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LANDFORM EVOLUTION IN MOUNTAIN AREAS

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THE ROPA RIVER CHANNEL CHANGES DURING 20TH CENTURY AT SZYMBARK (POLISH FLYSCH CARPATHIANS)

Abstract. This paper is dealing with the Ropa river channel changes, mainly deepening, in the period of 1908–2000, on the experimental section of 2,5 km, at Szymbark, — in Lower Beskid (Polish Flysch Carpathians), an experimental station of the Geographical Institute, Polish Academy of Sciences. Analysis of repeated surveys performed in the years of 1908 , 1969, 1987 and 2000 gave opportunity to calculate the rate of channel deepening for the studied periods. Results of this investigatins are clearly showing that, the rate of channel deepening has great variability of data on the surface of the river bottom as well as in the longitudinal river channel profile and cross-sections.This variability, with fluctuations of deepenning in the range 0–120 cm strictly depends on lithology, landslides on the river channel banks and hydrotechnical constructions.

Key words: fluvial processes, river channel deepening, river Ropa, Lower Beskid, Flysch Carpathians, Poland

INTRODUCTION

The gravel-bed river Ropa drains western parts of the Beskid Niski (Lower Beskid — mountainous area) and the Jasło-Sanok Depression (foothills area) in the Polish Outer, Flysch Carpathians (Fig. 1B).

The river and its valley was the subject of numerous investigations lasting over hundred years: geological, hydrological (river stage records and discharge measurements) as well as hydrotechnical works. Fourty years ago have been initiated the stationary investigations on the hydrogeomorphological processes of the Lower Beskid, by the staff of the Research Station at Geographical Institute of Polish Academy of Sciences (IG i PZ PAN) at Szymbark, near Gorlice. One of the targets of investigations was recognition the dynamics of fluvial processess forming the Ropa river in its mountainous course. In order to perform this task, on the left bank of the river, in nearby of the Research Station was established hydrological gauging station with gauge meter and the fixed cross-sections to measure the river discharge from the catchment of 303 km^2. Secondly, upstream of the gauging station, on the distance of 2,493 meters, was established exper-

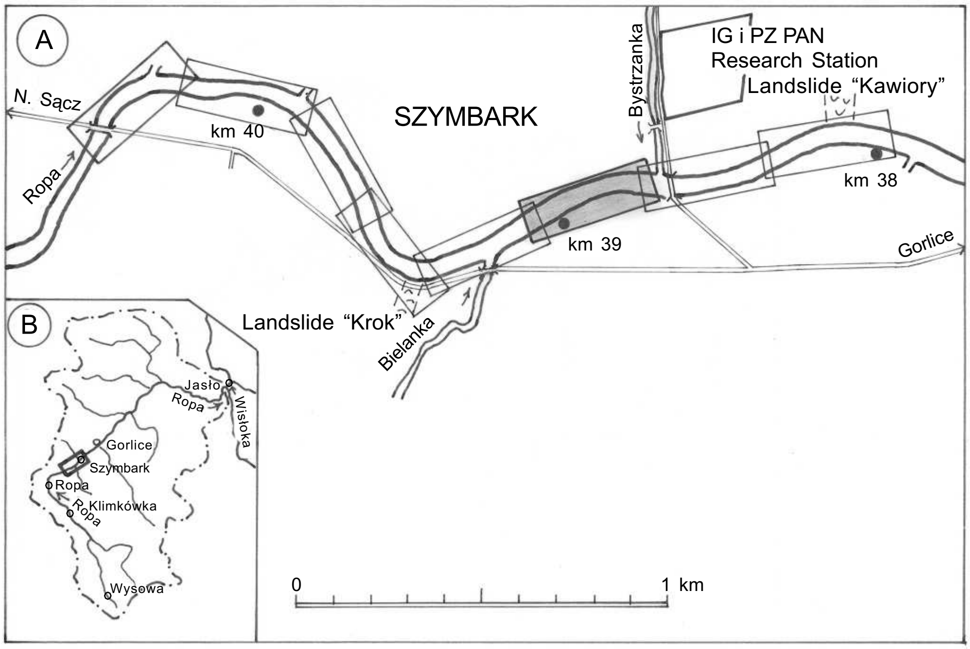

Fig. 1. A — Experimental sections of the Ropa river at Szymbark. Section presented in this article is marked in dark tone. B — Location experimental sections in the Ropa catchment

imental section of the river with fixed microtriangulation on both banks with concrete landmarks and polygonal network on the bottom of the river channel. Since July 1969 until December 2000 were performed repeated geodetic surveys of the Ropa channel, after discharges forming river channel. The map was drawn on the scale of 1 : 500. With this surveying frequency and accuracy, as well as monitoring displacement of the painted gravels, and taken photographs (including terrestrial photogrammetry), it was posible to detect even small changes of the river channel relief. Results of these investigations until 1980, in cross-sectional aspect, have been presented in several publications (Dauksza and Gil 1972; Dauksza 1976; Soja 1977; Dauksza et al. 1982).

The aim of this article is to present results of investigations on the deepening of the Ropa channel at Szymbark IG PAN from the year of 1908 to 2000 in the form of maps, long profile and cross-sections, representing most typical morphodynamical parts of the river.

The whole Ropa river drainage basin covers an area of 974 km^2, almost equally divided between two regions: mountainous (482 km^2), and foothills (492 km^2). The total length of the valley up to Jasło stands for 70 km, and river channel for 81 km. The length of the mountainous reach up to Szymbark is 37 km for the valley and 42 km for the channel (Fig. 1B).

Geological structure of the Ropa valley is fairly complex. It is builded-up mainly from alternately bedded, upper cretaceous and paleogene sandstones and shales of the flysch formation of the Magura and Silesian nappes (Oszczypko et al. 2008). Valley and river channel pattern and their longitudinal profiles are strongly influnced by tectonics and lithology of these nappes (Starkel 1969; Świdziński 1973).The whole valley is divided into "blocks" by transversal fault strikes, thrust planes, steep and overthrust folds (Jankowski 2007; Kopciowski et al. 1997a, b). Particular parts of the valley are reflecing this complicated geological structure. There are two main directions of the valley: carpathian, NW–SE, with the thrusts and folds extended parallely to it, and silesian, (NE–SW), followed by transversal faults.

From the village Ropa to Szymbark on the distance of 6 km, the valley is obsequent, parallel to the faults of the silesian direction (NE–SW) and crossing almost perpendicullary the thrusts and folds of the Magura nappe. Downstream of Szymbark, on the distance of 19 km, the valley enters into foothills area, beeing still obsequent. It had developed on the structures of the Silesian nappe (Kopciowski 1996). The bottom of the valley widens to 500 metres and from Gorlice to Jasło up to 1000 metres.

The river channel pattern in distinguished above river valley sections is also strongly influenced by the same factors. The valley floor is occupied by the alluvial terrace 3–5 m high builded up by coarse deposits of gravels, pebbles, and covered by sandy and loamy overbank facies (Dauksza et al. 1982).

River regime is mixed, rainfall-snowmelt-groundwater dependent, with the seasonal maximum of the run-off in spring (March to May) which stands for 36 to 42% of the yearly run-off (Ziemońska 1973). In the summer (June to August) is recorded about 41% of yearly precipitation with the maximum in July. Yearly precipitation at Szymbark for the period of 1968 to 2000 fluctuates around 700–1,000 millimetres. Coefficient of discharge (relation runoff to precipitation, expressed in %) represents "total influence environmental elements of the catchment on outflow" (Soja 1981). Peak flows in the Ropa river catchment are recorded only in the summer season (Soja 1981; Dauksza et al. 1982). Mean yearly discharges at Topoliny (confluence with Wisłoka river) varies from 1.3 $m^3 \cdot s^{-1}$ at low stage to 9.4 $m^3 \cdot s^{-1}$ at an average stage and as high as 191 $m^3 \cdot s^{-1}$ at mean high stage. Extremal maximum: 630 $m^3 \cdot s^{-1}$, noted on 16 July of 1934. Maximal discharges in mountainous area at Szymbark measured as high as 352 $m^3 \cdot s^{-1}$ (Soja 1977). Frequency of the maximal yearly discharges is highest in summer (36%). Discharges coefficient of irregularity (Qmax to Qmin) varies from 1800 at Topoliny to 3000 at Klęczany. Flood waves are displacing with the speed range 3.5 to 3.8 $m \cdot s^{-1}$ (Punzet 1991). From the point of view on the dynamics of the fluvial processes, the most important is "morpho-forming stage" which takes place when the movement of the river deposits leads to the new relief of the channel river, while "bankfull stage" means, that the water overpasses edge of the river channel, and is flowing through the floodplain.

Discharge data presented above were actual until the dam and reservoir "Klimkówka" was constructed on the river (Fig. 1B). Earthy, a 33 m high dam was completed in the year of 1994, 17 km upstream of the investigated area, encompassing catchment area of 210 km^2 and with storage capacity of 44 millions m^3. The dam and reservoir had changed river regime downstream. Recently, average guarantee, stable discharge takes out 2 $m^3 \cdot s^{-1}$. Maximum discharges with probability of 1% were reduced from 295 $m^3 \cdot s^{-1}$ to 70 $m^3 \cdot s^{-1}$ (*Zbiornik wodny Klimkówka...* 2000).

RIVER CHANNEL CHARACTERISTICS

River Ropa channel is cutted out in the gravelly, terrace forming the valley floor. Width of the channel, in the uppermost course at Wysowa is reaching 10–14 metres, 30–40 metres at Szymbark and 50–60 metres near the river mouth. Sinuosity on the foothill part of the catchment is much greater than this of mountainous area. Coefficient of channel sinuosity (ratio: length of the channel to the length of the valley axis) changes from 1.20 m in mountainous area to 1.35 in foothills area. At the beginning of 20^{th} century this coefficient was about 1.53 and dropped because of the river regulation in the lowermost part of the foothills area and several cut-off meanders. Depth of the channel changes from 1–1.2 m in the uppermost part of the valley to 3–3.5 m at Szymbark. Gradients of longitudinal profile changes from 13.5 promilles at Wysowa to 3.6 promilles at Ropa village and at Szymbark. In the foothills, is dropping to 2.3 promilles and to 0.9 promilles at the mouth. Larger contrasts in gradients has places in mountainous area, especially between river gaps and widenings of the valley floor.

On the most of the 2.5 km experimental section, actually there are stable river banks covered with riparian vegetation. During 20^{th} century had place substantial increase of this kind of river banks. At high stages, water flushes-out material from the roots of this vegetation. This process leeds to the undulating course of river banks. Almost on the entire length, channel is incised into bedrock up to 1 metre in mountainous area and less in the foothills. On this rocky channel bottom, the movable uconsolidated mixture of gravels and sands is forming variety of temporary (in geological sense) forms. Basically, on our Szymbark IG i PZ PAN section there are forms of lateral and vertical erosion in different stages of development. Locally river channel is formed by landslides encroaching to the river and creating river banks (km 39.4 and 38.1 on the Figs. 1A and 2). Among erosional forms cutted–out in the solid rocks there are erosional concavities and steps on outcrops of the sandstones of inoceramian beds, beeing local thresholds — especially on the distance 150 metres from 38,150 to 38,300 km. Among accumulation forms the most distinct are central and lateral bars. In the period of 1960^{th} and 1970^{th} these forms were very ephermal in its regular form. The cause of that was very rapid and intensive gravel exploitation — very often

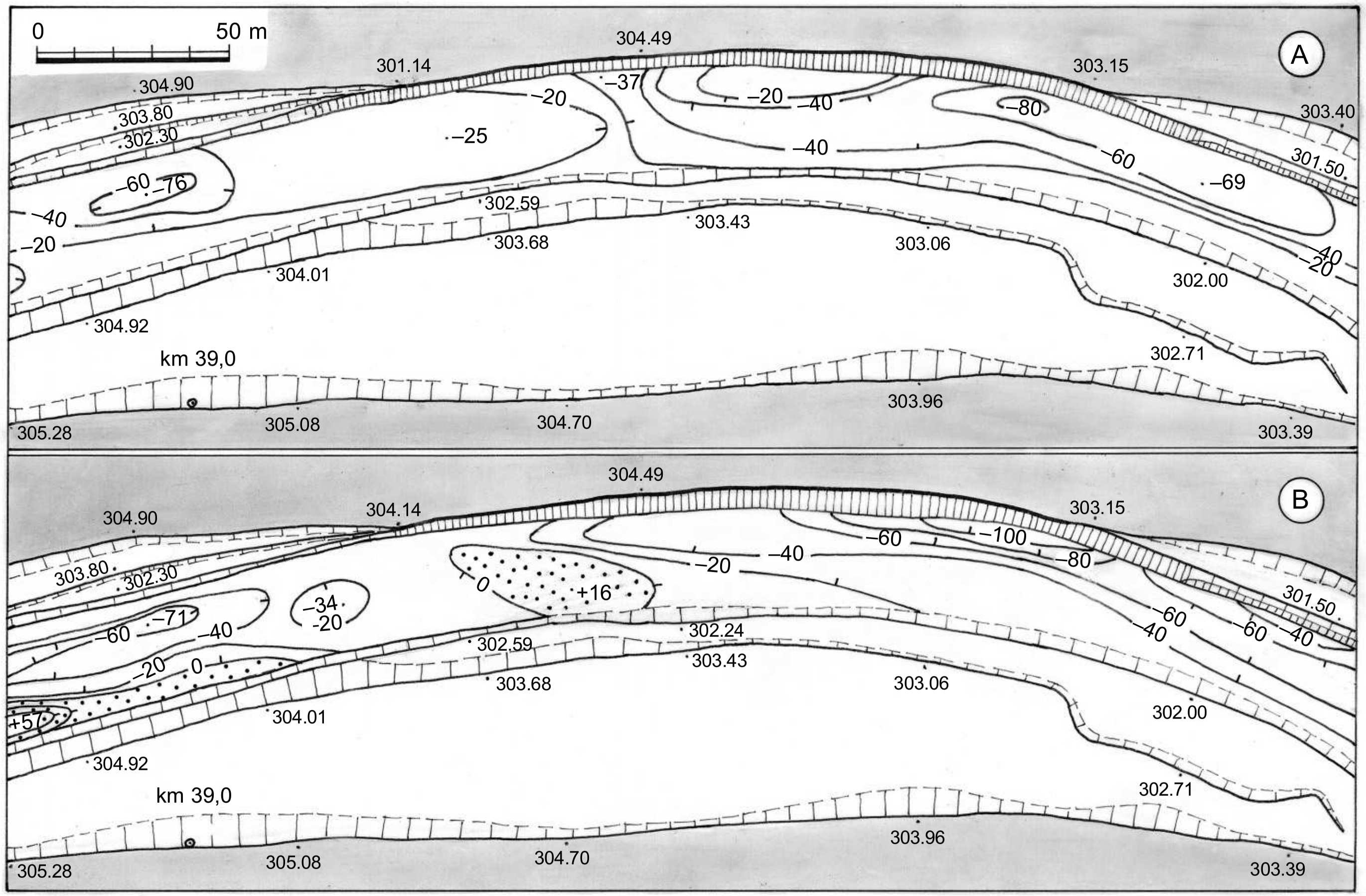

Fig. 2. Channel bottom changes in the period: A — 1969 to 1987, B — 1969 to 2000. Numbers are showing channel deepening or accumulation (dotted areas) in centimetres

to the water level and even to the bedrock below. Morphology of the river Ropa in the mountainous zone, could be described as pool-riffle channel and in part as step-pool, according to D.R. Montgomery and J.M. Buffington classification (1997). This type of the channel is composed of alternate sequens of bars, pools and riffles with sections of rocky steps.

CHANNEL DEEPENING

There are two approaches to monitor channel forms changes. The first, is morphological mapping of the channel forms on the basis of available topographic maps. A result of this work is an inventory of existing forms, so called "channel morphostatics" of the channel, repeated usually after morphologically important water rising stages. This method gives only qualitative data to evaluate channel changes, especially lateral erosion, less vertical erosion. The second method, so called "geodetical" approach (explained in introduction to this article), coupled with first approach gives both, qualitative and quantitative data. During 20th century channel formation and its metamorphosis, done by flood flows is superimposed by human activity, river regulation, bridges and dam construction, gravel excavation. Human activity had changed natural dynamics of fluvial processes. The data for evaluation the Ropa river changes were collected from the surveys accomplished in the years of 1908, 1969, 1987 and 2000. For each period between surveys were constructed maps of channel bottom surface change. By overlying these maps it was possible to obtain the rate of surface channel changes expressed in centimeters. An example of these maps exemlifying direction and scale of changes for the intervals 1969–1987 and 1969–2000 is shown from km 39,000 (left part of the map) to km 38,641. Figure 2A presents changes for the period 1969 to 1987 and Figure 2B for the period of 1969 to 2000.

Each of these maps is enabling us to read the value of the change at a particular point in the channel for the periods listed above, and allows us to detect areas more or less stable. For example, by comparing these two maps (Fig. 2A and Fig. 2B) are clearly seen possible tendencies of changes on the whole surface of the channel bottom. It is possible to say that left part of the channel has tendency for deepening, but also accumulation near the right river bank. Central part of the channel has tendency for slight accumulation and right part, along concave bank strong deepening. From comparison of these two maps is possible to see that the largest downcutting have had the place in two areas of these maps: on the left side (up to 71 cm) and the right side (increase from 80 to sligtly over 100 cm). Another important information is that this changes have constant tendency in the same places but with the slower pace for the period of 1987–2000. In the central part of these maps is seen tendency toward aggradation.

From our experimental part of the river there are presented six cross-sections (Fig. 3) at the kilometres of 40,480, 39,708, 38,870, 38,517, 38,183, and 38,122

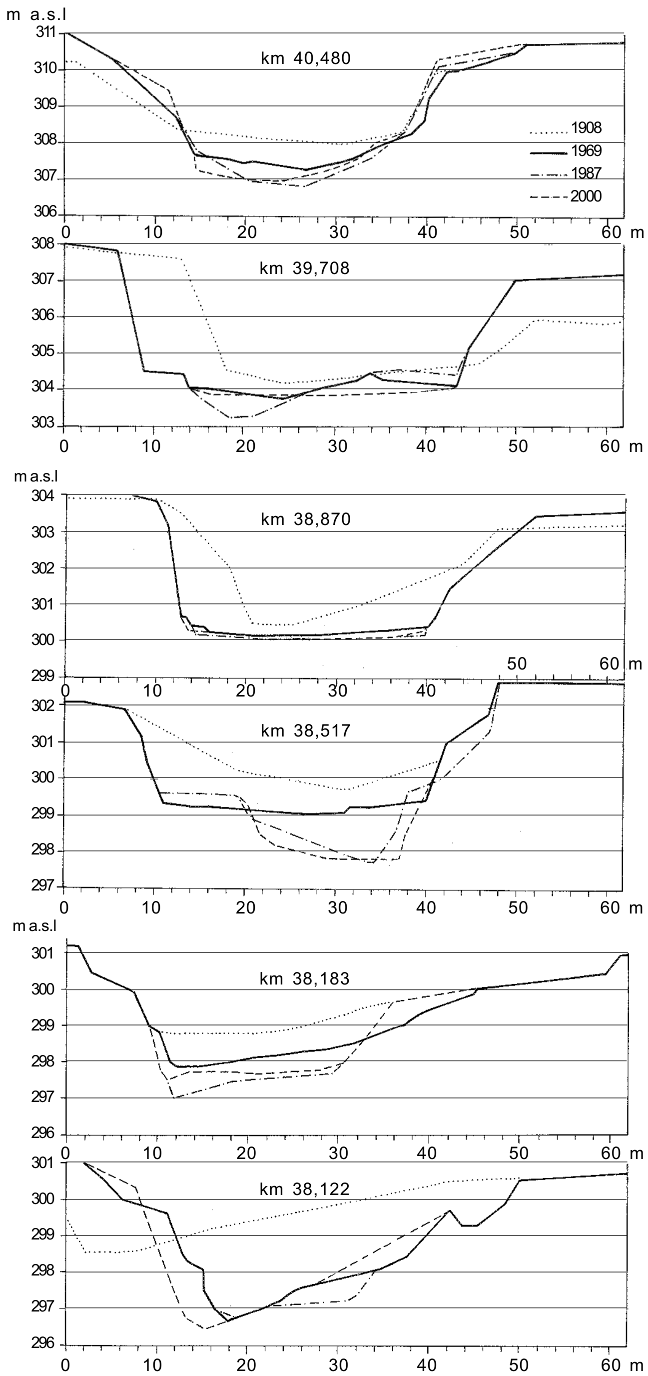

Fig. 3. Cross-sections of the river Ropa channel in years 1908, 1969, 1987 and 2000. A — at km 40,480 and 39,708, b — at km 38,870 and 38,517, c — at km 38,183 and 38,122

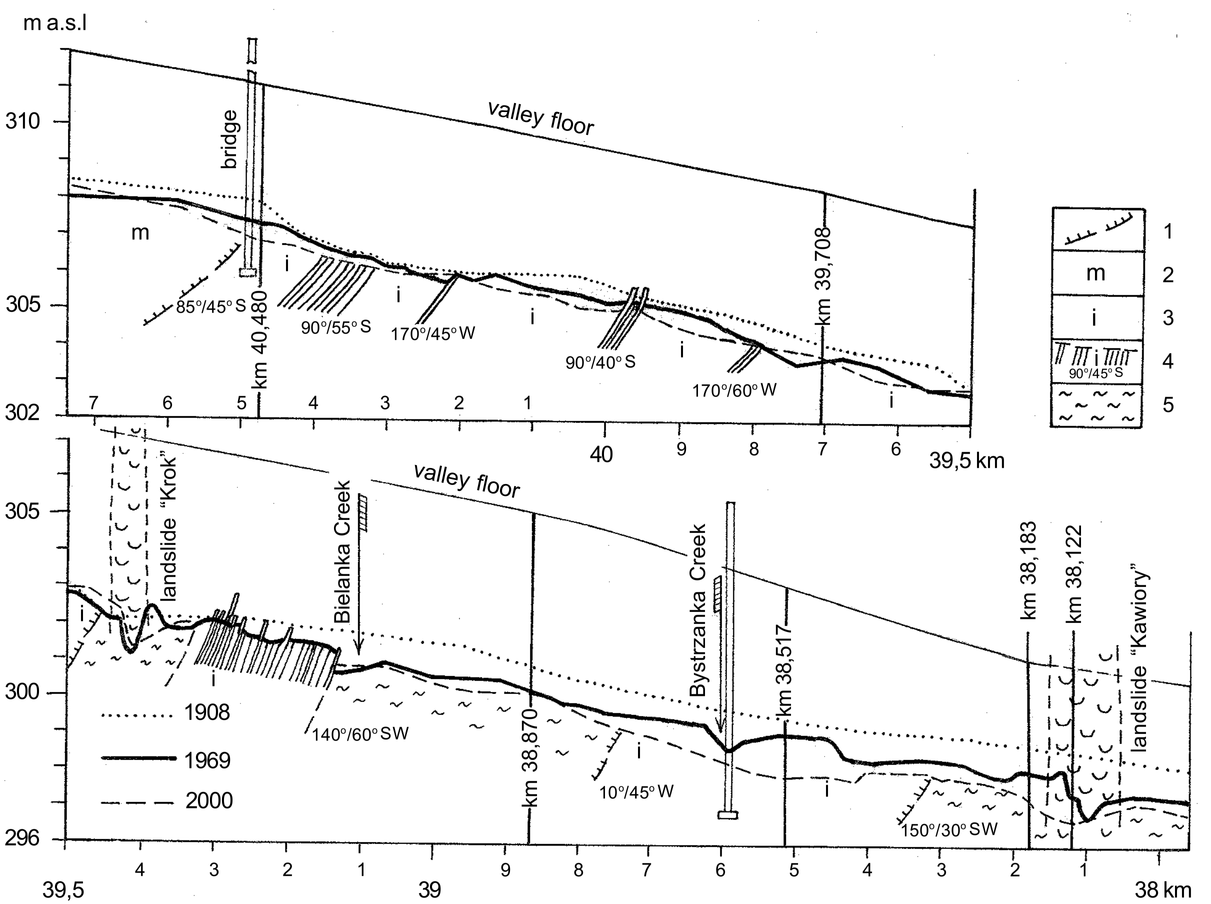

Fig. 4. Longitudinal profile of the bottom Ropa river in years 1908, 1969 and 2000 with marked cross-sections. 1 — Thrust, Slice; 2 — Magura Sandstones; 3 — Inoceramian Beds; 4 — Inoceramian Beds with outcrops of very resistant sandstones; 5 — Variegated Shales

representing different parts of the river channel and marked on the longitudinal profile (Fig. 4). Cross sections at km 39,708 and 38,870 are representative for stable sections or having moderately movable bed. Cross sections at km 38,122 represents part of the channel formed by landslide "Kawiory". Sections at km 40,480 and 38,517 are formed with strong influence of pillar bridges disturbing free water flow. On cross-sections are clearly seen all lateral and vertical channel changes — downcutting, aggradtionand shape changes.

An analysis of the longitudinal profile shows slower pace of channel downcutting at km 40,7 to 40,3 at the rate of 30 cm for the period 1969–2000, and at km 39,3 to 39,1 with the rate of downcutting dropped to zero, on outcrops of the sandstones of inoceramian beds. In our experimental part of the river from km 40,5 to 38,0 is clearly seen the same tendency in the same places for downcutting and aggradation for the periods of 1969–1987 and 1969–2000. Amplitude of these changes along the river course reaches 140 cm. There are two distinct peaks with fractional downcuttig or small aggradation, related to bedrock-very resistant parts of the channel, beeing the local thresholds. On the other side, there are two peaks of the channel downcutting, reaching 100 cm at landslide "Krok" (km 39,4) and 120 cm below the bridge, on the road to Bystra and Szalowa (km 38,5).

Another diagram (Fig. 5) presents rate of downcutting and aggradation along the river course, calculated as an average of the channel changes across of the cross sections for the periods of 1908–1969, 1969–1987 and 1969 to 2000. From

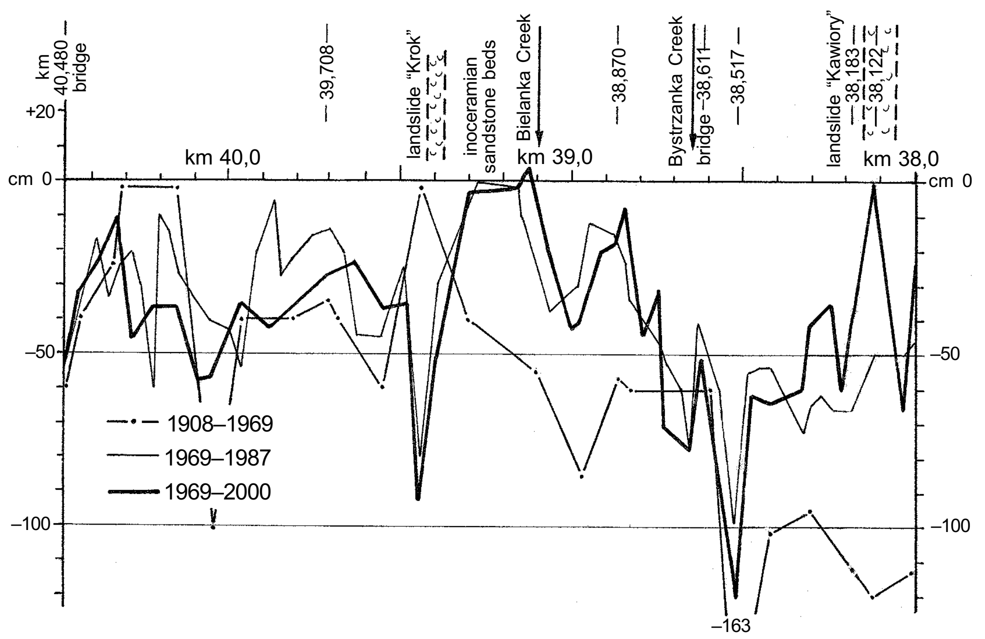

Fig. 5. Rates of river Ropa channel downcutting for the periods of 1969–1987 and 1969–2000

this diagram is possible to see different behaviour of the channel bottom in different periods. E.g. at the landslide ”Kawiory” (km 38,1) channel bottom was cutted down 50 centimeters in the period of 1969–1987 due to high frequency of floods in 1970-thies (D a u k s z a and K o t a r b a 1973) and later raised 50 centimeters in 1987–2000 due to reactivation of landslide. On this diagram amount of downcutting or aggradation for the period of 1987–2000 is the value of difference between two lines of the diagram for periods 1969–1987 and 1969–2000. The intensity of this activity had several periods of faster and slower pace.

The continuous monitoring of this pace is done by observations of minimum annual water stage at Ropa village gauging station (upstream of Szymbark), for the period of 1908–1984. In this timespan channel bottom lowered by 110 cm with relatively steady pace of erosion 1.4 cm per year. From geodetical measurements erosion for the same period is 90 cm. At Szymbark IG i PZ PAN for the period of 1968–1991 net erosion calculated from average low, yearly water stages was 63 cm (from geodetical measurements we obtained 41 cm). In both cases is discrepancy between values obtained by application of two methods. In my opinion geodetical data are more reliable because water stage depends on water depth and width. In practice water width at gauging station is not measured. Changing relief of cross sectional area puts some limitations on the reliability of data obtained from low water level readings. And one more limititation is that data cannot be extrapolated for hundreds meters and very often tens of kilometers.

Very good example of channel bottom changes is presented on Figure 4, showing great variability along the course of the valley. This big variability is related to the geological structure and resistance to erosion of a particular layer of the rock. Changes for the periods of 1969 to 1987, 1969 to 2000 and even in 1908–1969 are very close each other in the tendency of downcutting or aggradation in the same sections of the investigated area. From this diagram is clearly seen that the most of the downcutting, (nearly 90%), had place in the period of 1969–1987. In the period of investigation water raise, to the “morphoforming stage” was observed for 11 times. Among them the largest floods have had place in 1972, 1973 (the largest, overpassing bankfull stage) and in 1980.

General tendency for channel downcutting it does exist at the total length of the river, but with different rate of deepening. In our example most of the work on material removal was done in the period 1969–1987, and represents the period before river discharge regulation by the dam construction (up to 90%, of the total period), done basically by one flood of 1973.

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