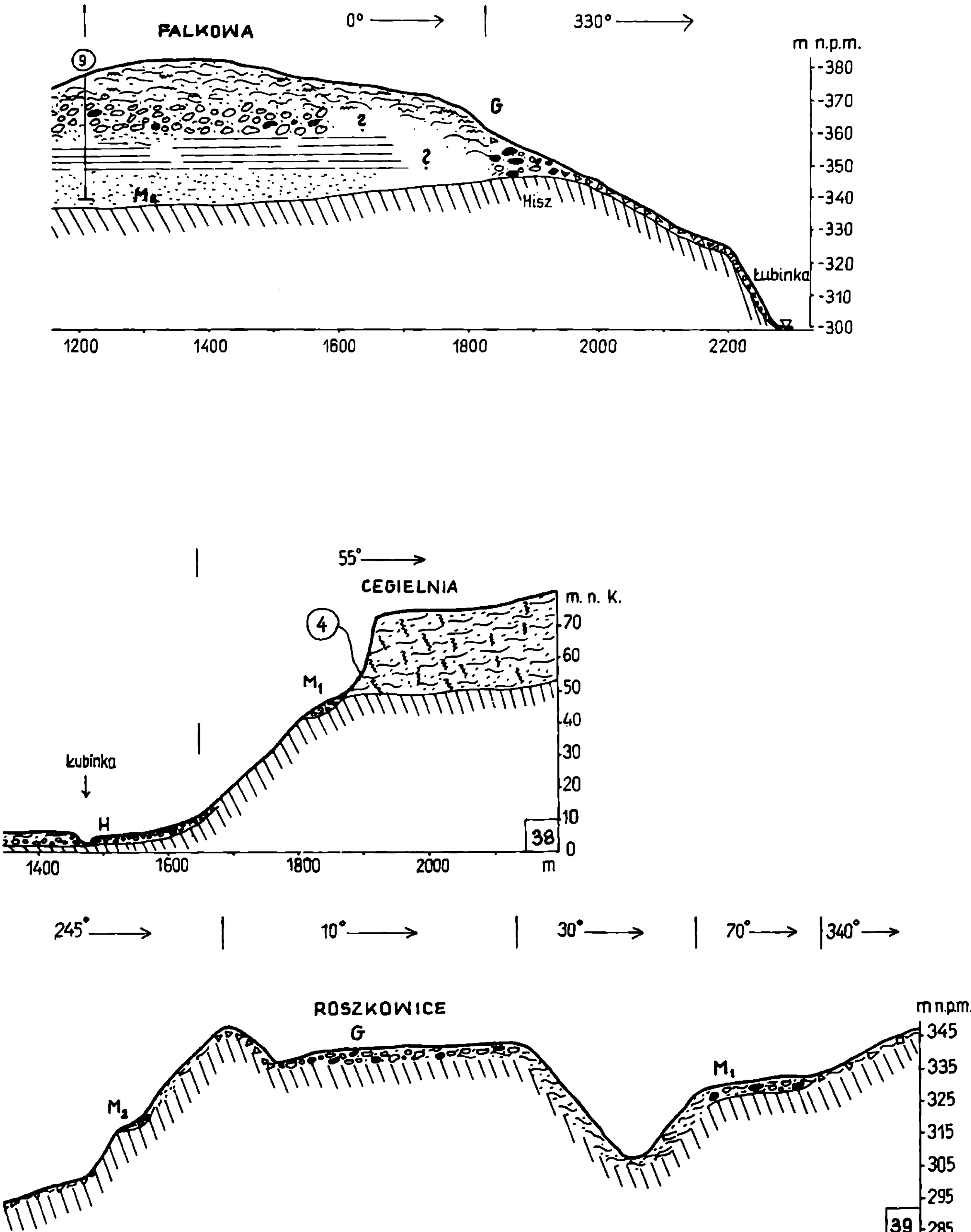


Fig. 9a, b. Geomorphological cross-sections of the Kamienica Nawojowska valley. For explanation – see Fig. 6

Fig. 9a, b. Przekroje geomorfologiczne przez dolinę Kamienicy Nawojowskiej. Objaśnienia jak na figurze 6

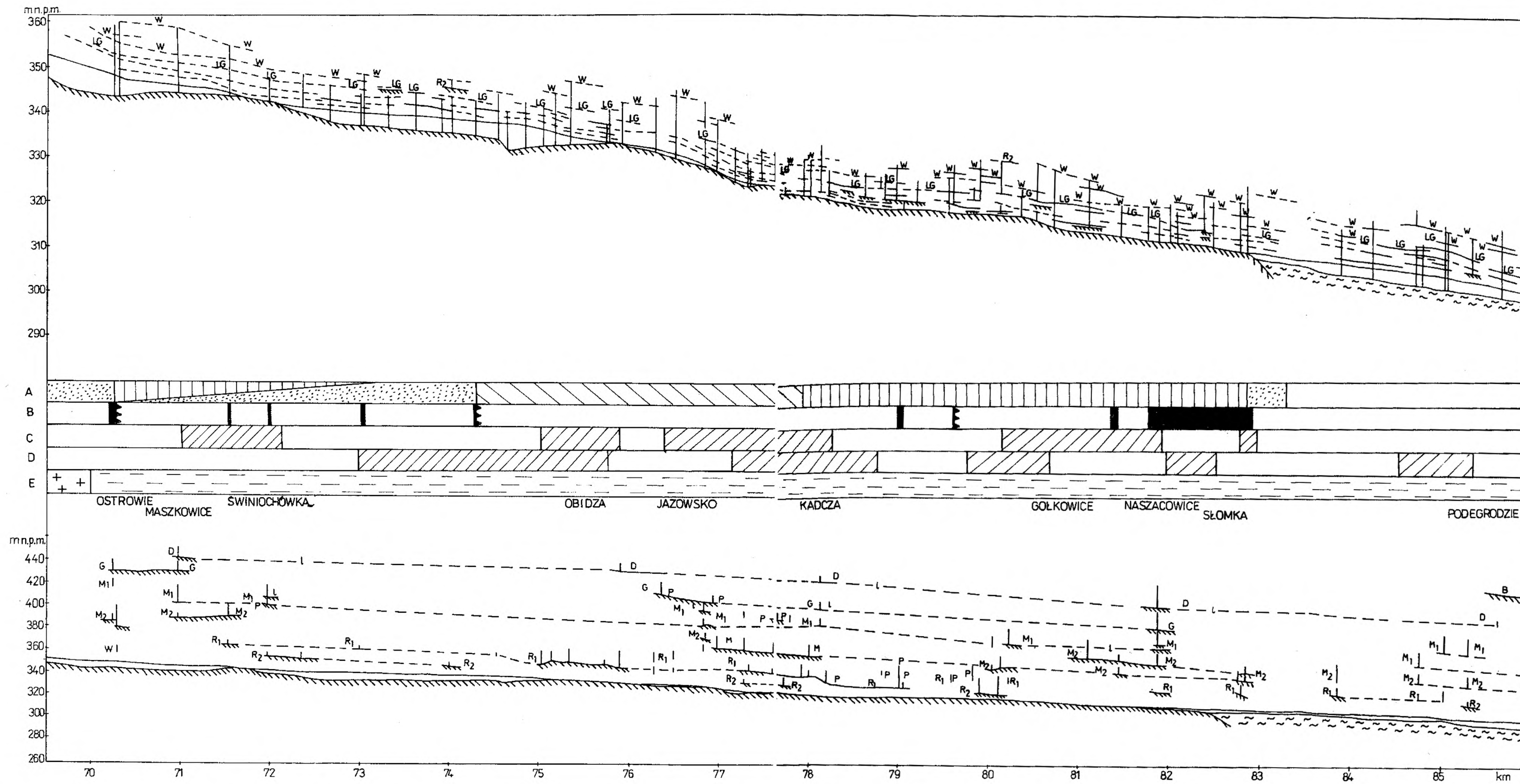


Fig. 10. Longitudinal profiles of the Dunajec terraces within the Łącko – Podegrodzie Foothills. Upper diagram – longitudinal profiles of the Last Glacial (*W*) and Late Glacial (*LG*), as well as Holocene terraces. Broken lines – left-hand side of the valley, continuous lines – right-hand side of the valley. Vertical lines – thickness of alluvial covers. Lower diagram – longitudinal profiles of rock socles of the Pleistocene terraces: *B* – Biber, *D* – Donau, *G* – Günz, *M1* – Mindel 1, *M2* – Mindel 2, *R1* – Riss 1, *R2* – Riss 2, *W* – Würm. *l* – left-hand side, *p* – right-hand side. *A* – resistance of solid rocks: diagonal lines – very resistant rocks, vertical lines – resistant rocks, horizontal lines – rocks of average resistance, dots – rocks of weak resistance, blank fields – rocks of very weak resistance. *B* – main faults, fault-zones and overthrusts. Faults striking along the river-course are hatchured. *C* – zones of disturbances of relative altitudes of the Pleistocene terraces. *D* – zones of disturbances of relative altitudes of the Holocene terraces. *E* – river-bed stretches where topographic profile of a river runs above (+) or beneath (–) the theoretical one, calculated by the Ivanov's method

Fig. 10. Profile podłużne teras Dunajca w obrębie Pogórza Łącko-Podegrodzkiego. Diagram górny – profile podłużne teras z ostatniego glacjału (*W*), późnego glacjału (*LG*) i holocenu. Linie przerywane – zbocze lewe, linie ciągłe – zbocze prawe. Kreski pionowe oznaczają miąższość akumulacji. Diagram dolny – profile podłużne cokołów teras plejstoceńskich: *B* – Biber, *D* – Donau, *G* – Günz, *M1* – Mindel 1, *M2* – Mindel 2, *R1* – Riss 1, *R2* – Riss 2, *W* – Würm. *l* – zbocze lewe, *p* – zbocze prawe. *A* – odporność skał podłoża: szrafura ukośna – skały bardzo odporne, szrafura pionowa – skały odporne, szrafura pozioma – skały średnio odporne, kropki – skały słabo odporne, puste pola – skały bardzo słabo odporne. *B* – ważniejsze uskoki, strefy dyslokacyjne i nasunięcia. Uskoki o biegu zgodnym z przebiegiem koryta rzeki zaszrafowano. *C* – strefy zaburzeń wysokości względnych cokołów teras plejstoceńskich. *D* – strefy zaburzeń wysokości względnych teras holoceńskich. *E* – odcinki koryta, w których profil rzeczywisty leży powyżej (+) lub poniżej (–) profilu teoretycznego, obliczonego metodą Ivanova

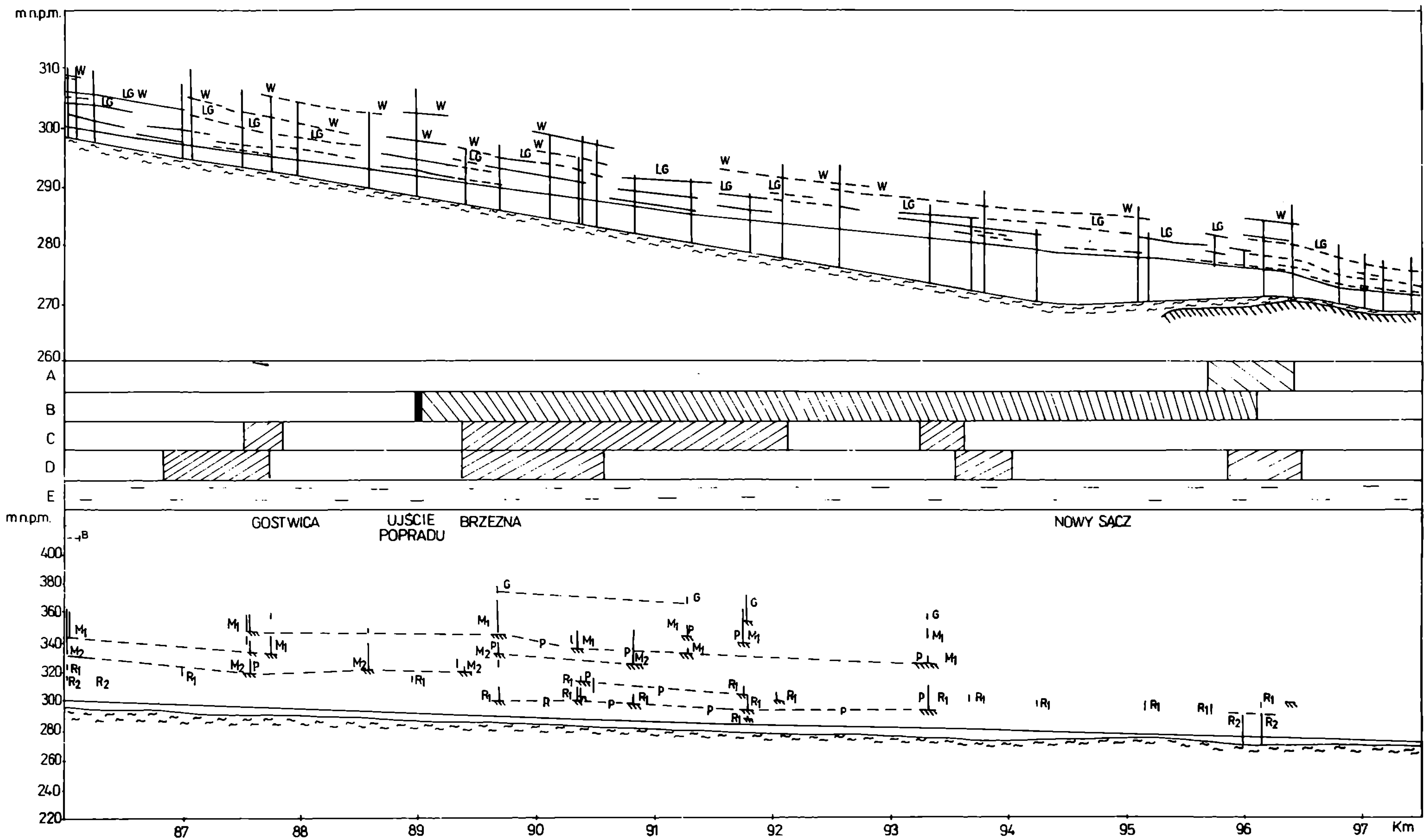


Fig. 11. Longitudinal profiles of the Dunajec terraces within the Nowy Sącz Basin. For explanation – see Fig. 10

Fig. 11. Profile podłużne teras Dunajca w obrębie Kotliny Sądeckiej. Objaśnienia jak na figurze 10

MINDEL

The structure of the Mindel fluvial covers reveals a remarkable two-fold division. In the hitherto prepared eleborations (cf. Klimaszewski, 1948b, 1967; Starkel, 1972; Oszczypko, 1973) this phenomenon was associated with two stadials of the Mindel glaciation. The latest results of Quaternary studies, however, permit the acceptance of the presence of two different glaciations (Fink and Kukla, 1977; Kukla, 1978; Różycki, 1978; Bucha et al., 1979). Różycki (op. cit.) called them the Nida and San Glaciations, which had to be separated by the Małopolanian Interglacial.

Considering the poor preservation of terrace covers in the Pieniny region, both glacials were not distinguished there.

Within the Dunajec valley in the Pieniny Mts., fragments of terrace covers are best preserved in the eastern part of the Nowy Targ Basin, namely between Dębno and Czorsztyn villages. On the southern margin of the Dębno – Frydman Graben, patches of 10 m thick alluvial cover rest on rock socle, 74 – 55 m high, i.e. 150 m above the base of similar deposits filling the graben bottom.

On southern slopes of the Gorce Mts. these covers preserved at Maniowy, Ciechorzyn and Brzeziny, and reach an altitude of 48 – 58 m. They consist of Tatra and flysch pebbles, which interfinger at the top with sandy-silty clays, including angular debris.

Farther to the east, the gravel patches can be seen above Czorsztyn (50 – 62 m) and beneath the Niedzica Castle (57.5 – 61 m). In the vicinity of Sromowce Niżne, fluvial gravels can be found from 60 m up to 100 m above the valley-bottom. In the Dunajec gorge these deposits rest on erosional flats, 85 – 95 m high (Drdoš, 1960).

Remarkable disturbances of relative terrace heights are characteristic of the eastern part of the Nowy Targ Basin and in the Dunajec-gorge. The lack of preserved fragments in the greater part of the Dunajec gorge seems to prove a strong, block-like upheaval of the eastern part of the Pieniny Mts.

To the north of the Pieniny Mts., the structure of the discussed terrace remnants allows us to distinguish two different alluvial series resting on rock socles.

MINDEL 1

Within the Dunajec water-gap in the Beskid Sądecki Mts., isolated gravel patches preserved within the Kłodne and Wietrznica meander loops (cf. Fig. 2). Strongly weathered flysch and Tatra gravels form a series of pebbles within highly cemented sandy clays.

On the northern margin of the Radziejowa Range, on the southern slopes of the Łącko – Podegrodzie Foothills, as well as on the southeastern margin of the Nowy Sącz Basin (cf. Fig. 3), a distinct two-fold division of alluvial covers can be seen. The splitting of terrace cover could evidence either the presence of two stadials within the Mindel glaciation, or post-sedimentary tectonic movements during the Mindel 1 – Mindel 2 interglacial.

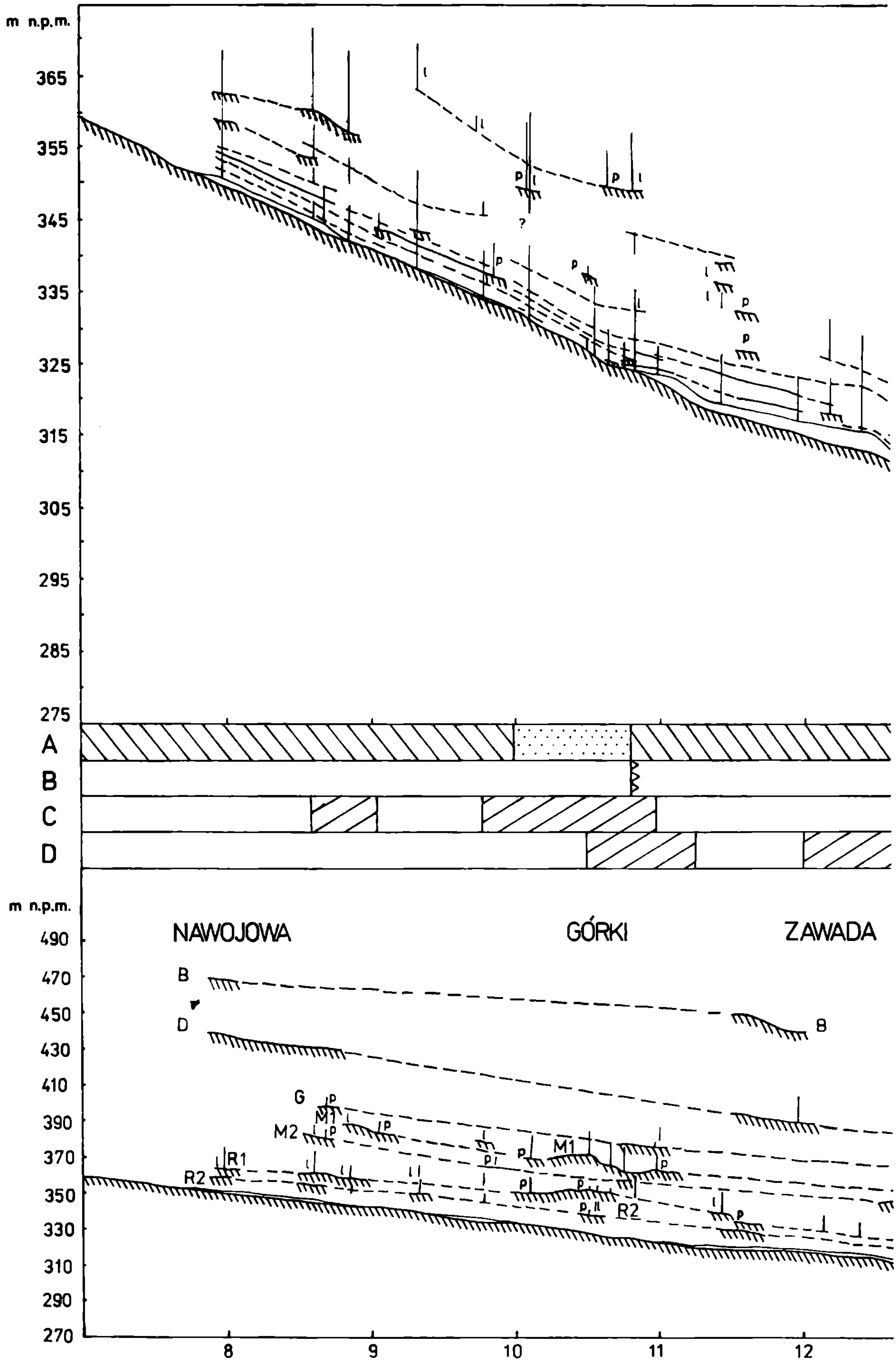


Fig. 12. Longitudinal profiles of the Kamienica Nawojowska terraces. For explanation – see Fig. 10

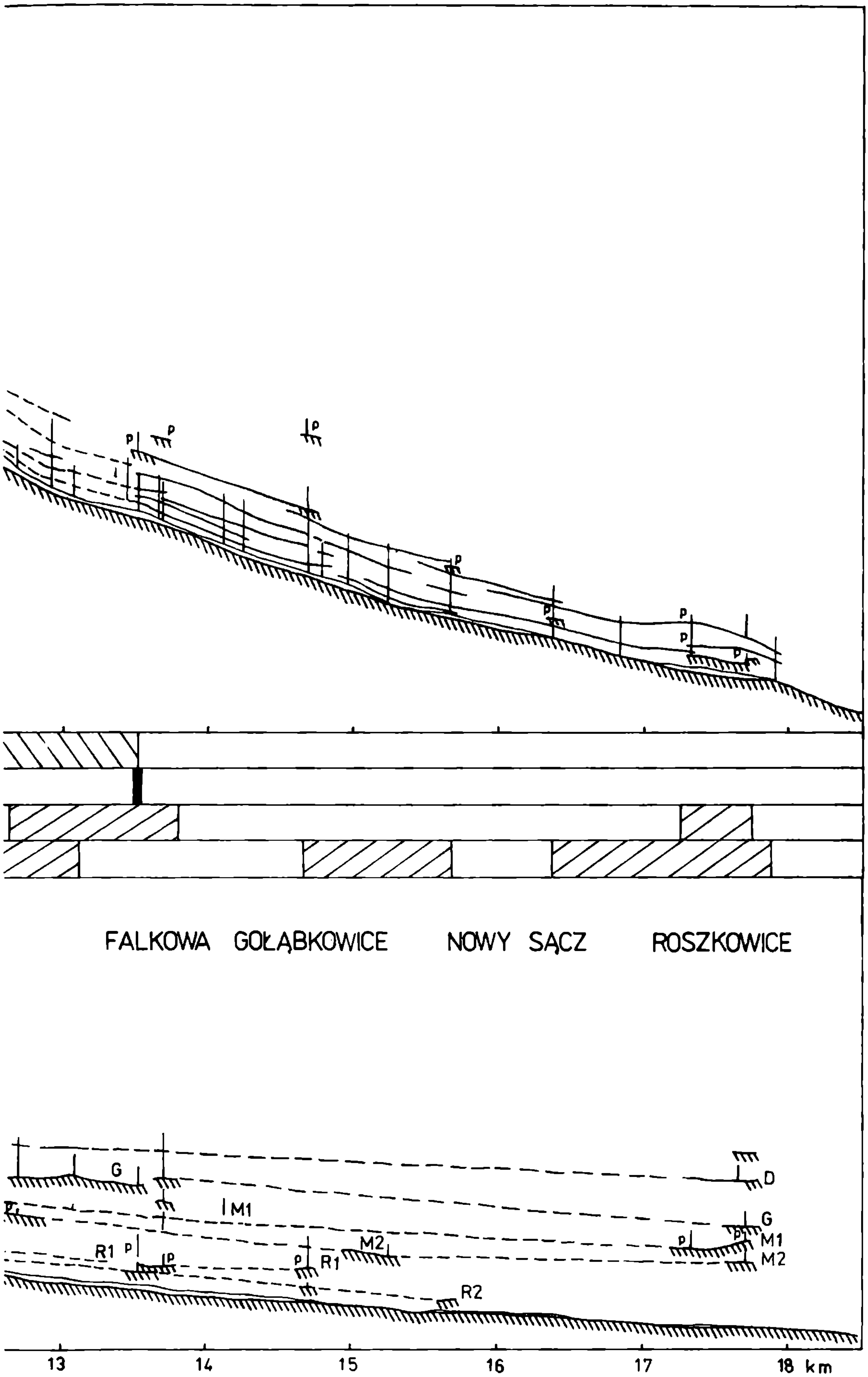
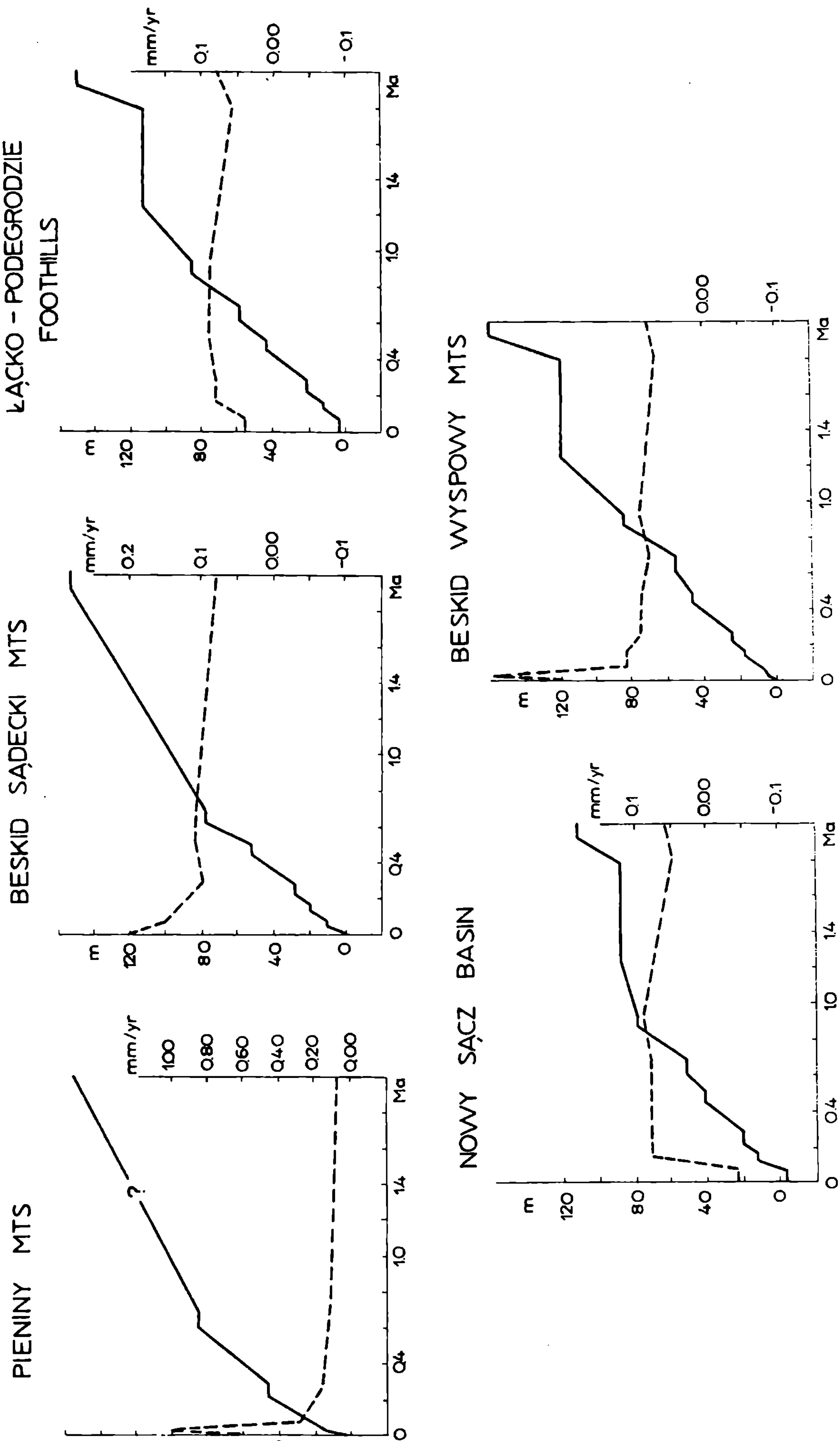


Fig. 12. Profile podłużne teras Kamienicy Nawojowskiej. Objaśnienia jak na figurze 10


PIENINY MTS
BESKID SĄDECKI MTS
ŁĄCKO - PODEGRODZIE FOOTHILLS
NOWY SĄCZ BASIN
BESKID WYSPOWY MTS
m
120
80
40
0
mm/yr
1.00
0.80
0.60
0.40
0.20
0.00
0.2
0.1
-0.1
Ma
0
0.4
1.0
1.4
?

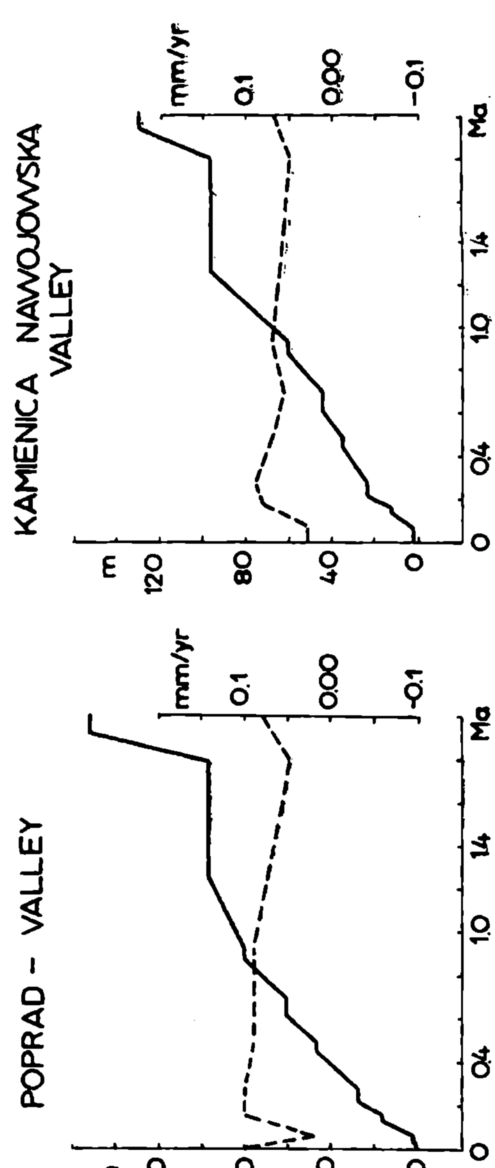


Fig. 13. Diagrams of uplift of the selected parts of the Dunajec drainage-basin in Quaternary times; continuity lines – curve representing absolute amount of erosional dissection, in metres, dotted lines – cumulative curve resembling rates of dissection, in mm/year.

Fig. 13. Diagramy obrazujące rozmiary wypiętrzenia wybranych części dorzecza Dunajca w czwartorzędzie; linia ciągła – krzywa przedstawiająca bezwzględne wielkości rozcięcia erozyjnego w metrach, linia przerywana – krzywa kumulacyjna obrazująca tempo rozcinania w mm/r.

The zones where terrace covers split seem to be associated with blocks separated by faults (cf. Fig. 14). On the northern margin of the Beskid Sądecki Mts. occur the Maszkowice, Jazowsko – Obidza and Gołkowice – Kadcza faults and, within the Nowy Sącz Basin, there are transverse faults connected with the Poprad fault-system.

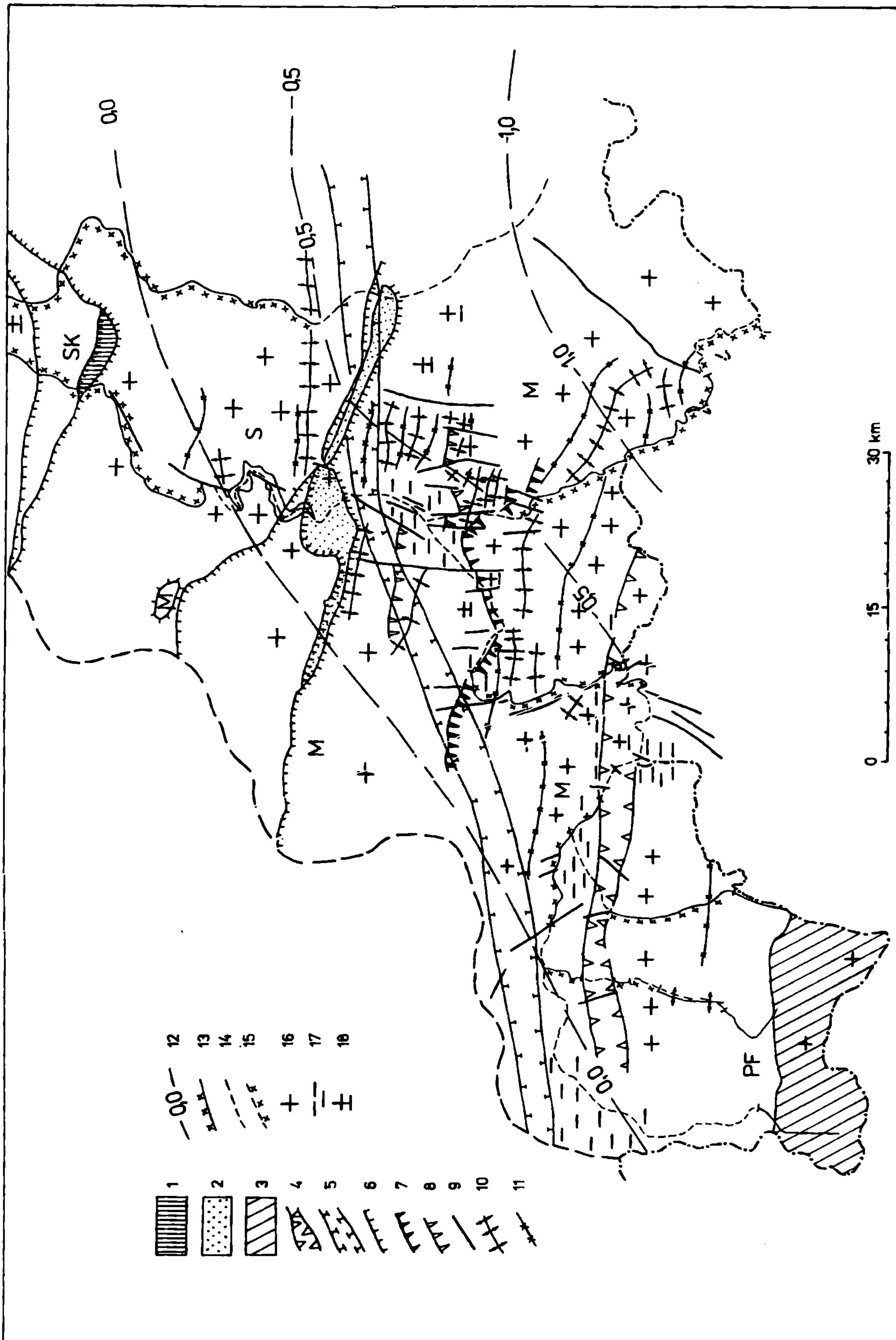
The Mindel glacial period was the last stage of Early Quaternary tectonic activity of the Pasadenian phase, which led to changes in the river pattern and caused disturbances in the longitudinal profiles of terraces in Slovakia (Harčar, 1975), resulting as well in the subsidence of lowlands situated south of the Carpathians (Baňacký, Harčar, and Sàbol. 1965; Baňacký, 1978).

On the southern margin of the Łącko – Podegrodzie Foothills and on the northern slopes of the Radziejowa Range there occur fluvial gravels, preserved mainly on the left-hand side of the Dunajec-valley. On the right-hand side of this valley, remnants of fluvial covers are preserved in the vicinity of Łazy Brzyńskie, Biegonice, Dąbrówka Polska and Zawada. They rest upon rock socles, cut into two distinct levels: 70 – 55 m and 56 – 45 m.

To the north of the Nowy Sącz Basin the Mindel I terrace is a rock or erosional-accumulational terrace, the altitudes of which are 73 – 66 m and 55 – 50 m. The splitting of rock socles is especially well visible between Roszkowice and Marcinkowice, as well as between Znamirowice and Tabaszowa.

In the Poprad valley rock benches, 50 – 60 m high, are covered by 23 – 16 m thick gravels, composed mainly of sandstone and quartzite pebbles, 4 – 6 to 15 – 18 cm in diameter. They are found within a matrix of strongly limonitised fine- and medium grained sands.

Minor disturbances to the north of Myślec are visible in longitudinal profiles of rock socles.



0,0
0,5
1,0
SK
S
M
PF
0
15
30 km
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

MINDEL 1 – MINDEL 2

During the Mindel 1 – Mindel 2 interglacial, dissection of the rock socles took place. On the northern margin of the Radziejowa Range the amount of erosional dissection reached a magnitude of 13 – 19 m. Higher values are characteristic of the Dunajec-gorge in the Beskid Sądecki Mts. (27 – 28 m), as well as of the lower Poprad valley (25 – 23 m). To the north of Nowy Sącz the depth of dissection was from 18 – 19 m in Roszkowice to 24 – 28 m in Wielopole and Tabaszowa. Lower values characterize the Kamienica Nawojowska valley (Fig. 12), and vary from 6 to 12 m.

MINDEL 2

During the following glacial period fluvial covers were laid down on erosional flats, 52 – 38 m high.

In the Dunajec water-gap in the Beskid Sądecki Mts., 4 – 22 m thick gravels cover rock socle which crops out at an altitude of 52 – 45 m above the valley-floor. Farther downstream, on the northern margin of the Radziejowa Range, as well as in the Nowy Sącz Basin, this socle divides into two levels: 47 – 41 m and 38 – 30 m (cf. Figs. 10 and 11). The thickness of gravelly-sandy deposits varies from 8 to 13 m. In the western part of the Basin, fluvial series occur only on the left-hand valley-side. The rock socle's altitude decreases towards the east. To the north of Nowy Sącz, terrace covers rest on the two-level socle: 47 – 38 m and 35 – 25 m.

The Mindel 2 terrace is preserved in the Poprad valley as an erosion-accumulational terrace (Wola Krogulecka, Zagórze Myśleckie, Myślec, Winna Góra) or as an escarpment on rocky valley-sides (Barcice Górne, Paryje, Popowice). Altitudes of rock socles decrease to the north, from 46 to 27 m.

Fig. 14. Neotectonic sketch of the Dunajec drainage-basin. *1* – Sub-Silesian unit, *2* – Grybów unit, *3* – Tatra units, *4* – Pieniny Klippen Belt, *5* – Pericarpathian lineament, *6* – overthrusts. Tectonic lines that were re-activated during the Quaternary: *7* – overthrust of the Krynica sub-unit, *8* – overthrust of the Nowy Sącz sub-unit, *9* – faults, *10* – axes of anticlines, *11* – axes of synclines, *12* – isolines of recent vertical crustal movements (according to Wyrzykowski 1971). River-bed stretches where the topographical profile runs: *13* – above, *14* – beneath, *15* – above and beneath interchangeably, the theoretical profile, calculated by the Ivanov's method. Areas which reveal Neopleistocene movements: *16* – positive, *17* – negative, *18* – positive and/or negative alternatively. *PF* – Podhale Flysch, *M* – Magura nappe, *S* – Silesian nappe, *SK* – Skole nappe

Fig. 14. Szkic neotektoniczny dorzecza Dunajca. *1* – płaszczowina podśląska, *2* – jednostka grybowska, *3* – jednostki tatrzańskie, *4* – pieniński pas skałkowy, *5* – lineament perykarpacki, *6* – nasunięcia. Linie tektoniczne uaktywniające się w czwartorzędzie: *7* – nasunięcie podjednostki krynickiej, *8* – nasunięcie podjednostki sądeckiej, *9* – uskoki, *10* – osie antyklin, *11* – osie synklin, *12* – izolinie współczesnych pionowych ruchów skorupy ziemskiej (według Wyrzykowskiego, 1971). Odcinki koryt rzecznych, gdzie profil rzeczywisty leży: *13* – powyżej, *14* – poniżej, *15* – powyżej i poniżej profilu teoretycznego, obliczonego metodą Iwanova. Obszary wykazujące ruchy tektoniczne w neoplejstocenie: *16* – dodatnie, *17* – ujemne, *18* – dodatnie i/lub ujemne. *PF* – flisz podhalański, *M* – płaszczowina magurska, *S* – płaszczowina śląska, *SK* – płaszczowina skolska

Table – Tabela 4

Altitudes of the Poprad terraces (in metres)
r – right side, l – left side, in brackets – altitudes of rock socles in metres
Zestawienie wysokości teras Popradu w metrach
r – strona prawa, l – strona lewa, w nawiasach – wysokości cokołów skalnych w metrach

<table>
<tr><th>Cross section</th><th>Brzezowica</th><th>Barcice Dolne</th><th>Cyganowice</th><th>Stary Sącz</th><th>Myślec</th><th>Winna Góra</th></tr>
<tr><td>Distance from the state boundary, km</td><td>52.5</td><td>56–57</td><td>57.5</td><td>58.5</td><td>60–61</td><td>62.5</td></tr>
<tr><td>Biber</td><td>(150) r</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Donau</td><td>–</td><td>(85–95) l</td><td>(90–100) rl</td><td>–</td><td>97–100(97) l</td><td>–</td></tr>
<tr><td>Günz</td><td>–</td><td>–</td><td>80–85(80) r</td><td>80–85(80) l</td><td>(80) r</td><td>–</td></tr>
<tr><td>Mindel 1</td><td>–</td><td>(60–70) l</td><td>–</td><td>–</td><td rowspan="2">64–69
(47) r</td><td>65–90
(55–80) r,
50–55(50) r</td></tr>
<tr><td>Mindel 2</td><td>–</td><td>(35) l</td><td>–</td><td>(40) r</td><td>27–30(27) r</td></tr>
<tr><td>Riss 1</td><td>27(17) r</td><td>25–29 l</td><td>27–33(27) l</td><td>20–25 l</td><td>17–20(15) l</td><td>20–30 r
15–20(11) r</td></tr>
<tr><td>Riss 2</td><td>–</td><td>16–23(16) l</td><td>12–15(10) l</td><td>–</td><td>–</td><td>10–15 l</td></tr>
<tr><td>Würm</td><td>6.5–7.5 r</td><td>8–11(–1) l
7–9 l</td><td>8.5 l</td><td>7–9 l</td><td>6–9 l</td><td>8–12 r</td></tr>
<tr><td>LG</td><td></td><td>6–7.5(–1) l</td><td>5–7.1 l</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Holocene</td><td>4–5(0) r
2–2.5(0) r
1(0) r</td><td>2–3(–1) l
0.5–1(–1) l</td><td>3–4 l
2–5 r
0.5 r</td><td>3–5 l
2 l</td><td>3.5–4 l
3.5 r
1–2 rl</td><td>4 l
2 rl</td></tr>
</table>

According to Smoleński (1918), Klimaszewski (1937, 1938b), Szaflarski (1937) and Oszczypko (1973), the Poprad was flowing through the pass between Winna Góra and Biegonice, at that time. Later, the river-bed shifted to the west.

In the Kamienica Nawojowska valley (cf. Figs. 9 and 12), the described terrace occurs as a rock (Nawojowa, Gołąbkowice) or erosional-accumulational terrace (Popardowa, Załubińcze). Alluvial covers, 3–6 m thick, rest up on 36–30 m high rock socles.

Deformations in longitudinal profiles of the socle are remarkable, and can be associated with increased tectonic activity of the whole Carpathians at the end of the Mindel glacial and during the Mindel-Riss stage (Starkel, 1971; Rühle, 1976; Baňacký, 1978; Šibrava, 1979).

Noticeable also are the increasing altitudes of rock socles in the Beskid Sądecki Mts., as well as their splitting into two levels (Kłodne, Boczów, Maszkowice, Naszacowice, Podegrodzie). This phenomenon is frequently connected with faults that transverse the contact zone between the Krynica and Nowy Sącz subunits, and those associated with the scissors-like Poprad fault-system (Oszczypko, 1973).

MINDEL – RISS

During the Mindel-Riss interglacial stage, a dissection of previously deposited alluvial covers, as well as their basement is known to have occurred. This was a period of intensive tectonic activity that affected both the Carpathians and the Alps (Kukla, 1978).

On the southern margin of the High Tatra Mts., between Lučivna and Ščyrbské Pleso moraine ridges, a tectonic trough was formed (Lukniš, 1959). The most effective upheaval of the Žilina basin and the Hron drainage-basin is confined to this period (Mazúr, 1963).

Along the southern margin of the Carpathians tectonic movements took place which caused the subsidence of the drainage-basin of the Middle Danube, as well as foster a number of disturbances of older river terraces (Pécsi, 1977).

The amount of dissection of the Mindel 2 terrace-socle within the Pieniny Mts. was from 22 to 44 m. The highest values occurred in the "Pieninian" water-gap, the lowest ones – were confined to the Niedzica (Kapuśnica) gorge.

Within the Dunajec water-gap in the Beskid Sądecki Mts. these values vary from 26 m in Krościenko to 34 m in Kłodne, and to 20 – 30 m in Boczów.

Along the northern margin of the Radziejowa Range and on the southern slopes of the Łącko-Podegrodzie Foothills, rates of erosion were lower and did not exceed 17 – 24 m. The highest values characterise the zone situated east of Jazowsko (cf. Fig. 10).

Within the Nowy Sącz Basin (Fig. 11) the depth of erosion is variable. In the vicinity of Podegrodzie it is equal to 11 – 15 m, but on the eastern margin of the Basin it rises up to 30 – 34 m.

In the Poprad valley, the considered values rise from 13 m in Barcice to 17 – 22 m near Winna Góra.

To the north of the Nowy Sącz Basin the amount of erosional deepening is 16 – 10 m, and in the Kamienica Nawojowska valley it attains a value of 12 – 20 m.

RISS

At the beginning of the Riss glacial stage a severe cooling trend started to predominate. The upper snow line in the Tatra and Beskidy Mts. lowered to an altitude of 1200 m above sea level, and mean annual temperatures in Krościenko and at the foot of the Tatra Mts. were –3 and –5°C, respectively (Klimaszewski, 1948b).

The terrace covers ascribed to that period reveal a distinct two-fold division

Table – Tabela 5

Altitudes of the Kamienica Nawojowska terraces (in metres)
r – right side, l – left side, in brackets – altitudes of rock socles in metres

Zestawienie wysokości teras Kamienicy Nawojowskiej w wybranych przekrojach, w metrach
r – strona prawa, l – strona lewa, w nawiasach – wysokości cokołów skalnych w metrach

Cross-section	Popardowa	Nadkamionka	The mouth of Kamionka	Zawada	Fałkowa	Gołąbkowice	Nowy Sącz	Roszkowice
Distance from headwaters, km	8.5–9	10	11	12	13.5	14.5	16	18
Biber	(117–122) l			(120–130) r				(96–106) r
Donau	(85–95) l			70–85 (64–70) r				(81–83) r
Günz	52–57 (52) r		52–55 (52) r		68–83 (60.5) r			56–60 (56) r
Mindel 1	(45) l	37–50 (37–40) r	40–44 (40) r		45 r		42–45 (42) r	46–51 (46) r
Mindel 2	36–40 (36) r		35–37 r		30? r	33 (20) r		36–40 (36) r
Riss 1	22–27 (15) l	17–25 (17) r		20–30 (16) l		21–25 (19) r		
Riss 2	10–13 (8.5) l		19 l	11–18	12–13 (11) r	10–12 (8–9) r		
Würm	7.5–11 l	7–10 l	8.5–11 l	6–7 (–3) l	6–6.5 r	7.5–9 r	5–8 (2.5) r	8(2) r
LG	5–7 l	4–5 l	4.5 l		4.5–5.4 r	5.5 l	4.5(0) r	5(2) r
Holocene	3.5 r	3–3.5(0) l 0.5(0) l	2–3 r, 1r	3–4 l r 2–3(2) l	3–3.5 r 1–2 r.	3.5 r 2 r, 1 r	1.5(0) r	3.5(1.5) r

that can prove the presence of two stadials (Klimaszewski, 1961, 1967; Starkel, 1972) or two different glacial periods, known as the Odranian and Wartanian (Różycki, 1978).

The author is not able to decide whether the Riss glacial period should be divided into two stadials or two separate glacials. The last concept, however, seems to be supported by the results of Quaternary studies, carried out in the Middle Europe (Fink and Kukla, 1977; Różycki, 1978; Brunnacker, 1979; Bucha et al., 1979), as well as in the USSR (Arkhipov, 1979). It is also proved by a specific sequence of sediments recorded in these two covers, typical for a glacial cycle. Two separate terrace steps, ascribed to the Riss stage, were distinguished in Slovakia by Mazúr (1963) and Vaškovský (1977).

Within the Pieniny Mts., the terrace under consideration is poorly preserved. The only criteria that allow the correlation of terrace remnants are the relationships between the Riss terrace and the one from the Last Glacial stage.

Between Dębno and Frydman these deposits lie 2 – 25 m beneath the present-day river-bed of the Dunajec. Around the Frydman Graben, the Riss terrace is a rock or erosion-accumulational one, exposed at 43 – 60 m within the Klippen Belt and 30 – 45 m on the southern slopes of the Gorce Mts. Similar altitudes of terrace socles (45 m) are preserved at Brzeziny, Ciechorzyn, Czorsztyn and Niedzica. Farther to the east, as far as Kąty, the rock socle's altitude decreases to 36 – 31 m.

In the Dunajec gorge within the Pieniny Mts. the described terrace occurs on the right-hand side of the valley, at an altitude of 40 – 45 m (Drdoš, 1960).

Downstream of the Dunajec gorge, in the Kras meander loop, sporadic Tatra pebbles can be found. They occur 35 – 36 m above the valleyfloor. To the south of Krościenko the thickness of gravel covers rises to 15 m.

In the longitudinal profile of the Riss terrace there are no remarkable deformations with the exception of the Dębno – Frydman Graben. The height difference between the base of Riss deposits within the Graben and its margin in about 40 – 50 m. Also noticeable is an increase in relative altitudes of terrace socles at Ciechorzyn, and its almost complete disappearance in the Dunajec gorge.

RISS I

Within the Dunajec water-gap in the Beskid Sądecki Mts., the Riss 1 gravelly-sandy cover rests on a sandstone socle (Fig. 6), the altitude of which decreases to the north from 26 m in Krościenko to 14 m in Zarzecze.

An upwarp of the socle in the vicinity of Kłodne (28 – 29 m) and Boczów (25 m) can be seen. The thickness of alluvial covers is from 5 to 11 m, but downstream of the gorge it rises up to 14 m.

Within the Łącko – Podegrodzie Foothills the altitude of rock socle decreases from 24 m at Maszkowice to 13 m at Opijówka, but at Jazowsko it rises again to 17 m.

Fluvial gravels, 3 – 5 m thick, are covered by silty-sandy loams containing angular debris. Similar altitudes of the terrace level (17 – 19 m) can be seen between Zawodzie and Gaboń, and downstream, they lower to 12 m (Fig. 10). Here gravels and sands underlie, 14 m thick yellow, sandy and sandy-silty loams. In the vicinity of Gołkowice the rock socle subsides to a height of 6 – 2 m above the valley-floor.

At the Płusy site, south-west of Podegrodzie, the strongly weathered gravel series is covered by 5–6 m thick, cemented silts and sandy silts. These deposits are cut by vertical joint surfaces, called by Tokarski (1978) "subvertical joints". This author attempts to correlate joint surfaces, reworked by precipitation waters, with young Pleistocene (Eemian) tectonic movements affecting the margin of the Nowy Sącz Basin. He classifies these surfaces as "faults" and tries to count stress-axes. However, both the character of silts and morphologic situation of slope clearly indicate the presence of a large landslide. This gravitational movement caused the formation of joints. Fissures which originated at that time were affected and reworked by precipitation waters which eroded a number of rills, recognized by Tokarski (op. cit.) as "tectonic striae on slickensides" (sic!).

In the vicinity of Płusy, within loess-like loams covering the Riss 1 terrace gravels, occur boreal assemblages of steppe gastropods (bottom: *Succinea oblonga elongata, Pupilla muscorum, Vallonia pulchella, Helicella* cf. *strata*, top: *P. muscorum, S. oblonga elongata, V. costata, V. pulchella*).

The sedimentation of silts and silt-sandy deposits started at the decline of the Riss glacial stage and continued during the Last Glacial period. Most of these sediments reveal stratification that can evidence the role of waters flowing downslope. Apart from previous concepts ascribing these loams to loess or loess-like deposits, Cegła (1963) described them as flysch waste-rocks.

Silts and silty loams overlie fluvial sequences associated with the Riss glacial stage and appear mainly on the left-hand side of the Dunajec valley. They crop out at similar altitudes above valley-floor (20–35 m). This fact enables correlation of the preserved terrace remnants.

On the southern margin of the Nowy Sącz Basin the Riss terrace forms a widespread alluvial fan of the Dunajec and Poprad rivers (Fig. 3). It can be seen at an altitude of 20–25 m above the river-beds. On the left-hand side of the Basin (Brzezna, Podrzecze, Chochorowice) the altitude of rock socles, built up from Badenian sands and clays, decreases from 12 to 5 m.

Between Biegonice and Nowy Sącz (Fig. 11), the terrace surface slopes gently from 27 m at Dąbrówka Polska to 14–12 m at Nowy Sącz. During the formation of this terrace cover, the Kamienica Nawojowska river joined the Dunajec, upstream of Nowy Sącz (Klimaszewski, 1948b; Oszczypko, 1973).

To the north of the Nowy Sącz Basin, the described terrace cover, 4–11 m thick, rests on 24–19 m high erosional flats. They occur on either side of the valley and form rock or erosion-accumulational terraces. In longitudinal profiles of the terraces a small upwarping of relative altitudes appears at Wielogłowy, Grodzisko and Znamirowice.

Within the Poprad valley, the altitudes of erosion-accumulational terraces decrease to the north, from 20 m at Brzezowica to 10 m at Biegonice. Terrace levels occur on either side of the valley, rising to 26–30 m above the river-bed.

In longitudinal profiles, as well as in cross-sections of the socle, there appear disturbances which seem to correlate with the trend of faults associated with the scissors-like Poprad fault-system.

In the Kamienica Nawojowska valley (Fig. 12), the relative altitudes of rock socles rise near the mouth of Kamionka stream, from 15 – 16 m to 17 – 24 m. An increase in relative heights is especially well visible on the right-hand side of the valley. To the north of Kamionka stream, the socle slopes down to an altitude of 13 – 12 m and farther to the north (Gołąbkowice) it rises up again up to 18 – 19 m above the valley-floor.

RISS 1 – RISS 2

During the Riss 1 – Riss 2 interglacial (interstadial?) period, the increased erosional activity is believed to have taken place. The depth of downcutting was from 14 to 3 m. The highest values are characteristic of the northern part of the Dunajec water-gap within the Beskid Sądecki Mts., and in the Jazowsko – Kadcza region (12 – 14 m), the lowest ones occur in the Nowy Sącz Basin. There are also differences in the considered values between both sides of the Dunajec valley, which are especially well visible within the Nowy Sącz Basin (6 – 13 m). This phenomenon can point to activization of vertical movements at that time. To the north of Nowy Sącz, the rates of bottom erosion are equal to 5 – 6 m. Higher values characterise the regions of Wielogłowy (9 – 12 m) and Biała Woda (8 – 9 m, cf. Figs. 4 and 7). Within the Poprad valley, however, these values are from 9 to 17 m.

RISS 2

Erosional flats, cut during the Riss 1 – Riss 2 interglacial stage, were covered by a lower series of gravels and sands. Within the Dunajec water-gap in the Beskid Sądecki Mts. it rests on a socle, 20 – 11 m high. Relative heights of the socle decrease northwards. The thickness of fluvial covers attains 9 – 14 m. Between Łącko and Nowy Sącz (cf. Fig. 10) it changes from 2 – 5 m near Maszkowice – Jazowsko to 10 – 12 m within the Nowy Sącz Basin. Gravels and sands rest on a rocky surface, 12 – 3 m high.

On the eastern margin of the Nowy Sącz Basin, the Riss 2 terrace level is an fill-top and/or an erosion-accumulational one. Its surface attains an altitude of 13 – 10 m above the valley floors. The rock socle, built up from Miocene clays, decreases downstream from 9 – 10 m at Biegonice to 3 m at Gaj and, in the vicinity of Nowy Sącz, it plunges beneath the present-day river-bed (– 2 m).

Appearing to the north of Nowy Sącz are rock and erosion-accumulational terrace steps, the altitudes of which vary from 18 m at Roszkowice to 8 m at Biała Woda.

In the valley of Poprad, a 7 – 16 m thick terrace sequence rests on a rough socle, sloping gently northwards (16 – 4 m). Near the town of Stary Sącz it plunges beneath the river bed. The Riss 2 terrace remnants, 20 – 15 m high, are preserved almost exclusively on the lefthand side of the valley.

Within the Kamienica Nawojowska valley (Figs. 3, 9, 12) there appear differences in the longitudinal profiles of terrace socles between the two valley sides. Higher altitudes are confined to the righthand side of the valley.

RISS 2 – WÜRM

At the end of the Riss 2 glacial stage, as well as during the following Eemian interglacial, there occurred intensive downcutting into the formerly deposited gravel series and their basement. Bottom erosion was favoured by suitable climatic conditions and by young tectonic movements. A warm and wet climate prevailed, being 2 – 3°C warmer and about 50% wetter than at present (Vaškovský, 1977). Tectonic activity of the Carpathians at that time is evidenced by disturbances of terrace levels of the Žitava river, described by Harčar (1975).

Rivers cut downwards to a depth of 20 – 25 m in the Pieniny Mts., and in the axial part of the Beskid Sądecki Mts. In the northern part of the Dunajec water-gap within this range the depths of erosional deepening decreased to 15 – 11 m. Within the Łącko Basin, the socle of younger alluvia rests 6 – 8 m beneath the present-day river-bed.

Between Jazowsko and Stary Sącz the amount of downcutting changed from 7 to 12 m. In the Nowy Sącz Basin it reached a value of 5 – 8 m beneath contemporaneous flood-plains, i.e. 15 – 8 m under the socle of the Riss 2 terrace steps. Higher values of erosional deepening are characteristic of the Roszkowice region (18 – 20 m), as well as of the lower course of the Poprad valley (17 – 10 m).

WÜRM

The highest terrace associated with the Last Glacial stage attains a height of 15 m above river-beds. Its Upper Pleniglacial age has been estimated on the basis of radiocarbon datings (Starkel, 1977).

Within the Nowy Targ Basin this terrace step originated as a result of erosional downcutting of the fluvioglacial cover, laid down during the Riss stage. In the course of the deposition of this cover, phases of fluvioglacial and periglacial sedimentation have occurred. Within the limits of the Dębno – Frydman Graben, terrace deposits attain a thickness of 6 – 25 m and occur beneath the present-day river-beds. On the graben margins, as well as in the bottom of the Dunajec valley, the Würm terrace is an erosion-accumulational one. The rock socle's altitude rises 15 – 38 m above the base of the Würm deposits that fill the graben. To the south of the graben area, the altitudes of rock socles are 5 – 11 m, but on the northern margin they rise to a height of 16 – 19 m.

Between Maniowy and Ciechorzyna decrease in relative heights is marked (8 – 10 m). Within the Niedzica (Kapuśnica) water-gap, remnants of fluvial gravels form two, poorly exposed levels: 18 – 26 m and 8 – 15 m. The latter could have been formed during the Late Glacial times. Within terrace covers, the remains of the Early Glacial *Mammonteus primigenius* Blum. were found (Kulczycki and Halicki, 1950). To the east of the Kapuśnica water-gap, relative altitudes of rock socles decrease.

The age of the Last Glacial terrace cover was estimated on the basis of radiocarbon datings (51 200 years BP) of pieces of wood, found in peat that overlies fluvial gravels at Kąty (Mamakowa, Mook and Środoń, 1975).

Within the Pieninian gorge, fragments of Last Glacial terraces, 20–25 m high, are preserved on the Slovakian side of the valley (Drdoš, 1960). Downstream of the gorge's outlet, in the vicinity of Krościenko, the rock socle's altitude is about 4 m above the riverbed. The terrace cover interfingers here with a solifluction cover, containing Pleniglacial and Late Glacial floristic remains (Klimaszewski et al., 1950).

In the longitudinal profiles of preserved Last Glacial terraces deformations occur, which are especially well pronounced within the Nowy Targ Basin. Between Maniowy and Szubieniczna Góra, the different altitudes of rock socles on either side of the valley are believed to be associated with the presence of re-activated faults.

An increase in the relative heights can also be seen near Sromowce Niżne, as well as within the "Pieninian" gorge. An unusual "jump" in the socle's altitude near Krościenko could evidence the lowering of the Krościenko Basin, situated within the contact-zone between the Pieniny Klippen Belt and the Magura unit (Watycha, 1976).

In the Dunajec water-gap within the Beskid Sądecki Mts., the Würm terraces occur at altitudes that vary from 9–11 m at Krościenko to 18 m at Kłodne and 10–13 m at Łącko. Heights of the rock socles vary from 4 m in the south to 10 m in the middle part of the gorge and, to 6–11 m at Wietrznica. Near the mouth of the Ochotnica river, the rock socle divides into three levels: 8–8.5 m, 6.5–7 m and 6 m.

A lower terrace step, cut during the Late Glacial times, is 5–8 m high. Gravels and sands cover a rock socle, the altitude of which changes from 5 m at Tylmanowa to 1.5 m at Wietrznica.

Between Łącko and Nowy Sącz, the Würm terrace forms a widespread plain, 8–13 m high. Lower, erosional steps are preserved locally. They were probably cut during the Hengelo interstadial. The basement of Late Glacial alluvia crops out sporadically and seems to be associated with tectonic blocks, separated by north-south striking faults that transverse the contact between the Krynica and Nowy Sącz subunits.

Within the margins of the Nowy Sącz basin, terrace levels are sometimes overlain by alluvial fans of the tributaries of the Dunajec.

Within the Grybów and Beskid Wyspowy Mts., the Last Glacial terrace forms two separate steps: 8–12 m and 6–8 m. Farther to the north, altitudes of the rock socle rise from –4 m at Chełmiec to 2.5 m at Roszkowice.

In the Poprad valley, the terrace steps under consideration occur on either side of the valley. The height of the terrace surface rises northwards from 7–9 m to 11–12 m. The rock socle is very rough. At Rytro it crops out 2 m above the flood-plain, between Życzanów and Barcice Górne it is exposed in the river-bed and, farther to the north, it plunges beneath the bed to a depth of 4–5 m.

Last Glacial terraces within the Kamienica Nawojowska valley (Fig. 9 and

12) form a large alluvial plain, reaching a height of 7 – 11 m in the middle river-course to 5 – 8 m in the lower one. The rock socle plunges from 3.5 m at Nawojowa to – 3 m at Zawada, but at Nowy Sącz it rises again above the valley-floor (2 – 2.5 m).

The Late Glacial terrace, 5 – 7 m high, is well developed in the all considered valleys. Its altitudes rise at Jazowsko. Between Łącko and Tabaszowa this terrace level is an erosion-accumulational terrace and, within the Nowy Sącz Basin, it forms a cut and fill terrace.

HOLOCENE

In response to climatic amelioration at the Pleistocene-Holocene boundary, as well as to a slight tectonic upwarp, there occurred final dissection of the Würmian and Late Glacial terraces. The depth of downcutting reached a value of 12 m in the eastern part of the Nowy Sącz Basin, 15 – 10 m between Czorsztyn and Sromowce Niżne, 20 m in the Pieniny gorge, 4 – 7 m at Krościenko, 1.5 – 5 m at Tylmanowa and 1 – 2 m at Wietrznica. These figures could represent the amount of possible upwarping at the decline of Late Glacial and during the Holocene. To the north of the Dunajec gorge in the Beskid Sądecki Mts., erosion affected the alluvial covers only. The rate of dissection was 3 – 5 m. In the Pieniny Mts. the eroded rills were filled with alluvia, 4 – 10 m thick. Pebbles and gravels are occasionally covered by a thin horizon of peat. The accumulation of organogenic material is confined to the Boreal phase (Birkenmajer and Środoń, 1960).

Another phase of climatic amelioration during the Early Holocene led to the dissection of deposited alluvial covers, as far as their substratum. During the period of intensive accumulation in the Atlantic phase (Starkel, 1977), another fluvial cover was laid down. Its thickness varies from 6 – 7 to 2 m.

The lowest Holocene cut and fill terrace reaches a height of 2 – 3 m above the river-bed.

Present-day erosional processes are most clearly visible within the Pieninian gorge, in the Kapuśnica water-gap, as well as at Ciechorzyn.

In the Dunajec water-gap in the Beskid Sądecki Mts. there are two Holocene terraces. In the vicinity of Kłodne, Klempowa, Wietrznica and Boczów their number increases up to 3 – 4 levels. Relative altitudes are about 2 – 4 and 0.5 – 1.5 m.

Between Łącko and Podegrodzie there appear 2 – 3 terrace steps. Within the Nowy Sącz Basin their number increases to 3 levels: 3.5 – 5 m, 2.5 – 3 m and 0.5 – 1(2) m. The thickness of recent alluvia attains a value of 10 m.

To the north of Nowy Sącz, the Dunajec valley-floor is composed of three terraces: superinundational (3.5 – 5 m), inundational (1.5 – 3 m) and flood-plain (1 – 1.5 m). The base of the alluvia lies 3 – 0.2 m beneath the river-bed.

In the Poprad valley the Holocene terraces are cut and fill ones and comprise two levels: 3 – 4 m and 0.5 – 2 m.

In the Kamienica Nawojowska valley three Holocene terrace steps appear: 3.5 – 4 m, 2 – 2.5 m and 0.5 – 1 m. These are exclusively fill top terraces.

THE ORIGIN OF TERRACE DEFORMATIONS

Disturbances in the longitudinal profiles of river terraces can be caused by a number of factors, namely:

1) different resistance of basement rocks,
2) the presence of meander loops,
3) development of "regression" terrace-steps,
4) increased erosional activity within highly tectonized areas,
5) vertical crustal movements along faults and/or re-activation of fold structures.

The last factor could have occurred within the Pieniny Klippen Belt (Ciechorzyn), along the northern margin of the Beskid Sądecki Mts. (Maszkowice, Obidza – Kadcza, Naszacowice), along the eastern margin of the Nowy Sącz Basin, as well as in the Beskid Wyspowy Mts. (Wielopole, Tęgoborze, Znamirowice).

Disturbances occur in the form of local upwarping of terrace socles, in the various heights of socles on the left and right valley sides and in the splitting of socles of the same age.

The morphology of the above-mentioned reaches of the Dunajec valley allows us to exlude the impact of resistance, the presence of incised meanders and

Table – Tabela 6

The amount of dissection of rock socles of the Dunajec, Poprad and Kamienica Nawojowska Quaternary terraces (in metres)

Rozmiary rozcięcia cokołów skalnych czwartorzędowych teras Dunajca, Popradu i Kamienicy Nawojowskiej

Time interval	Pieniny Mts.	Beskid Sądecki Mts.	Łącko – Podegrodzie Foothills	Nowy Sącz Basin	Beskid Wyspowy Mts.	Poprad valley	Kamienica valley
	Dunajec valley						
B – D		75	53	24	45 – 18	62	60 – 13
D – G			12 – 33	–	15 – 42	10 – 17	53 – 13
G – M1			29 – 15	32	35 – 15	23 – 13	7 – 17
M1 – M2	40 – 13	27 – 28	13 – 29	15 – 9	28 – 8	25 – 16	11 – 8
M2 – R1		34 – 20	31 – 11	14 – 30	16 – 6	15 – 22	20 – 12
R1 – R2	30 – 14	14 – 4	8 – 14	6 – 13	12 – 5	9 – 17	4 – 14
R2 – W		20 – 11	15 – 6	8 – 15	20 – 5	16 – 5	4 – 11
W – H	22 – 4	15 – 3	–2.5 to 3	0 to –5	2.5 to –0.5	2 to –5	3.5 – 0
W – LG	19 – 0	10 – 3	–	–	–	–	–
LG – H	8 – 0	5 – 0	–	–	0 – 4.5	–	–
H	–4 to 4	0 – 2	–	–	0 – 2	–	–

the development of terrace-steps associated with the backward erosion. Moreover, in the longitudinal profiles of river beds there occur peculiar troughs, formed in the basement rocks, the origin of which cannot be explained by erosional factors themselves. However, deformations of terrace heights within the Dunajec gorge in the Beskid Sądecki Mts. are the result of the presence of incised meander loops.

A remarkable increase in the relative altitudes of terrace socles, their splitting and, the presence of troughs within river-beds, seem to correlate with faults in the following areas: Mizerna – Ciechorzyn, Maszkowice, Obidza – Kadcza, Naszacowice, to the north of the mouth of Poprad, Rdziostów – Łęg, Tęgoborze and Znamirowice (cf. Figs. 10, 11, 14). In the Poprad valley, these deformations developed between Piaski and Myślec, and in the Kamienica Nawojowska valley between Górki and Falkowa (cf. Figs. 12 and 14).

A number of disturbances can be referred to the axes of fold structures, namely: the Lubań – Radziejowa syncline, the Zabrzeż – Brzyna syncline, the Czerniec – Łącko – Życzanów anticline, the Zabełcze syncline, the Paszyn anticline, the Stary Sącz – Myślec anticline and the Popowice anticline.

RATES OF UPLIFT

The depths of dissection of rock socles of the Dunajec, Poprad and Kamienica Nawojowska terraces during consecutive Quaternary stages, are shown in Tables 6 and 7 and in the Fig. 13. These values vary in different mountain groups.

Rates of dissection of rock socles of the Dunajec,
Tempo rozcinania cokołów skalnych teras Dunajca,

Time interval	$\times 10^3$ yrs[1]	Dunajec		
		Pieniny Mts.	Beskid Sądecki Mts.	Łącko Podegrodzie Foothills
D + D/G	870	–	0.06	0.01 – 0.04
G + G/M1	230	–		0.13 – 0.07
M1 + M1/M2	190	0.10 – 0.03	0.14 – 0.15	0.07 – 0.15
M2 + M2/R1	223		0.15 – 0.09	0.14 – 0.05
R1 + R1/R2	119	0.15 – 0.05	0.12 – 0.03	0.07 – 0.12
R2 + R2/W	85		0.24 – 0.13	0.18 – 0.07
W + H	73	0.30 – 0.05	0.15 – 0.00	–0.05 to +0.04

[1] Time estimation according to: van Montfrans (1971), Suggate (1974), Woillard (1979), Fair-

The most efficient Quaternary erosion affected the Dunajec water-gap in the Beskid Sądecki Mts., the Pieniny Mts., the Beskid Wyspowy Mts., and – to a lesser extent – the Łącko – Podegrodzie Foothills. The smallest rate of uplift is characteristic of the Nowy Sącz Basin. The amount of uplift decreased continuosly: from 62 – 13 m at the beginning of the Quaternary to 22 – 0 m in the Late Glacial period. At the end of the Würm glacial stage, as well as in the Holocene, a general subsidence took place, affecting the eastern part of the Nowy Targ Basin, the vicinity of Sromowce, the Krościenko Basin and the Nowy Sącz Basin. The absolute amount of subsidence varied from – 2 m in the Pieniny Mts. to – 8 m within the Nowy Sącz Basin.

Holocene upheaval can be noticed in the Eastern Pieniny Mts., in the axial part of the Beskid Sądecki Mts., as well as in the Beskid Wyspowy Mts. (4 – 2 m). The total amount of Quaternary uplift of the Dunajec drainage-basin can be estimated at 100 – 150 m in the Pieniny and Grybów Mts., 100 – 110 m within the Nowy Sącz Basin, 150 m in the Lubań – Radziejowa – Jaworzyna Krynicka Range and 120 – 160 m in the Beskid Wyspowy Mts.

An attempt to calculate the rates of dissection of rock socles of the Dunajec, Poprad and Kamienica Nawojowska terraces has been made (Table 7, Fig. 13). Assuming that tectonic movements were affecting the described territory during the whole Quaternary, average "cumulative" velocities for particular Quaternary stages (B – H, D – H etc.) were counted. Another calculation concerned the rate of uplift during a glacial and the following interglacial period (D + D – G, G + G – M1 etc.). The obtained results are shown in the Fig. 13. It can be concluded that the rate of uplift during the Early Quaternary was rather small

Table – Tabela 7

Poprad and Kamienica Nawojowska terraces, in mm/yr
Popradu i Kamienicy Nawojowskiej, w mm/r

valley		Poprad valley	Kamienica Nawojowska valley
Nowy Sącz Basin	Beskid Wyspowy Mts.		
–	0.02 – 0.05	0.01 – 0.02	0.05 – 0.01
0.14	0.02 – 0.07	0.10 – 0.06	0.03 – 0.07
0.08 – 0.05	0.15 – 0.04	0.13 – 0.08	0.05 – 0.04
0.06 – 0.13	0.07 – 0.03	0.06 – 0.10	0.09 – 0.05
0.10 – 0.05	0.10 – 0.04	0.08 – 0.14	0.03 – 0.12
0.09 – 0.18	0.24 – 0.06	0.19 – 0.06	0.05 – 0.13
– 0.04 to – 0.11	– 0.01 to 0.11	0.02 to – 0.07	– 0.05 to 0.03

bridge (1978), Różycki (1978), Lindner (1980)

(0.01 – 0.06 mm per year). Since the Günz glacial stage, calculated velocities have increased and differentiated in various mountain ranges. Between the Günz and Riss 2 glaciations, a rate of erosion did not exceed a value of 0.15 to 0.03 mm per year. The highest rates were confined to the Beskid Sądecki Mts. axis.

An increase in velocity occurred during the Riss 2 and the Eemian stages (0.24 – 0.05). In the course of the Last Glacial stage and the Holocene, however, the direction of movements changed. The Pieniny and Beskid Sądecki Mts. (0.15 – 0) as well as the Beskid Wyspowy Mts. were then uplifted, whereas the other regions underwent subsidence. The Nowy Sącz Basin was lowered at a rate of – 0.04 to – 0.11 mm per year. During the Last Glacial stage the highest rate of erosional dissection occurred (1.0 – 0.08 mm per year), being decreased in the Holocene times.

The mean rate of Quaternary uplift of the Dunajec drainage basin does not cxceed a value of 0.08 to 0.05 mm/yr.

FACTORS CAUSING TECTONIC MOVEMENTS

A number of factors, causing various rates of tectonic movements in the Dunajec drainage-basin, can be taken into consideration. These are as follows:

1) Quaternary overthrust of the Carpathians onto their foreland or backward thrusting of the platform under the Carpathian orogen. The first view can be supported by the results of geodetic measurements, cited by Liszkowski (1975) and Kvitkovič (1978). They revealed horizontal movements of the flysch nappes, directed to NW and NE. The second hypothesis, known as the "pessular" theory of Teisseyre (1921), has recently been discussed by Karnkowski (1977). This theory agress well with the theory of plate tectonics, applied to the Carpathians (Bird and Dewey, 1970; Horvath, 1974; Ney, 1976; Książkiewicz, 1977). It assumes:

2) the collision of Euroasiatic and Pannonian plates along the subduction zone following the northern margin of the Pieniny Klippen Belt. In this zone earthquakes are likely to appear.

3) Re-activation of deep-seated faults.

4) Regional isostatic compensation after the retreat of the Mindel ice-sheet from the northern part of the Dunajec drainage-basin. This theory seems to be thoroughly inappropriate. Investigations carried out by Mörner (1979) revealed that after the retreat of the Scandinavian ice-cap, regional isostatic compensation did not last longer than 5 – 6 thousand years.

5) Quaternary mobility of the Carpathian substratum. Its role in the formation of the present-day Carpathian morphology has already been noticed by Henkiel (1975). These movements seem to be associated with re-activated faults, transversing the Carpathian basement. This theory is confined to hypotheses 1 and 3. The author supports the hypothesis number 1.

CONCLUDING REMARKS

Within the area under investigation the remains of three planation surfaces occur: the Beskidy level (520 – 875 m), formed during the Early Sarmatian, the intermontane level (265 – 500 m), formed during the Pannonian and, the foothills level (150 – 270 m), formed during the Romanian. The Early Quaternary "river-side level" (90 – 150 m) represents fragments of the Biber and Donau valley-bottoms of the Dunajec, Poprad and Kamienica Nawojowska rivers.

The amount of uplift of the Dunajec drainage-basin during the Moldavian phase reached 210 – 380 m and, during the following Attican and Rhone phases, varied from 75 to 300 m. A lower degree of uplift is confined to the Valachian (25 – 120) and Quaternary Pasadenian phases (15 – 100 m). The axial part of the Beskid Sądecki Mts. underwent the most intensive upheaval.

The Pliocene deposits, occurring at the foot of the Lubań Range, were re-deposited from previously higher situated sites as a result of tectonic movements which subsided the border zone between the Pieniny Klippen Belt and the Magura nappe. An important role was also played by solifluction processes which occurred during the Last Glacial stage.

The antecedent Dunajec water-gaps (Niedzica, Pieniny, Beskid Sądecki), as well as the captured Poprad valley in the Beskid Sądecki Mts., were formed mainly during the earliest Quaternary times.

The total amount of Quaternary uplift of the Dunajec drainage-basin varies from 100 – 110 m in the Nowy Sącz Basin and the Spiš Pieniny Mts. to 150 m in the other regions.

On the basis of analyses of Quaternary river terraces, especially their rock socles, as well as differences in the thickness of fluvial covers, a number of regions showing different adjustment to tectonic pattern has been distinguished.

1. The Dębno – Frydman Graben, with a depth of 130 m, was formed during the Early Quaternary and underwent downward movements lasting to the present day. The northern and southern margins of the eastern part of the Nowy Targ Basin were uplifted with the same intensity until the Riss Glaciation. Since that time, the Lubań Range has revealed a relatively faster uplift.

2. The Pieniny Mountains were uplifted during the Pleistocene by block-type movements. The amount of uplift after the Mindel glacial stage reached 50 – 85 m. The surroundings of the Pieniny water-gap and the eastern margin of the Nowy Targ Basin were more strongly uplifted than the area situated between Czorsztyn and Sromowce Niżne. Small disturbances in terrace socles, visible in longitudinal profiles, are connected with the presence of large dislocation zones, striking NNW – SSE. The rate of uplift was relatively constant. During the Holocene, the eastern part of the Pieniny Mts. seemed to undergo a slight uplift. The western parts, however, remained stable or underwent slight subsidence.

3. The Krościenko Basin. With regard to the Pieniny Klippen Belt and the Beskid Sądecki Mts., the rate of uplift was much smaller here. During the Late Glacial downward movements began to predominate. These processes

were continued in Holocene times. The Krościenko Basin and the Dębno – Frydman Graben are both situated in the zone of subsidence associated with the contact between the Pieniny Klippen Belt and the Magura unit.

4. The Beskid Sądecki Mountains underwent intensive tectonic movements during the whole Quaternary. Their activity is especially well recorded in the morphology of the Dunajec and Poprad water-gaps. A higher rate of uplift is associated with the regions of Kłodne, Wietrznica and Boczów. Due to tectonic movements during the Mindel glacial stage, a splitting of rock terrace socles took place. The amount of uplift decreases northwards. Within the Poprad valley, south of the Nowy Sącz Basin, disturbances in rock socles' longitudinal profiles can be seen. These have been formed since the Riss Glaciation. In the Holocene, the axial part of the Beskid Sądecki Mts. reveals positive movements, causing splitting of the terrace levels. The differentiation in heights of the socles can reflect the orientation of structural elements, which comprise the Krynica subunit of the Magura nappe.

5. The Dunajec valley between Łącko and Gołkowice is situated along the contact between the Krynica and Nowy Sącz subunits of the Magura nappe. Intensive tectonic movements have been affecting this area since earliest Quaternary times. Especially active are blocks separated by north--south striking faults (Maszkowice, Jazowsko – Obidza, Gołkowice – Kadcza). Within these blocks, rock socles of the Mindel and Riss terraces underwent splitting. Differences between the left and right valley sides are also visible here.

At the end of the Last Glacial and in the Holocene, the Łącko Basin and the region situated west of Jazowsko, were strongly subsided. The substratum of recent alluvial covers was thrown down to a depth of 5 – 8 m beneath the river-bed. It can be suggested that these movements were associated with the above mentioned fault zones.

6. The Nowy Sącz Basin. In comparison with other parts of the Dunajec drainage-basin, positive movements are more weakly pronounced here. During the Last Glacial and the Holocene, they were substituted by negative movements, the amount of which was 6 – 8 m. During the Riss 2 and the Holocene, cut and fill terraces were formed. The upheaval of the northern margin of the Basin during the earliest Quaternary (Biber – Donau) resulted in the deposition of coarsegrained sediments, which crop out between Gostwica and Brzezna.

Deformations in the longitudinal profiles of rock socles of the Mindel and Riss terraces, the patches of which occur along the southern border of the Basin, seem to be associated with the Dunajec – Poprad fault system. This system was rejuvenated during the Meso- and Neopleistocene. Between Dąbrówka Polska and Biegonice, the socles of the Mindel 2 terrace is situated 9 – 12 m higher than that in the northern margin of the Nowy Sącz Basin. This phenomenon can be related to the presence of rejuvenated fault, transversing the Badenian deposits which underlie recent alluvial covers. The orientation of the present--day Dunajec river-bed coincides with the course of that fault.

7. The Grybów Mountains. In comparison with the Jaworzyna Krynicka Range, the intensity of positive movements was weaker here. The more intensive uplift started at the end of the Last Glacial. Uplifted areas are confined to the surroundings of Kunów, Falkowa, Gołąbkowice, Górki and Załubińcze.

8. The Beskid Wyspowy Mountains. Unlike the Nowy Sącz Basin, the Beskid Wyspowy Mts. revealed a much stronger intensity of uplift. This tendency continued also in the Last Glacial and the Holocene. The regions of Rdziostów, Łęg, Just–Doliny and, after the Mindel Glaciation, also the surroundings of Wielogłowy, Biała Woda and Znamirowice, underwent a faster upheaval. A splitting of terrace socles can be seen at Zabełcze (Donau), Wielogłowy (Mindel 2), Znamirowice and Tabaszowa (Mindel 1 and 2). Disturbances in the longitudinal profiles of rock socles seem to be associated with the orientation of the Magura overthrust.

It can be concluded that the Pliocene-Quaternary tectonic movements, affecting the Dunajec drainage-basin area, reflect the tectonic mobility of the flysch substratum. This mobility may refer to still continuing process of the backward thrusting of the Easteuropean platform under the Carpathians.

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STRESZCZENIE

Niniejsze opracowanie dotyczy ruchów neotektonicznych, zaznaczających się w środkowej części dorzecza Dunajca (polskie Karpaty Zachodnie), zapoczątkowanych u schyłku sarmatu, a kontynuujących się w pliocenie i czwartorzędzie. Przeprowadzone badania zmierzały do poznania przebiegu późnoneogeńskich i czwartorzędowych ruchów tektonicznych oraz ich wpływu na rzeźbę tej części Karpat. W celu określenia charakteru i intensywności tych ruchów wykonano szczegółowe zdjęcie geomorfologiczne (fig.2, 3, 4)w skali 1:25000. Przeprowadzono analizę związku form i pokryw terasowych w profilu pionowym, w przekroju poprzecznym (fig. 6—9) oraz w profilu podłużnym (fig. 10, 11, 12) dolin Dunajca, Popradu oraz Kamienicy Nawojowskiej. Badano zróżnicowanie form i osadów w obrębie poszczególnych pokryw, stosunek form i facji osadów rzecznych do stokowych, wzajemny stosunek teras do siebie, a przede wszystkim — relacje pomiędzy pokrywą osadową a cokołami skalnymi. Dodatkowo wykorzystano dostępne zdjęcia lotnicze.

Korelację wiekową teras umożliwiły badania sedymentologiczne pokryw terasowych, określenie ich stosunku do pokryw soliflukcyjnych i przykrywających utwory akumulacji rzecznej glin pylastych i pylasto-piaszczystych, jak również wykorzystanie dotychczasowych datowań metodą paleobotaniczną i ^{14}C.

W celu rekonstrukcji ruchów tektonicznych zachodzących w późnym neogenie przeanalizowano zachowane w obrębie dorzecza powierzchnie częściowego zrównania.

Na omawianym obszarze zaznaczają się trzy powierzchnie częściowego zrównania: beskidzka (520—875 m), powstała w dolnym sarmacie, śródgórska (265—500 m), utworzona w pannonie oraz pogórska (150—270 m) pochodząca z romanu. Wczesnoczwartorzędowy poziom „przydolinny", wznoszący się 90—150 m nad dnami dolin, reprezentuje fragmenty dawnych den dolinnych Dunajca, Popradu i Kamienicy Nawojowskiej z okresów Biber i Donau.

Rozmiary wypiętrzenia dorzecza Dunajca (tab. 1, 2, fig. 5) w trakcie fazy mołdawskiej wyniosły 210—380 m, a w fazach attyckiej i rodańskiej od 75 do 300 m. Słabsze rozmiary osiągnęły ruchy wypiętrzające w fazie wołoskiej (25—120 m) oraz czwartorzędowej fazie pasadeńskiej (15—100 m). Najsilniejszemu wypiętrzaniu podlegała osiowa część Beskidu Sądeckiego (Pasma Lubania, Radziejowej i Jaworzyny Krynickiej).

Występujące u podnóża Pasma Lubania utwory plioceńskie spoczywają na wtórnym złożu. Uległy one przemieszczeniu z wyżej leżących stanowisk (poziom pogórski) dzięki ruchom obniżającym strefę kontaktu Pienińskiego Pasa Skałkowego z jednostką magurską (skośne podniesienie Pasma Lubania).

Antecedentne przełomy Dunajca (niedzicki, pieniński, beskidzki) oraz regresyjny przełom Popradu przez Beskid Sądecki tworzyły się głównie w najstarszym czwartorzędzie.

Sumaryczna wielkość czwartorzędowego wypiętrzenia dorzecza Dunajca (por. fig. 13) wyniosła 100 – 110 m w Kotlinie Sądeckiej i Pieninach Spiskich do 150 m na pozostałym obszarze.

Analiza zaburzeń w profilu podłużnym cokołów skalnych teras oraz w profilach koryt Dunajca, Popradu i Kamienicy Nawojowskiej (tab. 3, 4, 5, fig. 10, 11, 12), jak również zróżnicowana miąższość pokryw akumulacyjnych, pozwalają wydzielić kilka obszarów (por. fig. 14) o zróżnicowanych tendencjach tektonicznych i porównać rozmieszczenie stref deformacji z przebiegiem struktur tektonicznych podłoża (tab. 6, 7, fig. 14).

1. Zapadlisko Dębna – Frydmana, o głębokości ponad 130 m, powstało we wczesnym czwartorzędzie i podlega obniżaniu do czasów współczesnych. Północne i południowe obrzeżenia wschodniej części Kotliny Nowotarskiej podnosiły się w starszym plejstocenie z jednakową intensywnością. Ruch ten zaczął różnicować się w neoplejstocenie – szybszemu podnoszeniu ulegało wówczas Pasmo Lubania.

2. Pieniny wykazywały w plejstocenie ruchy wypiętrzające, o charakterze blokowym. Rozmiary podniesienia po okresie Mindel wyniosły 50 – 85 m. Silniej podnosił się rejon przełomu pienińskiego, słabiej – odcinek Pasa Skałkowego między Czorsztynem a Sromowcami Niżnymi. Zaburzenia w profilach podłużnych cokołów teras dowiązują do przebiegu wielkich dyslokacji o kierunkach NNW – SSE, przecinających dolinę Dunajca. Tempo podnoszenia było stosunkowo wyrównane. W trakcie holocenu słabym ruchom podnoszącym zdaje się podlegać wschodnia część Pienin, rozcięta przełomową doliną Dunajca. Pozostała część Pienin jest stabilna, względnie słabo się obniża.

3. Kotlina Krościenka. W stosunku do Pienińskiego Pasa Skałkowego tempo podnoszenia było tu znacznie słabsze, a u schyłku ostatniego glacjału zaczęły przeważać ruchy obniżające, kontynuujące się w holocenie. Zarówno Kotlina Krościenka, jak i zapadlisko Dębna – Frydmana leżą w strefie subsydencji towarzyszącej kontaktowi Pienińskiego Pasa Skałkowego z płaszczowiną magurską.

4. Beskid Sądecki. Intensywne ruchy tektoniczne zaznaczają się tu w całym czwartorzędzie w przełomach Dunajca i Popradu. Silniejszemu podnoszeniu zdaje się podlegać rejon Kłodnego, Wietrznicy i Boczowa, nieco słabszemu – rejon Tylmanowej. W trakcie glacjału Mindel ruchy tektoniczne doprowadziły do rozdzielenia się jednowiekowych cokołów tarasowych na dwa poziomy. Rozmiary wypiętrzenia maleją ku północy. W dolinie Popradu, na S od Kotliny Sądeckiej, zaburzenia w profilach cokołów skalnych zaznaczają się począwszy od glacjału Riss. W holocenie, w osiowej partii Beskidu Sądeckiego przeważają ruchy wypiętrzające, przejawiające się w rozdzielaniu poziomów terasowych. Zróżnicowanie wysokości cokołów dowiązuje do przebiegu elementów strukturalnych podjednostki krynickiej płaszczowiny magurskiej.

5. Dolina Dunajca pomiędzy Łąckiem a Gołkowicami została założona na kontakcie tektonicznym podjednostek krynickiej i sądeckiej płaszczowiny magurskiej. Intensywne ruchy tektoniczne zaznaczały się w trakcie całego czwartorzędu. Szczególną aktywnością odznaczały się bloki oddzielone uskokami Maszkowic, Jazowska — Obidzy oraz Gołkowic — Kadczy, o przebiegu południkowym. W strefach tych miało miejsce rozdzielanie się cokołów skalnych teras Mindel i Riss, zaznaczyły się tu również różnice w wysokościach cokołów pomiędzy północnym a południowym zboczem doliny (rejon Jazowska). W Kotlinie Łącka oraz na zachód od Jazowska, u schyłku ostatniego glacjału i w holocenie, zaznaczyły się silne ruchy obniżające. Ich efektem jest obniżenie podłoża aluwiów Dunajca do 5 — 8 m poniżej poziomu rzeki. Można przypuszczać, iż ruchy te wiązały się z uaktywnieniem wyżej wymienionych stref dyslokacyjnych.

6. Kotlina Sądecka. Ruchy podnoszące były tu najsłabsze w dorzeczu Dunajca, a w ostatnim glacjale i holocenie zaczęło przeważać obniżanie, sięgające 6 — 8 m. Mioceńskie podłoże aluwiów teras najmłodszych zapada poniżej poziomu koryt rzecznych począwszy od Płusów (w dolinie Dunajca) i Cyganowic (w dolinie Popradu). Terasy Riss 2, Würm, z późnego glacjału i holoceńskie są tutaj terasami włożonymi, akumulacyjnymi.

Wypiętrzanie północnego obrzeżenia kotliny w najstarszym czwartorzędzie (Biber — Donau) doprowadziło do sedymentacji utworów gruboklastycznych pomiędzy Gostwicą a Brzezną.

Deformacje w profilu podłużnym cokołów teras z glacjałów Mindel i Riss na południowym obrzeżeniu kotliny zdają się dowiązywać do przebiegu systemu uskokowego Dunajec — Poprad, uaktywniającego się w środkowym i późnym plejstocenie. Pomiędzy Dąbrówką Polską a Biegonicami podłoże terasy z glacjału Mindel 2 leży o 9 — 12 m wyżej w porównaniu z północnym obramowaniem kotliny. Można przypuszczać, iż wiąże się to z uaktywnieniem uskoku w podłożu utworów mioceńskich, wzdłuż którego biegnie obecnie koryto Dunajca.

7. Góry Grybowskie. W porównaniu z Pasmem Jaworzyny Krynickiej ruchy podnoszące były tu słabsze. Jedynie u schyłku ostatniego glacjału zaznaczyło się wypiętrzanie o większej intensywności. Obszary podlegające podnoszeniu grupowały się w Kunowie, Falkowej, Gołąbkowicach, Górkach i Załubińczu.

8. Beskid Wyspowy. W odróżnieniu od Kotliny Sądeckiej, ruchy podnoszące zaznaczały się w jego obrębie z większą intensywnością. Silniejszemu podnoszeniu ulegały: rejon Rdziostowa, Łęgu i Justu — Dolin, a począwszy od glacjału Mindel — także rejon Wielogłów, Białej Wody i Znamirowic. Rozdzielanie się cokołów skalnych jednowiekowych teras na dwa poziomy zaznacza się w okolicach Zabełcza (Donau), Wielogłów (Mindel 2) oraz Znamirowic i Tabaszowej (Mindel 1, 2). Deformacje profilu podłużnego cokołów zdają się dowiązywać do przebiegu nasunięcia jednostki magurskiej.

Można przypuszczać, iż plioceńsko-czwartorzędowe ruchy tektoniczne, obserwowane w obrębie dorzecza Dunajca, stanowią odzwierciedlenie mobilności podłoża fliszu, związanej prawdopodobnie z niezakończonym jeszcze procesem podsuwania się przedmurza pod Karpaty.

EXPLANATIONS OF PLATES — OBJAŚNIENIA PLANSZ

Plate — Plansza I

Fig. 1. Potoczki. A brickyard in Pliocene clays and debris-containing loams. Upper part of the profile redeposited solifluctionally.

Fig. 1. Potoczki. Cegielnia w iłach plioceńskich i glinach z rumoszem. Osady górnej części profilu przemieszczone soliflukcyjnie.

Fig. 2. Potoczki. Solifluction cover overlying Pliocene deposits.

Fig. 2. Potoczki. Pokrywa soliflukcyjna w stropie utworów plioceńskich.

Plate — Plansza II

Fig. 1. Płusy. A horizon containing carbonate concretions and calcareous detritus of the caliche type, underlying silty-sandy loams.

Fig. 1. Płusy. Poziom konkrecji węglanowych i miału wapiennego typu caliche, podścielający gliny pylasto-piaszczyste.

Fig. 2. Barcynka. Mudstones infilling a channel within Early Quaternary conglomerates.

Fią. 2. Barcynka. Mułowce wypełniające rynnę erozyjną wyciętą w zlepieńcach wczesnoczwartorzędowych.

Plate — Plansza III

Fig. 1. The valley of Dunajec at Sromowce Średnie. A Riss erosion-accumulational terrace level (R) gradually passing into the solifluction slope (s).

Fig. 1. Dolina Dunajca w Sromowcach Średnich. Terasa skalisto-osadowa z glacjału Riss (R), łagodnie przechodząca w spłaszczenie podstokowe z pokrywą soliflukcyjną.

Fig. 2. Kąty. A Riss terrace level (R) in the foreground, terraces from the Last Glacial (W) on the right-hand side of the valley. Macelowa Mt. in the background.

Fig. 2. Kąty. Poziom terasy Riss (R) na przednim planie, dalej na prawo płaty terasy z ostatniego zlodowacenia (W). W głębi Macelowa.

Fig. 3. Falkowa. Fluvial gravels deposited by the Kamienica Nawojowska river during the Mindel 1 glacial stage. Pebbles derived exclusively from flysch deposits of the Magura nappe.

Fig. 3. Falkowa. Seria żwirowa zdeponowana przez Kamienicę Nawojowską w glacjale Mindel 1. Otoczaki wyłącznie fliszowe.

Fig. 4. Płusy. Joint surface within silty loams overlying a series of gravels, deposited during the Riss 1 glacial stage. The surface was reworked by rainwash and resembles that of a slickenside.

Fig. 4. Spękanie w glinach pylastych przykrywających serię żwirową Riss 1. Powierzchnia spękania przemyta przez wody opadowe przypomina lustro tektoniczne.

Plate — Plansza IV

Fig. 1. A brickyard in Nowy Sącz—Załubińcze. Silty and sandy loams containing numerous illuvial horizons, overlying pebbles of the Mindel 2 terrace.

Fig. 1. Cegielnia w Nowym Sączu—Załubińczu. Gliny pylaste i piaszczyste z licznymi poziomami iluwialnymi, przykrywające serię żwirową terasy Mindel 2.

Fig. 2. Myślec. A contact between highly weathered fluvial gravels of the Mindel terrace cover and strongly cemented, decalcified, silty and silty-sandy loess-like loams.

Fig. 2. Myślec. Silnie scementowane i odwapnione gliny lessopodobne, pylaste i pylasto-piaszczyste, przykrywające zwietrzałe otoczaki serii terasy Mindel.

Plate — Plansza V

Fig. 1. Dąbrówka Polska. Strongly cemented silty loams, penetrated by subvertical joints, and overlying the Mindel 2 terrace cover.

Fig. 1. Dąbrówka Polska. Silnie scementowane gliny pylaste ze spękaniami subwertykalnymi, nadbudowujące serię żwirową terasy Mindel 2.

Fig. 2. Winna Góra. A quarry of the Magura sandstones composing a meander hill on the Poprad river. Strong tectonization indicates the presence of a fault zone.

Fig. 2. Winna Góra. Kamieniołom piaskowców magurskich budujących górę meandrową nad Popradem. Gęsta sieć spękań wskazuje na obecność strefy uskokowej.

Photos taken by J. Wieczorek (Figs. 1, 2, 5, 6, 7, 8, 11, 12) and the author.


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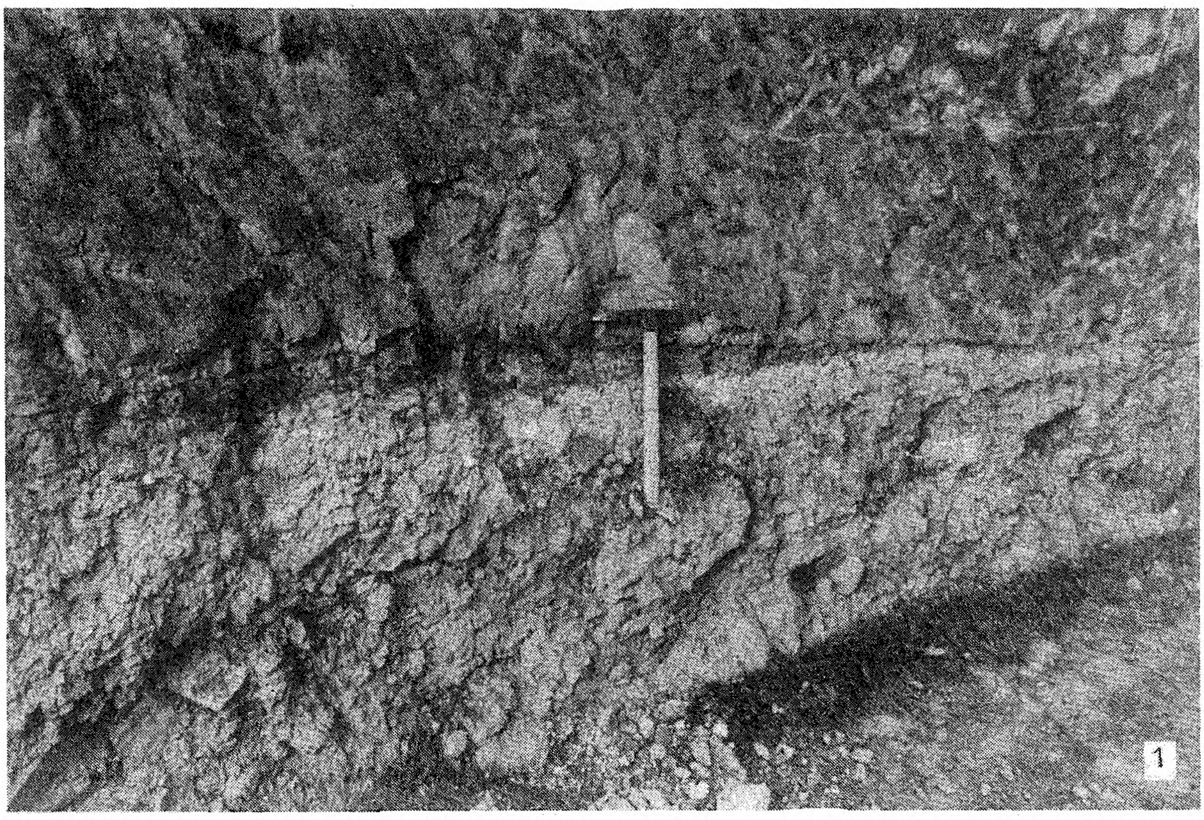
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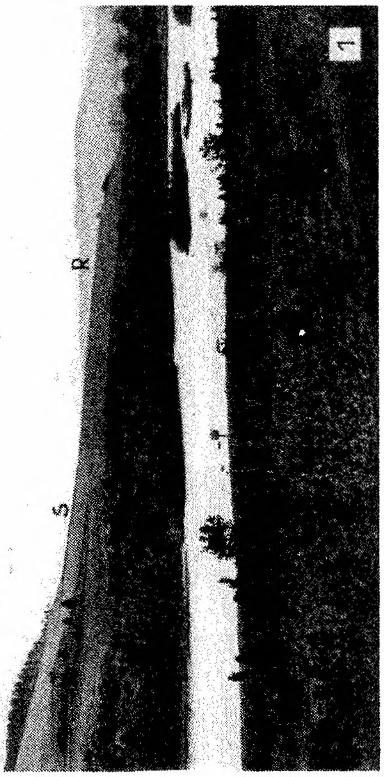

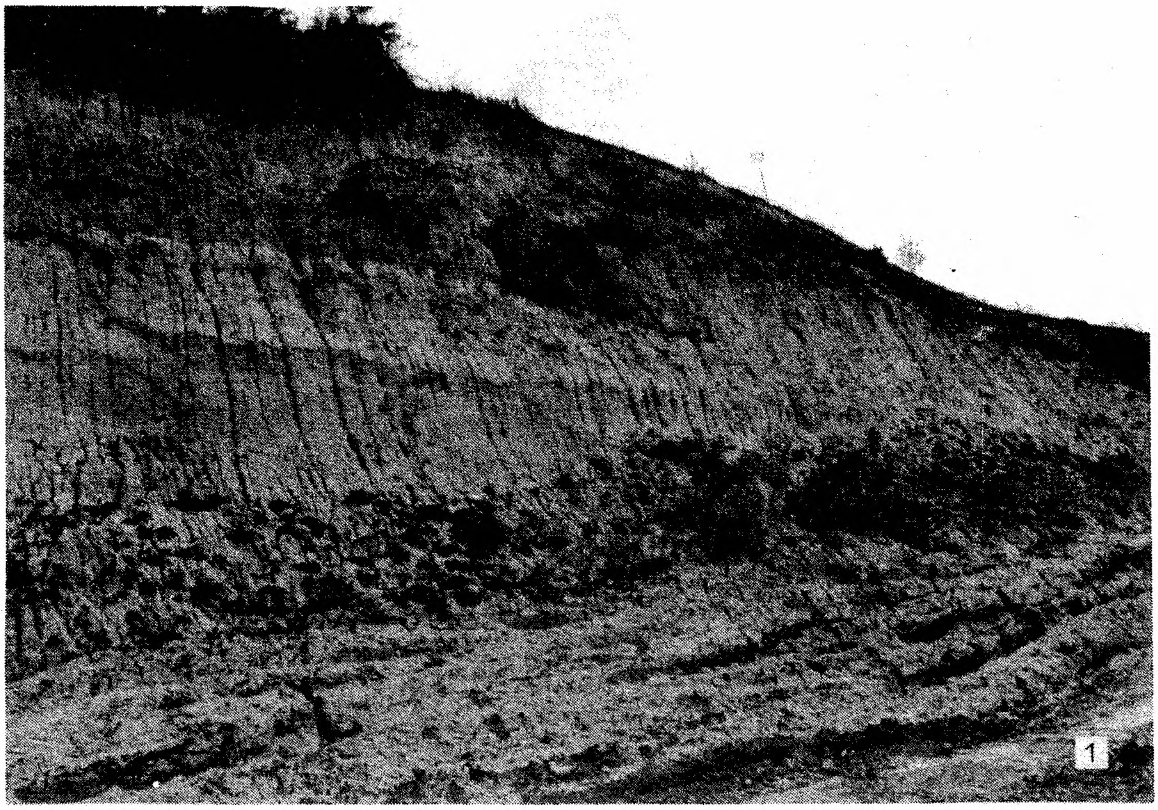
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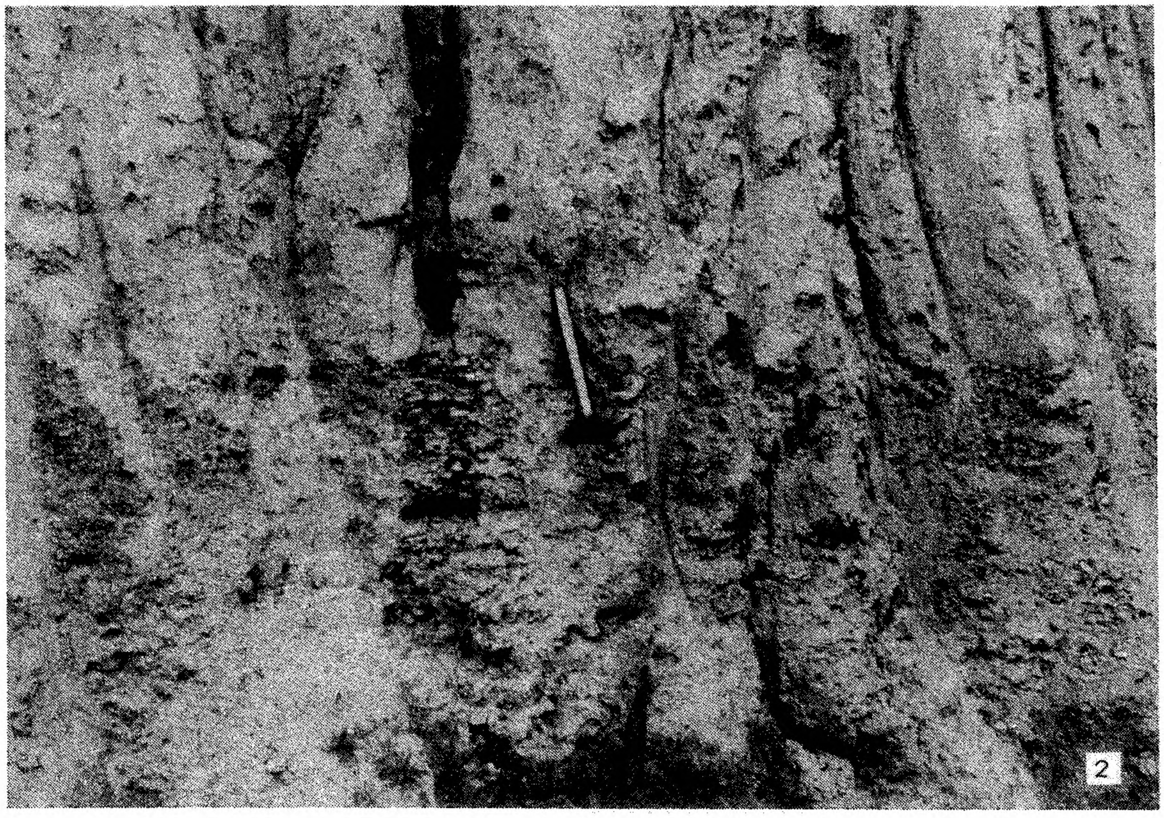
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