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BEATA WOSKOWICZ (SOSNOWIEC)

GRAVEL-BED CHANNEL TRANSFORMATION DURING FLOOD, SUBCARPATHIAN OŚWIĘCIM BASIN, POLAND

Gravel-bed rivers of a braided channel pattern exist in the intramountain depressions of the northern mega-slope of the Western Carpathians and on their direct foreland. For over 20 years the transformation of such rivers during large floods has been an object of investigation (Froehlich et al. 1972; Baumgart-Kotarba 1980, 1983a, 1983b, 1985; Grocholska 1988). Since the beginning of the 20th century, the rivers have been embraced by regular engineering works intending to create a single straight channel, and to build the impounding reservoirs. Nevertheless many of these rivers are characterized by a refreshing of the braided pattern phenomenon. The role of the large flood of July 1997 in the Soła braided channel transformation in the direct Carpathians foreland is presented in this article. Investigations carried out here are related to KBN Project 6 PO4E 020 11.

STUDY AREA

The Soła river is the Carpathian tributary of the Vistula river. It is 90 km long and its drainage basin area is 1,375 km^2. The catchment of the Soła river comprises a part of the Western Beskidy Mts (1,000–1,500 m a.s.l.), a part of the Carpathian foothills (300–500 m a.s.l.), and the Oświęcim Basin (220–270 m a.s.l.) (Fig. 1A). Forested mid-mountains with deeply incised valleys and steep slopes form the Carpathian part of the Soła drainage basin. In this area the Soła dissects a flysch bedrock (sandstones, shales, marls). Through weathering, these resistant rocks produce boulders and gravel. In the Carpathian foreland the Soła valley was incised into Quaternary Period deposits overlying Miocene Period deposits. Coarse-grained alluvium was formed during the Vistulian Period. At the time, the Scandinavian ice-sheet margin was c. 300 km north of the Carpathian border, and the upper part of the drainage basin was covered presumably with mountain tundra (Klimek 1995). During this cold period, physical weathering was induced by periglacial climate and thick gravel alluvial covers accumulated on the Carpathian foreland.

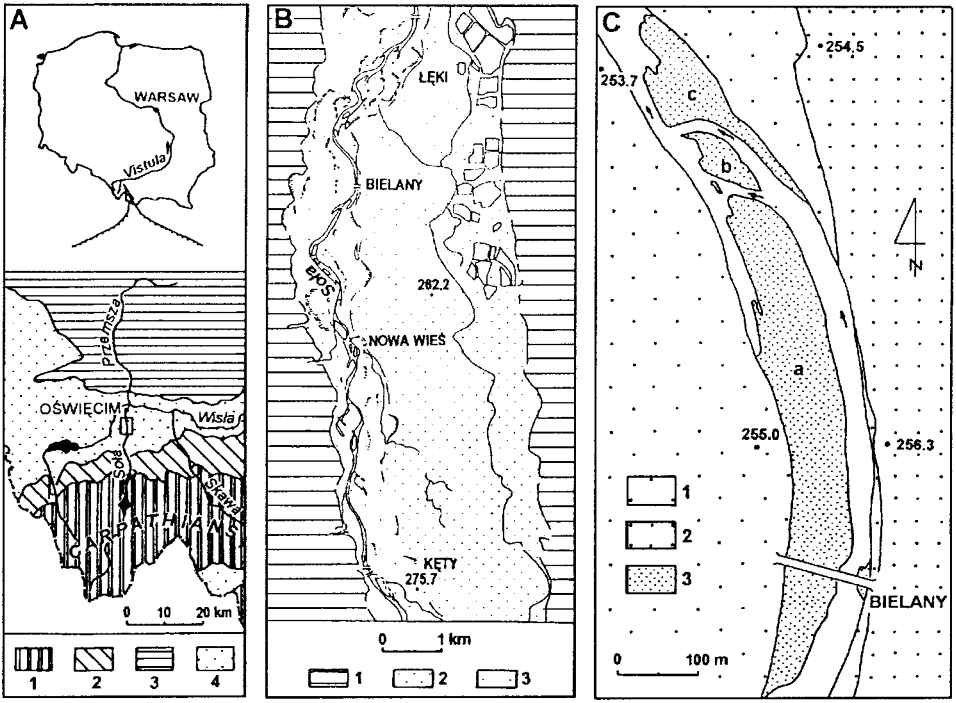

Fig. 1. Location of the study area. A. Relief of the Soła drainage basin: 1 — mid- and low mountains — Beskidy Mts, 2 — Carpathian foothills, 3 — basins, 4 — Silesian — Cracow Upland, B. The Soła valley floor within the Oświęcim Basin between Kęty and Łęki (after Grocholska 1991): 1 — Pleistocene level, 2 — upper level of the Holocene valley floor, 3 — lower level of the Holocene valley floor, C. The Soła channel pattern downstream of the Bielany bridge after the 1997 flood: 1 — upper level of the Soła valley floor, 2 — lower level of the Soła valley floor, 3 — gravel bars

In the upper river reach (from the source area to Żywiec), the Soła valley slope is up to 10 m · km^{-1}, while on the Carpathian foreland it is an average of 2.2 m · km^{-1} (Punzet 1971). Almost 90% of the Soła catchment belongs to the Carpathian area, which lends to the river its mountainous character. The Soła river has a rain-snow-ground regime (Ziemońska 1973). The hydrological regime is characterised by highly fluctuating water stages and discharges. The annual level of water stages in the low river reach (Oświęcim gauge station) reaches 1.2–5 m. Annual precipitation in a mountain part of the catchment ranges between 1,000 and 1,300 mm, where summer rains evidently prevail. About 40% of the total annual precipitation falls during the three rainiest months (i.e. from June to August), and the largest floods also occur in this period. Floods due to snowmelting (in March and April) are long-term and usually lower in discharge than summer floods, because of the high hipsometric range of the drainage basin. Minimum water level stages and discharges occur in November.

The current Soła hydrologic regime on the Carpathian foreland is controlled by three impounding reservoirs, built in 1936–1967 in the mountainous part of the catchment in Tresna, Porąbka and Czaniec. The mean discharge of the Soła in Oświęcim gauge, estimated for the 1961–1997 period, is 20 $m^3 \cdot s^{-1}$. By the time the Soła Cascade was built in 1958, the discharges reached up to 1,300 $m^3 \cdot s^{-1}$ (Punzet 1971). Maximum discharges on the Carpathian foreland have been reduced to 889 $m^3 \cdot s^{-1}$ (Oświęcim in 1970) after construction of the reservoirs. Nearly all the flood peak waters derived from the spring snowmelt period are stored in these reservoirs.

The large slopes and low retention potential of flysch bedrock cause overland flows, to dominate decidedly after rainfall in the drainage basin area. Consequently, large and torrential floods take place during rainy periods and very low discharges are typical during the dry times (Punzet 1971).

MORPHOLOGY OF THE SOŁA VALLEY FLOOR AND RIVER-BED

On the Carpathian foreland the Soła valley floor is about 3–3.5 km wide. It is bordered by 5–15 m high erosional scarps of Pleistocene terraces. The eastern scarp is straight and higher than the western one with traces of concave former the Soła undercuts. Two distinct hipsometric levels have been noted within the Holocene alluvial plain (Grocholska 1988) (Fig. 1B). Near Kęty the higher level reaches 5–6 m above the mean water stage and comprises the eastern part of the valley. The lower level of the alluvial plain comprises its western part and reaches 2–4 m above mean water level. A valley floor is built up of a several metres thick gravely-sandy alluvium overlain by fine grained overbank deposits. The Soła valley floor cross-section in the vicinity of Bielany is shown in Figure 2.

The Soła alluvial plain has been formed by braided river activity. The braided alluvial plain originated from the lateral accretion of the inactive part of the former channel during the catastrophic floods. This could form a new flood channel (Baumgart-Kotarba 1983a, 1989). It consists of fossil bars and palaeochannels of low sinuosity. The palaeochannels formed in the youngest Holocene Period (Klimek 1987) are the only forms that have been preserved within the Soła alluvial plain. The lack of older palaeochannels indicates that they have been destroyed through erosion by a laterally migrating river (Grocholska 1988). Some traces of channels from the second half of the 19th century and the beginning of the 20th century are well exposed (Klimek et al. 1986).

The lower level of the alluvial plain is submerged during large floods, when overbank occurs. The alluvial plain is covered with overbank deposits of various thicknesses and grain-sizes. A thin layer of fine-grained sediments, mainly sands, covers a fossil bar surface. Visibly different palaeochannels are mostly filled with silty deposits. Their thickness varies according to the age of

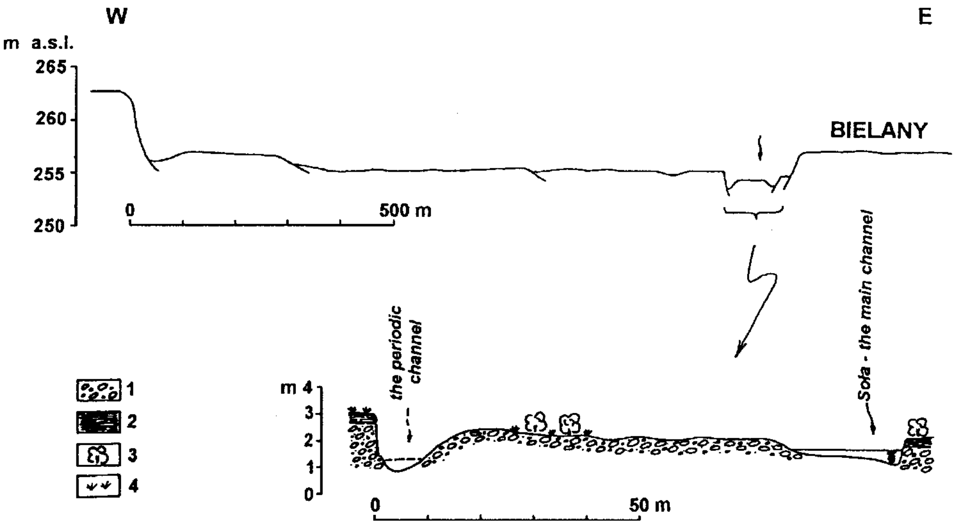

Fig. 2. Cross-section of the Soła valley floor near Bielany. 1 — gravels, 2 — sandy-silty deposits, 3 — willow scrubs, 4 — grass

palaeochannels and reaches a maximum value of up to 2.75 m in its oldest structures (Grocholska 1991, 1993; Wilk 1998).

In the 19th century the Soła river still existed as a braided river. It resulted from its hydrologic regime — a very large irregularity of discharges of high amplitudes (Punzet 1971), steep slope, and supply of the coarse-grained debris from eroded banks to the alluvial channel. An engineering works began at the beginning of the 20th century cut-off the secondary channels and dam construction. Only in some reaches of the alluvial channel can braided pattern be found nowadays. The river course is straighter in all other reaches. However, large floods can destroy the protection of the bank transform and the channel pattern to more a primary platform.

CHANNEL TRANSFORMATION OF THE FORE-MOUNTAIN RIVER REACH DURING 1997 FLOOD — TEST AREA NEAR BIELANY

In the fore-mountain Soła reach the braided pattern has been preserved downstream from the Bielany bridge (Fig. 1C). The river-bed is 65–125 m wide. A group of gravel bars of diagonal platform exists in the slightly sinuous Soła channel. These bars are built up of poorly sorted gravel as well as finer material (Photo 1). Bar forming material was derived mainly from erosional undercuts of the alluvial plain and the existing channel bars as well. A river reach several kilometres long between Bielany and the Czaniec dam — the last one in the Soła Cascade — is a potential source of sediment supply. However, this source

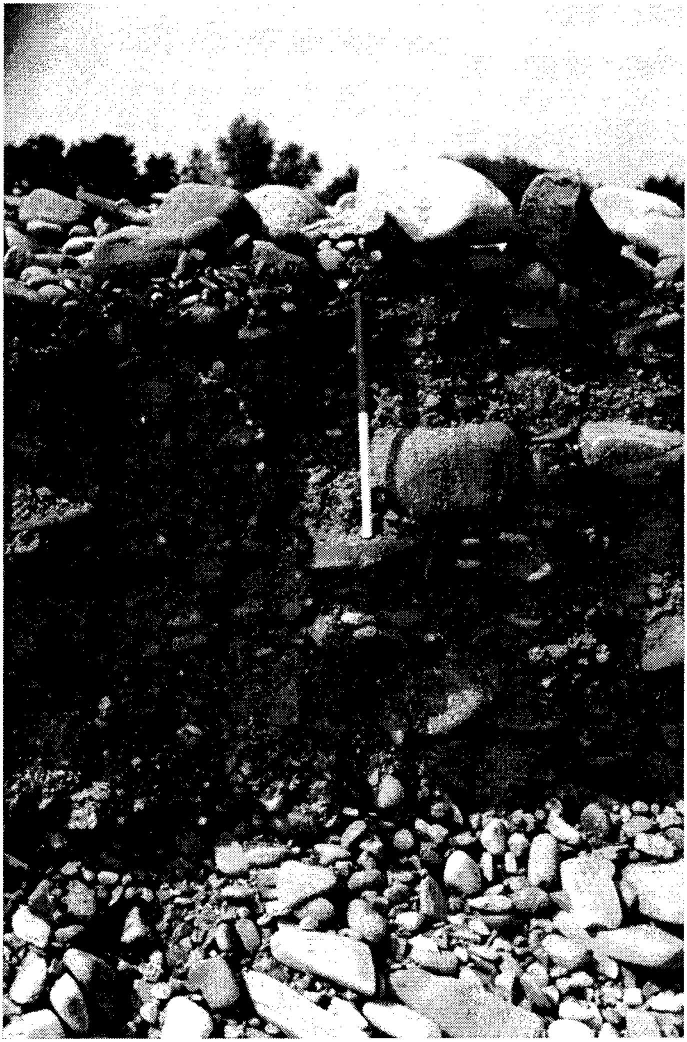

Photo 1. Structure of sediments forming the longitudinal gravel bar. Note that deposits are of very non-uniform grain-size. Pavement layer is clearly differentiated from underlying sediments both by grain-size and sorting. Scale is 20 cm

is partly limited by the armor provided by the bar (similarl to Bielany) and the protection of the banks.

Before July 1997 there were two large gravel bars within the Soła channel: a longitudinal bar and a mid-channel bar in a position further downstream. Their shapes finally formed during the September flood of 1996, which reached 759 $m^3 \cdot s^{-1}$ in the Oświęcim gauge station (12 km downstream the test area). Longitudinal bar (a) located close to the left channel bank is nearly 600 m long and up to 85 m wide (at a low water stage). It consists of three parts, varying both in age and plant colonisation

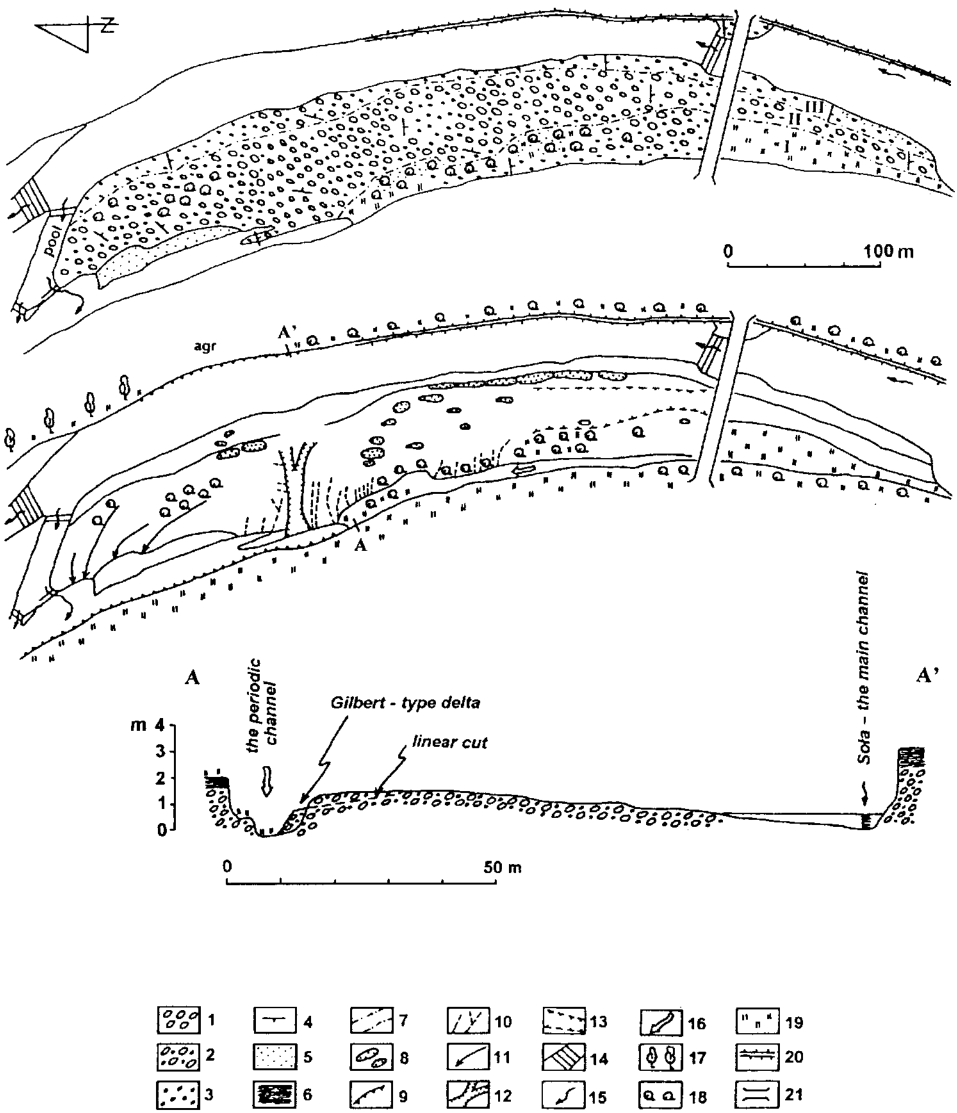

Fig. 3. Sketch of the Soła longitudinal gravel bar downstream of the Bielany bridge after the 1997 flood. 1 — gravels of the maximum diameters up to 25 cm, 2 — gravels of the maximum diameters up to 20 cm, 3 — gravels of the maximum diameters up to 10 cm, 4 — direction of imbrication, 5 — fine grain (sand, mud) deposit, 6 — sandy-silty deposit, 7 — limits of different parts of the bar, 8 — gravel and sand shadows, 9 — bank undercuts, 10 — linear cuts on the bars edge, 11 — linear cuts in the downstream part of the bar, 12 — chute channel, 13 — depression on the bars surface, 14 — riffle, 15 — current direction at low water stages, 16 — current direction in inactive channel at low water stages, 17 — riperian vegetation, 18 — willow scrubs, 19 — grass, 20 — engineering constructions, 21 — bridge, agr- formlands; A — A — cross-section

ratio (Fig. 1C, Fig. 3). The highest and oldest part of the above mentioned bar is covered with grass and willows and is overgrown to a large extent. The lowest part of the bar, visible at the low water stage only, is built of gravel up to 10 cm in diameter, distinctly finer than at the higher part. During the high stages it is separated from the bank by narrow, secondary channels. The mid-channel bar (b) was formed as the result of gravel sedimentation in a zone downstream from the longitudinal bar (a). This was presumably previously attached to the right river bank. It is partly forested and consists of the upstream part and the downstream one.

Heavy and continuous rainfalls in July 1997 caused the flood. In Oświęcim the gauge discharge reached 832 $m^3 \cdot s^{-1}$ during the flood peak (Fig. 4). The lowest level of the alluvial plain was submerged by flood waters up to 0.6 m in depth. The hydrograph of the Oświęcim gauge shows that in the period from 6 to 11 June 1997 the fall in flood waters was more abrupt than the previous rise. Poor sorting of gravely-sandy sediments deposited during the falling stage in the upstream bar zone (b) confirms the data that suggests an abruptly decreasing flow (Fig. 5).

The Soła channel pattern near Bielany after the flooding is presented in Fig. 1C. During the low and mean water stages, the main current in the vicinity of the bridge is close to the right river bank and a long gravel bar exists near the left bank. About 500 m downstream from the bridge the river is divided into two branches flowing round the mid-channel bar. About 100 m downstream the river flows in a single channel again, the left bank is eroded, and a side bar continues along the right bank.

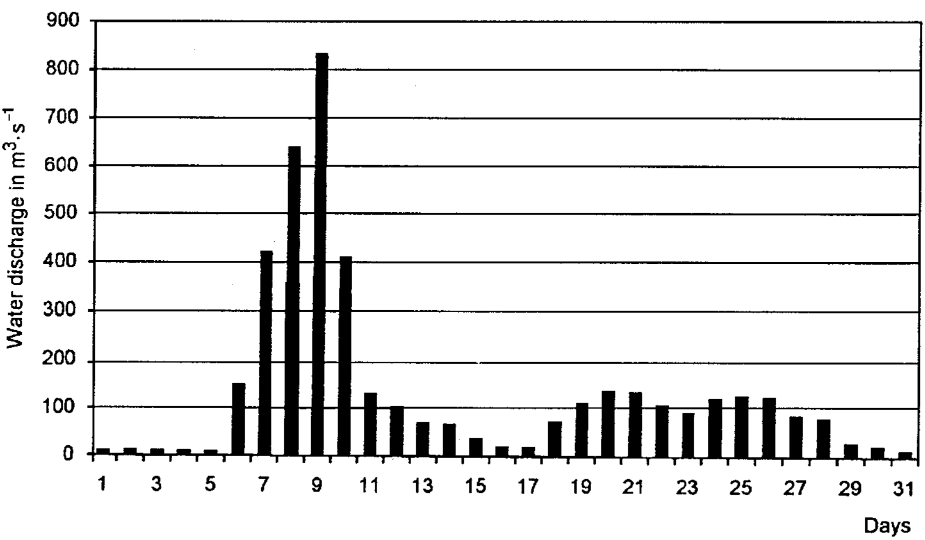

Fig. 4. Water discharges of the Soła river at Oświęcim in July 1997. Source: Institute of Meteorology and Water Management

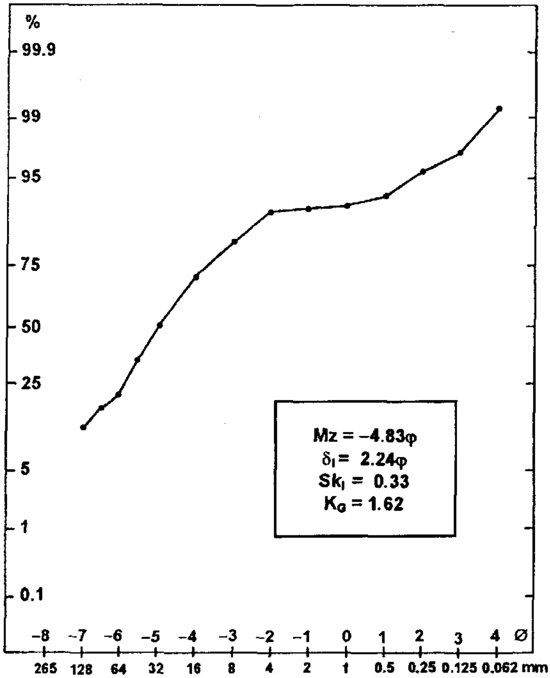

Fig. 5. Cumulative curves of grain-size distribution and grain-size indices of material deposited in the upstream part of the mid-channel bar during the 1997 flood. The 79.2 kg sample from sub-pavement layer. The grain-size indices after Folk and Ward (Gradziński et al. 1976). Mz — mean diameter, δ_I — inclusive graphic standard deviation, Sk_I — inclusive graphic skewness, K_G — graphic curtosis

On the right river bank a 70 m long alluvial undercut occurs. The upper level of the alluvial plain (3 m high), has shifted 2.5 m through erosion. Moving downstream from this place, the lower bank of the alluvial plain has receded up to 10 m; the vegetation cover was destroyed and most of the alluvium was eroded in this zone. In consequence of these processes the river bed has been widened markedly. A side bar emerged close to the right bank, downstream from the above mentioned undercuts. This bar consists of two parts: a strongly elongating part (Fig. 1C) originating in a remodelled section of the alluvial plain, and a more downstream part built up of a material derived from the eroded alluvial plain. The latter is distinctly bipartite. Comparing the thickness of both the downstream parts of the bar to the grain-size and orientation of imbricated gravel in pavement, one may say that the bars originated in different phases of the flood. The upper part of bar, located close to the alluvial plain, originated during flood crest-in bankfull and overbank discharge. On the other hand, the lower part of the bar was created during the stage of decreasing water, when the main flow was shifting towards the left bank. The right branch of the Soła changed its direction from the north-west to the west as a result of the side bar accretion (Fig. 1C).

The flood in June 1997 has changed the general platform of previously existing bars in the Soła channel. The vegetation cover on the surface of the upstream part of the longitudinal bar (a) was destroyed, and sediments of the oldest part of the bar were reworked by water (refreshing the bar surface). At the same time a downstream part of the bar was overlain with a gravel layer several centimetres thick. Willow scrubs overgrowing in the upstream part of the bar were almost completely destroyed, and a 0.8 m thick gravely-sandy cover has accumulated there.

Bar surfaces were erosionally dissected. A pattern of linear cuts is visible on downstream bar zones and close to the left margin of longitudinal bar. During the falling phase the flow concentrated in numerous channels which underwent progressive abandoning. Other, still active channels dissected some parts of the bars. Generally, these linear cuts are shallow and narrow, but their lengths are more differentiated (from few tens of centimetres to several metres). One such linear cut on bar (a) was active for a long time, becoming deeper and wider in the process. In this way a large chute channel emerged. Material derived from its erosion was deposited in the form of a long gravel bar continuing along the left margin of the channel for a distance of 35 metres. The current chute channel is active only when discharge is above 40 $m^3 \cdot s^{-1}$ in the Oświęcim gauge.

Small deltas have accumulated down the marginal slope of longitudinal bar (a) in the mouths of the linear cuts. Their gravely-sandy sediments were deposited in deeper water with lower velocity. The deltas are characterised by steep slope faces and their thickness is equal to the depth of the water (i.e. up to 1 m). These are Gilbert-type deltas (*vide* Gradziński et al. 1976). Gravel deltas exist in downstream parts of mid-channel bar (b) as well (Photo 2), however they are of larger scale — the slip face of the greatest one is 1.8 m high (Photo 3). These deltas are built of material eroded in the upstream bar part and deposits close to a slope separating the upper (upstream) bar zone from the lower (downstream) one.

Abundant gravely, rarely sandy shadows are formed on the bar surfaces downstream the willows and trees. The spinally shaped platform shadows are mostly up to 0.6 m high and 2.5 m long. Sediments of gravel shadows are structureless and very poorly sorted. They are composed of 25–0.2 cm gravel-sized grains with a small admixture (up to 10%) of the finer ones (sands and silts). This is evidence that gravel shadows accumulated suddenly from high velocity currents. Well-developed pavements cap the surfaces of all the forms. Few sand shadows are built of stratified sands, in a narrow, vertical sequence (Photo 4, Fig. 6). These features indicate that the sands underwent successive deposition from the decreasing flow. Fining downstream successions have been noted both in sand and gravel forms.

The middle part of the longitudinal bar, overgrown by several-year old willows, was an area of nearly continuous fine-grained deposition, up to 0.7 m

Photo 2. Downstream part of mid-channel bar. Surface relief is up to 3 m

Photo 3. Slipslope of the largest delta accumulated in distal zone of mid-channel bar. The pole is graduated in 25 cm intervals

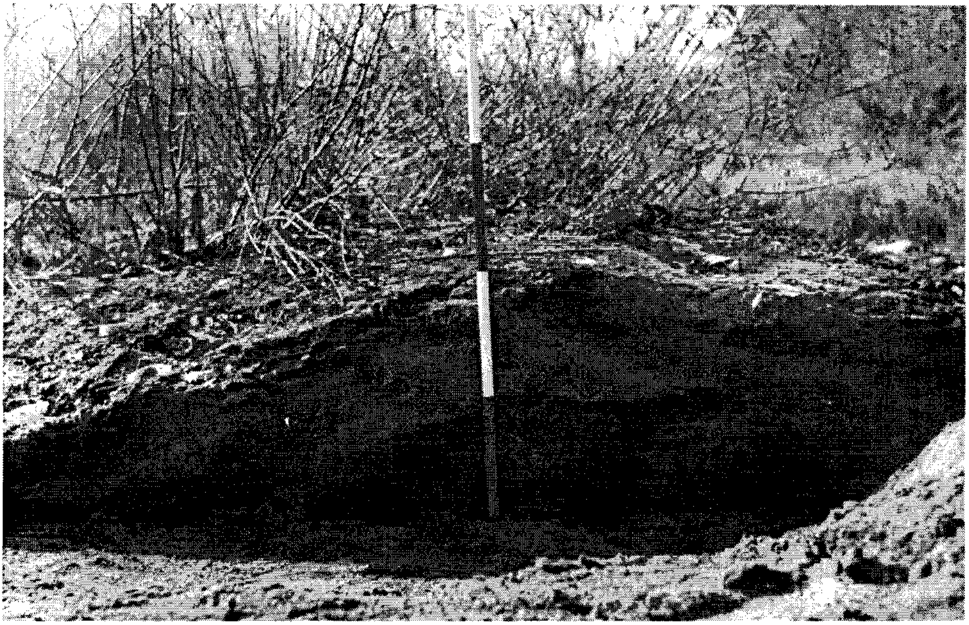

Photo 4. Structure of sediments forming the sand shadow. The pole is graduated in 25 cm intervals

Photo 5. Fine-grained sediment deposited on vegetated surface, dissected during falling water level (13 VII 1997). Flow from right to left

thick (Photo 5). The cover is dominated by medium-grained sands (Fig. 7). Lack of stratification is evidence that sediment settled out of suspension after the flood crest. Material deposited on this bar of vegetation is an initial sediment of overbank facies.

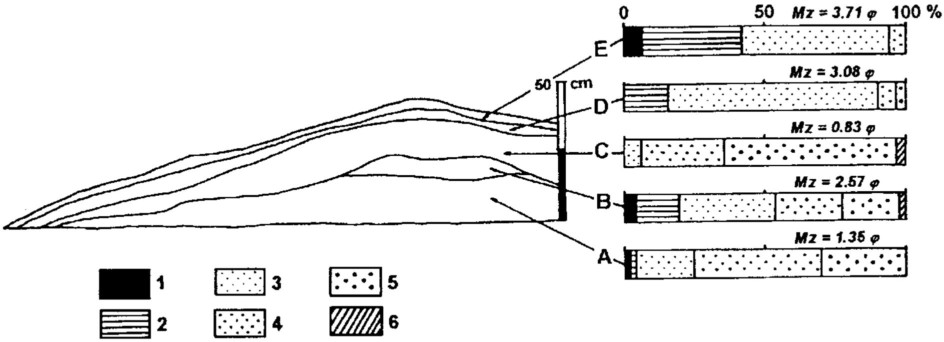

Fig. 6. Grain-size distribution of sediments from succeeding layers of sand shadow presented on Photo 4. Sand shadow built up of A and B layers was accreted by C, D and E layers during the July 1997 flood. Grass roots are visible in the top of layer B. 1 — clay (< 0.0039 mm), 2 — silt (0.062–0.0039 mm), 3 — fine sand (0.25–0.062 mm), 4 — middle sand (0.5–0.25 mm), 5 — coarse sand (2–0.5 mm), 6 — gravels (here: 6–2 mm), Mz — mean grain-size

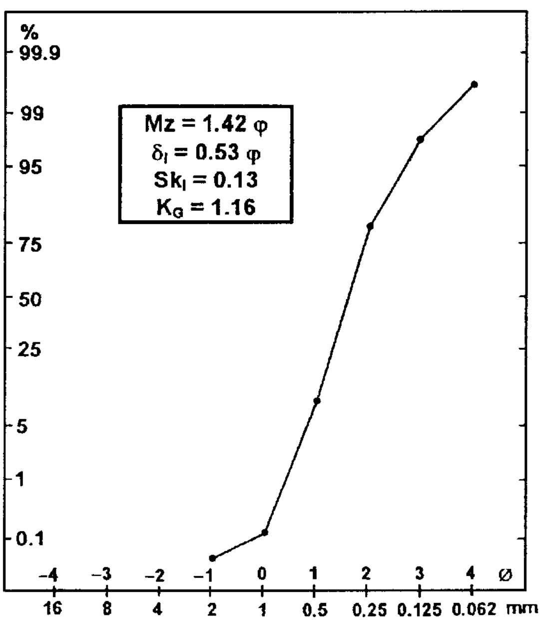

Fig. 7. Cumulative grain-size plot and grain-size parameters of sediment presented on Photo 5

CONCLUSIONS

Gravel bars in braided reaches of the Soła river undergo transformation during large floods. In conditions of limited sediment delivery to the alluvial channel, the bar transformation consists mainly of surface remodelling. Bar surfaces are capped with gravel and/or sands and are also dissected by falling flood waters. Total transformation of the bars is a sporadic phenomenon because of their armour and cover of vegetation. New bars originate very seldom.

University of Silesia
Earth Sciences Faculty
41-200 Sosnowiec, Będzińska 60, Poland

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STRESZCZENIE

B. Woskowicz

TRANSFORMACJA ŻWIROWYCH ŁACH KORYTOWYCH PODCZAS POWODZI, KOTLINA OŚWIĘCIMSKA

Na północnym przedpolu Karpat w biegu rzek żwirodennych, pomimo prac regulacyjnych i zabudowy hydrotechnicznej, przetrwały fragmenty koryt roztokowych. W ich obrębie występują łachy żwirowe, które ulegają transformacji pod wpływem dużych wezbrań. Badania nad sposobem transformacji koryta roztokowego przeprowadzono w odcinku Soły koło Bielan.

Podczas powodzi w lipcu 1997 maksymalny przepływ Soły w Oświęcimiu wyniósł 832 $m^3 \cdot s^{-1}$, przy średnim rocznym przepływie 20 $m^3 \cdot s^{-1}$. Wezbranie to w badanym odcinku Soły koło Bielan nie zmieniło zarysu znajdujących się w korycie łach żwirowych. W warunkach ograniczonej dostawy materiału do koryta, spowodowanej regulacją rzeki, transformacja łach polegała głównie na przeobrażaniu ich powierzchni. W obrębie ich doprądowych części nastąpiła depozycja materiału żwirowego o miąższości od kilku do kilkadziesięciu centymetrów. Części łach porośnięte zwartymi zaroślami wiklin zostały nadbudowane materiałem piaszczystym o miąższości do 0,7 m. Na powierzchni łach, za kępami drzew i wiklin zarówno porastających łachy jak i przyniesionych przez wody wezbraniowe, rozwinęły się liczne cienie żwirowe.

W częściach zaprądowych powierzchnie łach ulegały rozcinaniu, a u wylotu większości rozcięć linijnych usypane zostały niewielkie delty żwirowe o stromym skłonie — typu gilbertowskiego.

W okresach bezpowodziowych łachy są szybko kolonizowane przez roślinność, która utrwala ich powierzchnie i ułatwia późniejszą nadbudowę osadami piaszczystymi.