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GEOLOGICAL CONTROL ON THE OSŁAWA RIVER MEANDER AT DUSZATYN, WESTERN BIESZCZADY MOUNTAINS, POLISH OUTER CARPATHIANS

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Abstract: At Duszatyn village (Western Bieszczady Mts.), the Osława River forms an unique meander loop which is not typical for the mountainous area. Detailed analysis has shown that this landform was created due to the evolution of two left-hand tributaries of the Osława River during the formation of its regressive water-gap. These processes were determined by mass movements which have strongly stimulated the fluvial system. The origin of the Osława River meander was largely controlled by lithological differences in rock resistance, orientation of the joint pattern, as well as the presence of bordering oblique and thrust faults which have had a bearing on the diversified neotectonic uplift of the area.

Key words: neotectonics, structural control, Quaternary alluvium, Osława River, Western Bieszczady Mountains, Polish Outer Carpathians.

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INTRODUCTION

In the Osława River valley at Duszatyn village, Western Bieszczady Mts., 26 km downstream from its headwaters, a landform unique for mountaineous areas occurs. The river, flowing formerly to the north, downstream of Duszatyn village suddenly turns to the west and its course marks a nearly full circle. Denudational spur mounting some 50 m above the river bed is located within the river meander (Fig. 1; cf. also Margielewski, 2002 b). The valley lenght within the meander is 1,700 m, whereas the distance between the river in the highest point of the bend and lowest one in the neck of the meander is only 120 m (Fig. 1). The height difference of water table in the river bed between these points is about 12 m (Fig. 1 – site a). In the neck of the meander (cut by a railway track), an erosional surface occurs bearing remnants of fluvial gravels that represent a palaeo-bed of the Osława River, which previously used to flow straight northwards. The meandering section of the valley represents a river gap. Fluvial sediments, 8-m-thick, occur in the outermost part of the meander (Fig. 1 – site b). Three landslide zones registered in the meandering segment of the valley have significantly stimulated the development of the characteristic fluvial system of the Osława River (Fig. 1 – sites: 1–3).

GEOLOGICAL SETTING

The Osława River bend is situated in the zone of occurrence of two elements of the Dukla Nappe of the Outer Flysch Carpathians: the Marginal Fold, thrust over the Fore-Dukla Zone to the northeast, and the Komańcza-Wisłok Wielki Fold, thrust upon the Marginal Fold from the south (Ślączka, 1964; Ślączka & Żytko, 1979; Ślączka & Kamiński, 1998; see also Figs 1, 2).

The Marginal Fold, covering the major part of the area, represents a thrust-sheet (slice) with totally reduced SW limb (Ślączka, 1964, 1968). A characteristic feature of this element is strong sigmoidal bending of the slice, observed to the north of Komańcza village (from NW–SE to N–S). It is associated with a fault zone situated between the Osława and Osławica Rivers, 1.5–2 km to the north of the meander (Fig. 2; cf. Ślączka, 1964, 1968; Malata, 2001).

The Komańcza-Wisłok Wielki Fold is situated in the SW part of the studied area and it is characterized by a strong reduction of its NE limb. It is thrust upon the Marginal Fold adjoining the meander (Fig. 2; cf. Ślączka, 1968).

Strata that build both the above folds dip relatively steeply (20–40°) to the SW (Figs 2, 3). The oldest in the Marginal Fold are lower Hieroglyphic beds (Eh_1; Palaeocene–Eocene), represented by shales and thin- to medium-

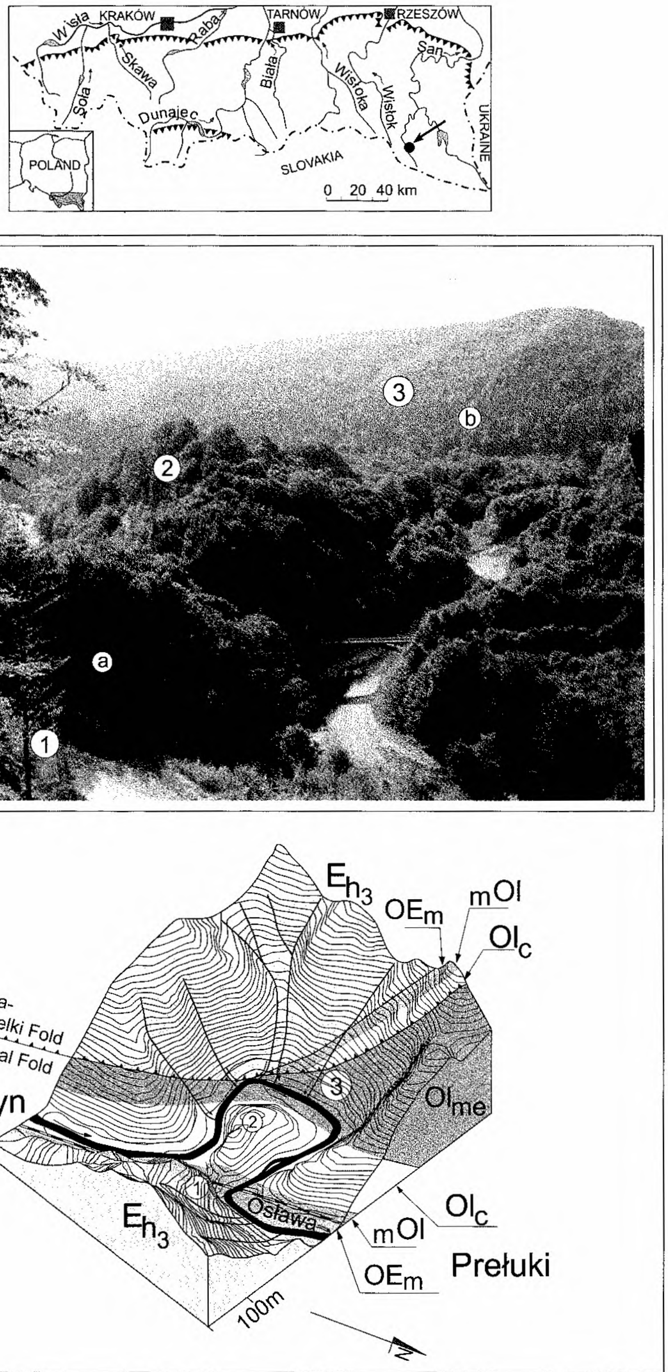

Fig. 1. Location of the Osława river meander. Below – orthogonal projection of hypsometry with Z value and geology of the area. 1–3: landslide zones, a–b: position of alluvial sediments. Geology after Ślączka (1973): E_{h3} – upper Hieroglyphic beds; OE_m – Mszanka Sandstones; $_mOl$ – Sub-Cergowa Marls; Ol_c – Cergowa Sandstones; Ol_{me} – Menilite Shales

bedded sandstones, of total thickness up to 800 m. Above the lower Hieroglyphic beds, there occur thick-bedded Przybyszów Sandstones (E_p; middle Eocene), and upper Hieroglyphic beds (Eh_3; Eocene), of total thickness about 115 m, represented by thin- and medium-bedded siliceous sandstones intercalated with shales (in the lower part – variegated shales – łc; cf. Ślączka, 1968; Ślączka & Żytko, 1979). They occur in the NW and SE fragments of the meander (Figs 1, 2). In the lithostratigraphic sequence, the Hieroglyphic beds are overlain by a series of thick-bedded Mszanka Sandstones (OE_m; Eocene–Oligocene), 30 m thick, interbedded with dark-brown shales (Ślączka, 1973). Above the Mszanka Sandstones, a discontinuous horizon of black "leafy" shales (OE_l) occurs, bearing hornstones about one dozen metres thick, including isolated sandstone beds. The Mszanka Sandstones and the black shales crop out in the northern segment of a landslide above the Prełuki-Duszatyn road (Figs 2, 3, 4).

The sub-Cergowa Marls ($_mOl$; Oligocene), occurring above the black "leafy" shales, are represented by several

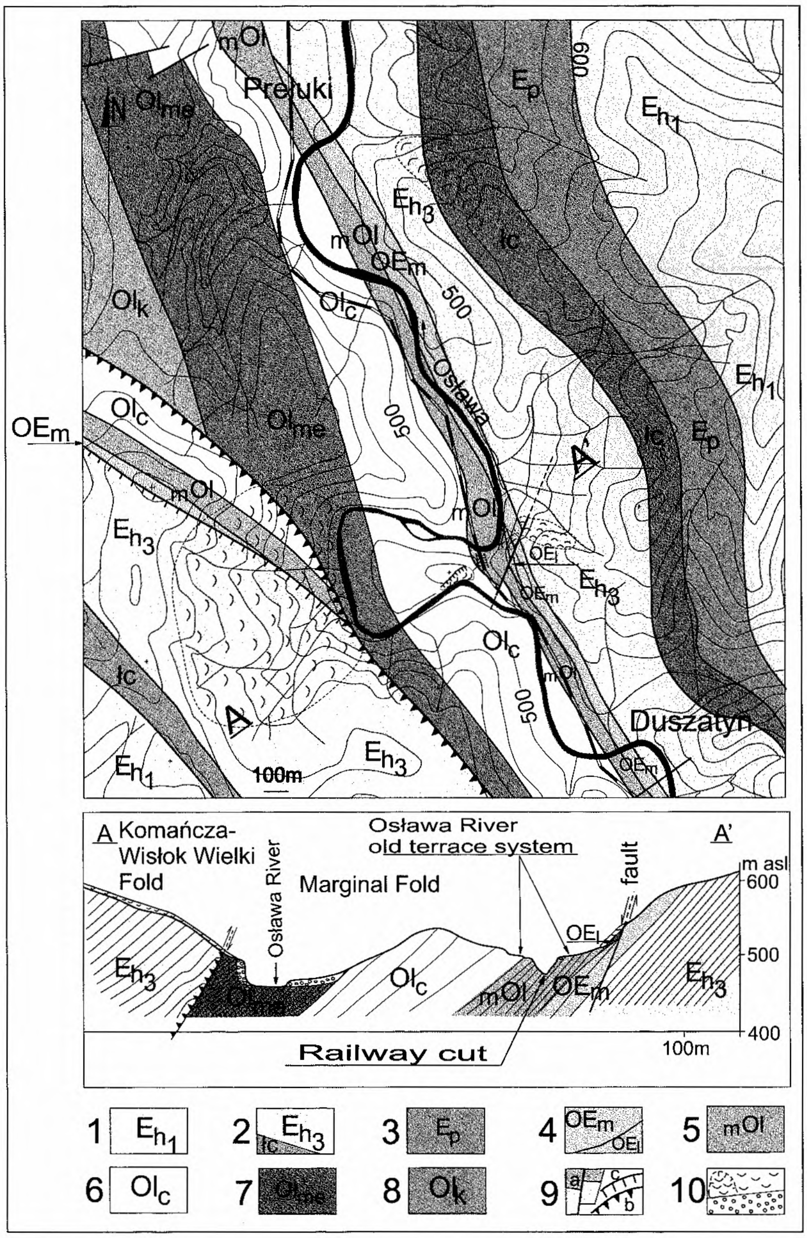

Fig. 2. Geological sketch and cross-section of the Osława river meander (geological setting after: Ślączka, 1960–63, 1964, 1973; Ślączka & Żytko, 1979): *1* – lower Hieroglyphic beds (Eh_1); *2* – upper Hieroglyphic beds (Eh_3), with variegated shales (łc); *3* – Przybyszów Sandstones (E_p); *4* – Mszanka Sandstones (OE_m) with shales (OE_l); *5* – Sub-Cergowa Marls ($_m$Ol); *6* – Cergowa Sandstones (Ol_c); *7* – Menilite Shales (Ol_{me}); *8* – Krosno beds (Ol_k); *9* – dislocations: a – fault; b – overthrust; c – sliced fold; *10* – colluvia and gravels

tens of metres thick series of hard, grey-brown marls with hornstones, showing a characteristic bluish colour due to weathering. They crop out in the lower segments of a landslide above the Prełuki-Duszatyn road, and in the bed and banks of the Osława River near the railway bridge. In the upper part of the series, marls are interbedded with shales, hornstones and thin-bedded sandstones, which crop out in the railway cut (Ślączka, 1968, 1973).

The sub-Cergowa Marls are overlain by the thick-bedded Cergowa Sandstones (Ol_c; Oligocene), some 300 m thick, bearing local thin inserts of marly shales. In the study area, the Cergowa Sandstones form a denudational spur within the Osława River meander (Figs 1–3). They also crop out within rocky scarps of a landslide which frames the southern slope of the spur.

The Menilite Shales (Ol_{me}; Oligocene), overlying the Cergowa Sandstones, are represented by dark-brown, argillaceous and siliceous shales with hornstones, and infrequent inserts of sandstones, as well as horizons bearing calcareous shales and marls that crop out in the meander area (Ślączka, 1968). The Lower Krosno beds (Ol_k; Oligocene), occurring above the Menilite Shales, are represented by brown shales and grey calcareous shales, bearing horizons of the Krosno sandstones (Ślączka, 1968; cf. Fig. 2).

In the Osława River meander area, the Komańcza-Wisłok Wielki Fold is composed mainly of the Hierogly-

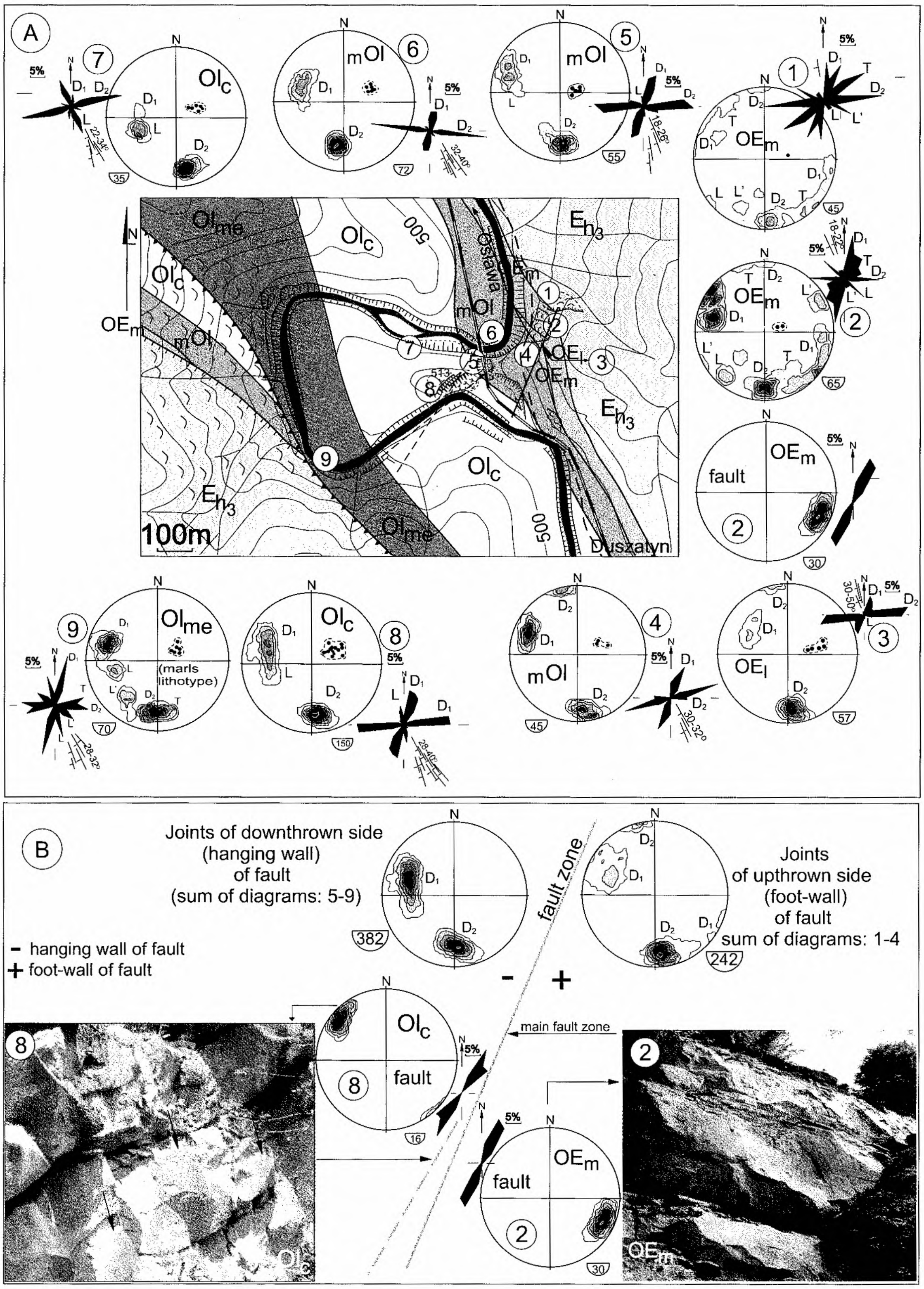

Fig. 3. Structural analysis of the area of the Osława river meander: A – joints and faults presented on the basis of a geological map (see Fig. 2), B – comparison of the sum of joint surfaces for the footwall and hanging wall of the main fault, and attitude of fault surfaces cutting the Mszanka Sandstones (slickensided surfaces; diagram and photo 2) and the Cergowa Sandstones (surfaces with traces of mineralization; diagram and photo 8). Joints and faults plotted on rose-diagram and contour diagram (equal area lower hemisphere plot, contour interval: 2.5–5–7.2–10–12.5>%). Joint sets (D, T, L) have been distinguished according to Mastella *et al.* (1997). For other explanations – see Fig. 2

phic beds, which overlie the Cergowa Sandstones and sub-Cergowa Marls, as well as – at places – the Mszanka Sandstones (Ślączka, 1960-63, 1968; cf. Fig. 2).

TECTONIC ANISOTROPY OF ROCKS IN THE MEANDER LOOP

In all the strata occurring in the meander loop, the prevailing orientations of joints represent sets diagonal to the bearing of beds: the D_1 set aligned N10–30° E and dipping ca. 75–85° to the SE, and the D_2 set arranged N80–90° E and dipping ca. 70–85° to the north (Fig. 3A; cf. also Margielewski, 2002 b). These conjugate sets represent leading joints which are marked consistently in every lithostratigraphic unit of the entire sequence (Fig. 3A). Their orientations coincide with regional joint sets described from the eastern part of the Polish Outer Carpathians (N10–19° E and N75–84° E, respectively; cf. Mastella & Zuchiewicz, 2000; Mastella & Konon, 2002). The diagonal joint sets are accompanied by a poorly marked set of longitudinal joints L, striking ca. N150–160° E and, occurring in places, a set of transversal joints T, striking N60° E (Fig. 2). Within the Mszanka Sandstones cropping out in the head scarp of the landslide above the Duszatyn-Prełuki road, one can take notice of evident dispersion of joints, caused by strong disintegration of sandstones in the vicinity of a fault zone (Figs 3A–B; 4a–b). The surface of the rock head scarp developed in these rocks is commonly slickensided. Observations of tectonic microstructures of the scarp indicate that it is the fault surface of the footwall of a normal fault (Fig. 3B.2; see also Jaroszewski, 1972; and Dadlez & Jaroszewski, 1994).

Slickensides on the surface indicate that the fault strike is parallel to that of the joint set D_1 orientated N10–30° E, although its dip is opposite to that of the joints (Fig. 3A – diagram 2, Fig. 4.1). The strike of the fault (N10°E) is compatible with that typical for faults prevailing in the eastern segment of the Polish Outer Carpathians (Mastella & Szynkaruk, 1998). Its orientation coincides with the extent of photolineaments (SSW–NNE) interpreted for the Dukla Nappe in the surroundings of Duszatyn (*vide* Zuchiewicz, 1997; 2000), as well as in the adjacent Sanok-Cisna area (Doktór *et al.*, 2002). The fault zone occurring above the Osława River meander is accompanied by strong dispersion of joints within adjacent rocks.

Smooth, dark-coloured surfaces with traces of mineralization are visible in the Cergowa Sandstones, which occur in the landslide's rocky walls that frame the denudational spur (Fig. 3B-8). These surfaces dip steeply to the SE, and form one system striking ca. N30–50°E, parallel to the surfaces of D_1 joints (Fig. 3B – diagram 8). However, these surfaces are now strongly weathered, eroded, and devoid of slickensides. They probably represent fault surfaces associated with a dislocation zone cutting the Mszanka Sandstones in the head scarp of the landslide. Another dislocation connected with this fault system (cutting the Marginal Fold) is identified on geological maps in the southern part of the study area at Duszatyn village (Ślączka 1960–63; Ślączka & Żytko, 1979; see also Fig. 2).

The second zone of strong tectonic deformation occurring near the meander is connected with the thrust of the Komańcza-Wisłok Wielki Fold over the Marginal Fold. According to available geological maps, the overthrust is relatively steep and adjoins external (SW) section of the meander (Ślączka, 1960–1963, 1973; Ślączka & Żytko, 1979). Numerous landslides cover the zone of the overthrust. In the southern, peripheral part of the meander, characteristic marls of the sub-Cergowa Marls lithotype crop out in the Osława River bed (Fig. 3A – site 9). They may belong to the upper part of the Menilite Shales (see Ślączka, 1968). Increased density of joints within the marls and their strong dispersion (Fig. 3A – joint diagram 9) suggest a proximity to the overthrust.

The third fault zone bordering the area of the meander is connected with a sigmoidal bend of the Marginal Fold (Ślączka, 1968, 1973). The zone, trending WSW–ENE, is located ca 1.5–2 km to the north of the river bend (Fig. 2).

LANDSLIDES IN THE AREA OF THE OSŁAWA RIVER BEND

Apart from numerous small landslides, three vast landslide zones are located in the area of the Osława River meander (Fig 1. 1–3, Fig. 4). Their formation could have significantly influenced upon the fluvial system, stimulating development of the meander.

The first landslide zone is located above the bend of the Osława River and Prełuki-Duszatyn road (Fig. 1 – zone 1, Fig. 4). It was formed within the Mszanka Sandstones, shales with hornstones, and sub-Cergowa Marls. Within this zone, there occur several landslides with circular head scarps that comprise an extensive form of the composite type, which was shaped in several stages. The oldest (northern) segment of the landslide developed in the Mszanka Sandstones and gradually propagated to the south, embracing the "leafy" shales and sub-Cergowa Marls. One of younger stages was related to downpours in 1997, which triggered formation of numerous landslides throughout the Outer Carpathians (Mrozek *et al.*, 2000). At that time, the landslide was formed mainly in the Mszanka Sandstones. Its circular head scarp, 8 m high, developed partly along the fault, and it is characterized by the occurrence of numerous slickensides, as well as disintegrated sandstones. Debris colluvium occurs at the feet of the scarps. The youngest generation of mass movements in this zone, extended to the south, was connected with heavy rains in spring 2000 (Margielewski, 2002 c). The landslide formed at that time included the "leafy" shales, as well as the sub-Cergowa Marls in lower parts. The head scarp was formed along the fault plane developed in shales and accompanied by a tectonic breccia. Extensive colluvial swells formed of broken rock material are located at the foot of the scarp (Fig. 4).

Gravitational movements in the above zone were initiated at the fault plane, at which rock masses were broken along tension cracks (Margielewski & Urban, 2003), and then transported along the bedding planes dipping parallel to the slope (Margielewski, 2002a, 2004). It means that the

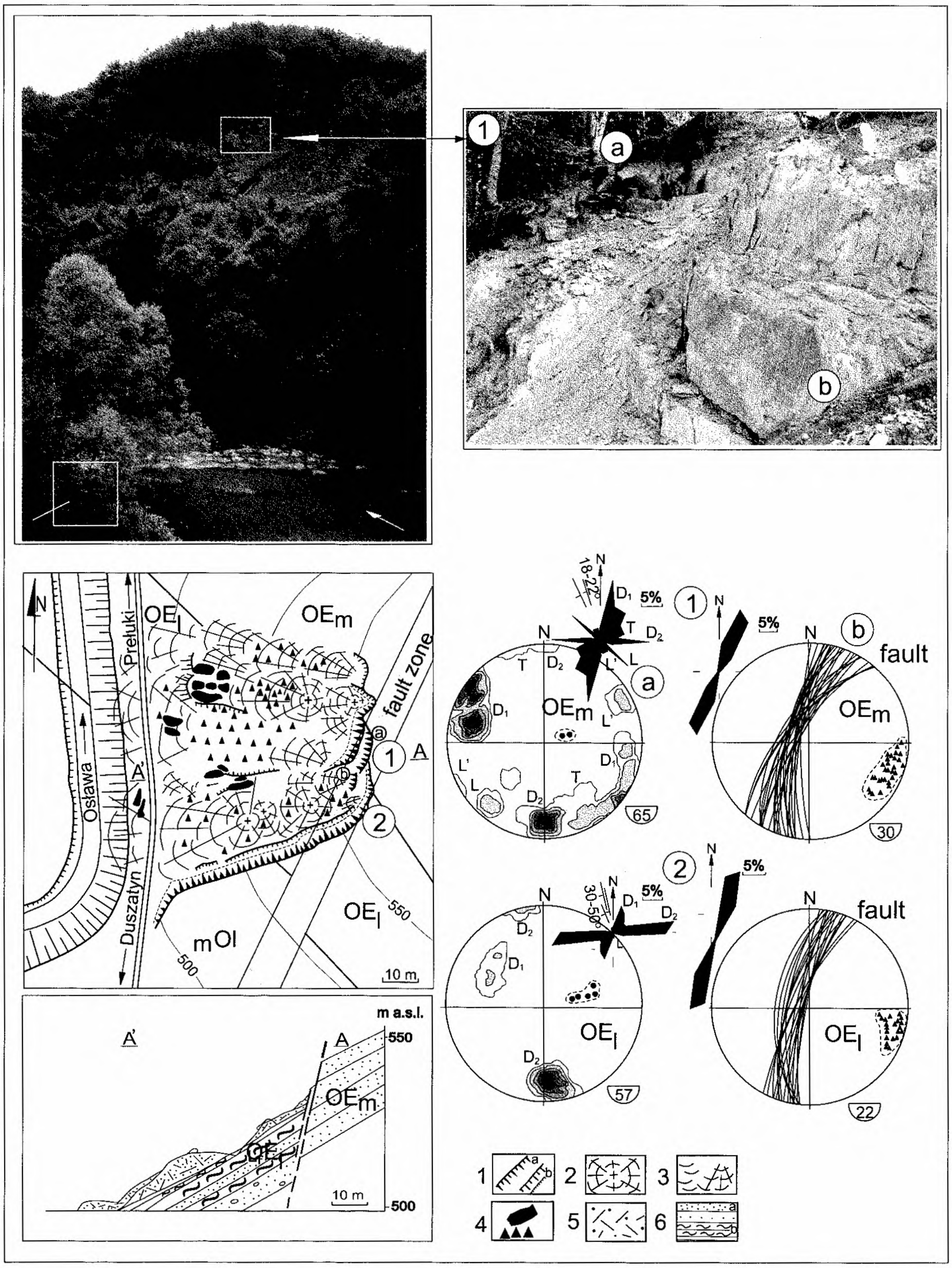

Fig. 4. Landslide above the Osława River bend. Sketch of the landslide with cross- section: joints on rose- and contour diagrams (explanations on Fig. 3). Fault surfaces presented on rose- and great circle diagrams (equal area lower hemisphere plot): as the attitude of slickensides in Mszanka Sandstones (1), and the attitude of surfaces accompanied by tectonic breccias in "loafy" shales (2). Above: pictures of the landslide and landslide's head scarp showing strong tectonic disintegration of the Mszanka Sandstones (a) with slickensided surfaces (b). Explanations: 1 – scarp (a – rocky, b – creeped); 2 – colluvial swell; 3 – colluvial tongue and creeping; 4 – rock blocks and debris fields; 5 – mixed colluvial material; 6 – sandstones (a) and shales (b) on the cross section. For other explanations – see Fig. 2

landslide represents the translational, sliding-consequent type (cf. Bober, 1984; and Zabuski *et al.*, 1999). Reactivation of this landslide zone still causes periodical destruction of the Prełuki-Duszatyn road.

The second landslide zone was developed on the SE slope of the denudational spur of the Osława River meander, being built up of the Cergowa Sandstones (Fig. 1 – zone 2). The vast landslide head scarp is up to 40 m high and extends from the lower part of the valley to the uppermost part of the spur. It is composed of rock walls formed in thick-bedded sandstones. In relation to the bedding, the landslide represents a subsequent landform (Zietara, 1969; Bober, 1984; see also Fig. 3A– diagram 8). The height and (sub)vertical surfaces of the walls indicate that topple must have been the predominate type of mass movements. Subsequently, the rock masses separated along a tension crack, following the pre-existing joints, were disintegrated and shifted down. The process developed in several phases related to a gradual entrenchment of the Osława River into the bedrock, what resulted in the formation of several steps on the rock walls. At the feet of the walls, talus cones developed being formed of the material broken and fallen from rock scarps. The lower segments of the walls were partly changed by quarrying in the past.

The third, most extensive landslide zone is developed upon exposures of the Menilite Shales, sub-Cergowa Marls, Cergowa Sandstones, and Hieroglyphic beds in the western part of the meander. It is situated close to the Komańcza-Wisłok Wielki Fold thrust (Fig. 1, zone 3; Fig. 3A) and extends between the Osława River valley and the uppermost parts of the surrounding mountains (Ślączka, 1973; Ślączka & Żytko, 1979). Numerous typical forms of landslide relief, like: colluvial swells, colluvial ramparts, circular head scarps, and landslide lakes, indicate a polyphase development of the zone. Strong morphological transformation of the zone is caused by left-hand tributaries of the Osława River. The Osława River, cutting the left, 8-m-high, bank has stimulated the development of numerous shallow landslides formed in the Menilite Shales (Marginal Fold), the Hieroglyphic beds, sub-Cergowa Marls, and Cergowa Sandstones (Komańcza-Wisłok Wielki Fold), as well as in the alluvial infill of the valley.

NEOTECTONIC SETTING

The Osława River valley in the vicinity of Duszatyn and Prełuki is situated within the strongly elevated Wysowa-Jaśliska-Duszatyn zone (Rączkowski *et al.*, 1985; Zuchiewicz, 1994, 1995 a). The area of the Osława River bend is generally framed by few fault zones which are predisposed to reactivation of tectonic movements. In this part of the Carpathians, numerous epicentres of earthquakes have been registered, e.g. near Dukla town, as well as in the Slovak and Ukrainian Carpathians (Pagaczewski, 1972; Schenk *et al.*, 2001; Guterch & Lewandowska-Marciniak, 2002). The Osława River meander is delimited by a steep overthrust of the Komańcza-Wisłok Wielki Fold on the western side, and bordered by a normal fault on the east. The footwall of the latter fault is exposed in the landslide occurring upstream the river bend, whereas the hanging wall covers the meander loop (Fig. 3B). The WSW–ENE – trending fault zone, related to a sigmoidal bend of the Marginal Fold, frames the northern margin of the area (Figs 2, 5), whereas another one, striking NW–SE, marks the southern boundary of the zone (Ślączka, 1960–63; Ślączka & Żytko, 1979).

A close examination of maps featuring morphometric indices of the study area points to unequal neotectonic uplift of the territory delimited by these faults (Fig. 5: 1–4). The areas characterized by the highest relief energy (referred to the values of erosional dissection) are located in close proximity to the meander, and are slightly shifted to the north. They mark rather precisely trends of the principal fault lines: overthrusts of the folds in the western side and the fault on the east (Fig. 5: 1–2). The same areas are characterized by an increased density of tributary creek valleys, typical for downthrown sides of fault zones (Fig. 5: 4; cf. also Sroka, 1992; Margielewski, 1997). It suggests that the areas adjoining the meander from the west and north (separated by faults) could have been uplifted faster than the area of the meander itself. The neotectonic uplift of the Komańcza-Wisłok Wielki Fold, thrust over the Marginal Fold, is also confirmed by the occurrence of hanging valleys of the left-hand tributaries of the Osława River, as well as by a characteristic deflection of its two left tributaries. Close to the overthrust, one can observe a shift of the mouth section of the valleys towards the east, i.e., contrary to the Osława River flow (see Fig. 3A – vicinity of site 9). The fault zone delimiting the meander area from the north (cf. Ślączka, 1968; Ślączka & Żytko, 1979) is also marked on the maps of morphometric indices (Fig. 5: 1–4). The location and direction of this zone is especially well visible on the map of relief energy (Fig. 5.1), and the map of the upper envelopping surface (Fig. 5.3).

The differences in local hydraulic gradient of the Osława River in the Duszatyn-Prełuki section can confirm unequal rate of neotectonic uplift of the area, being probably related to fault reactivation. The average hydraulic gradient of the entire Osława River bed is estimated at 5.683‰ (Zuchiewicz, 1994, 1995a, b). The hydraulic gradients estimated for short sections of this river (using benchmarks marked on the 1:10,000 maps) are variable (Fig. 5.5). Upstream of Duszatyn, the hydraulic gradient reaches 8.89‰, whereas downstream, between the fault zone in the vicinity of Duszatyn (*vide* Ślączka, 1960–63; Ślączka & Żytko, 1979) and the outer part of the river meander, it drops to 5.32‰ (6.00‰ for the shorter section of flow within the meander), resembling the mean value. Close to the normal fault (downstream of the meander), it rises again to 7.60‰ (Fig. 5.5). Towards Prełuki village, the hydraulic gradient gradually diminishes and reaches the values close to the average (6.86‰ and 5.43‰). The next apparent growth of this parameter (7.83‰) is observed over the northern fault zone, in the vicinity of Prełuki village (Fig. 5.5; cf. also Ślączka, 1964).

The hypothetical gradient of the Osława River after cutting across the meander neck should reach ca. 100‰ in this section. It should be noted that shortly upstream of the meander and within the meander itself, the real hydraulic gradient is similar to the average value, whereas upstream and downstream of the meander it distinctly grows in relation to the neighbouring segments. Decreased values of hydraulic gradient within the meander in relation to the neighbouring areas can be associated with a smaller rate of neotectonic uplift of the southern part of the meander, as well as with depositional processes in the meandering valley. In the outermost, western part of the meander, the Osława River flows through its alluvia (gravel, silt), incising the sediments which are remnants of the older stage of total infilling of the river valley (Fig. 6.2).

An anastomosic pattern of the river in the northern section of the loop indicates its overloading, what could lower the hydraulic gradient within the meander. Shortly down-

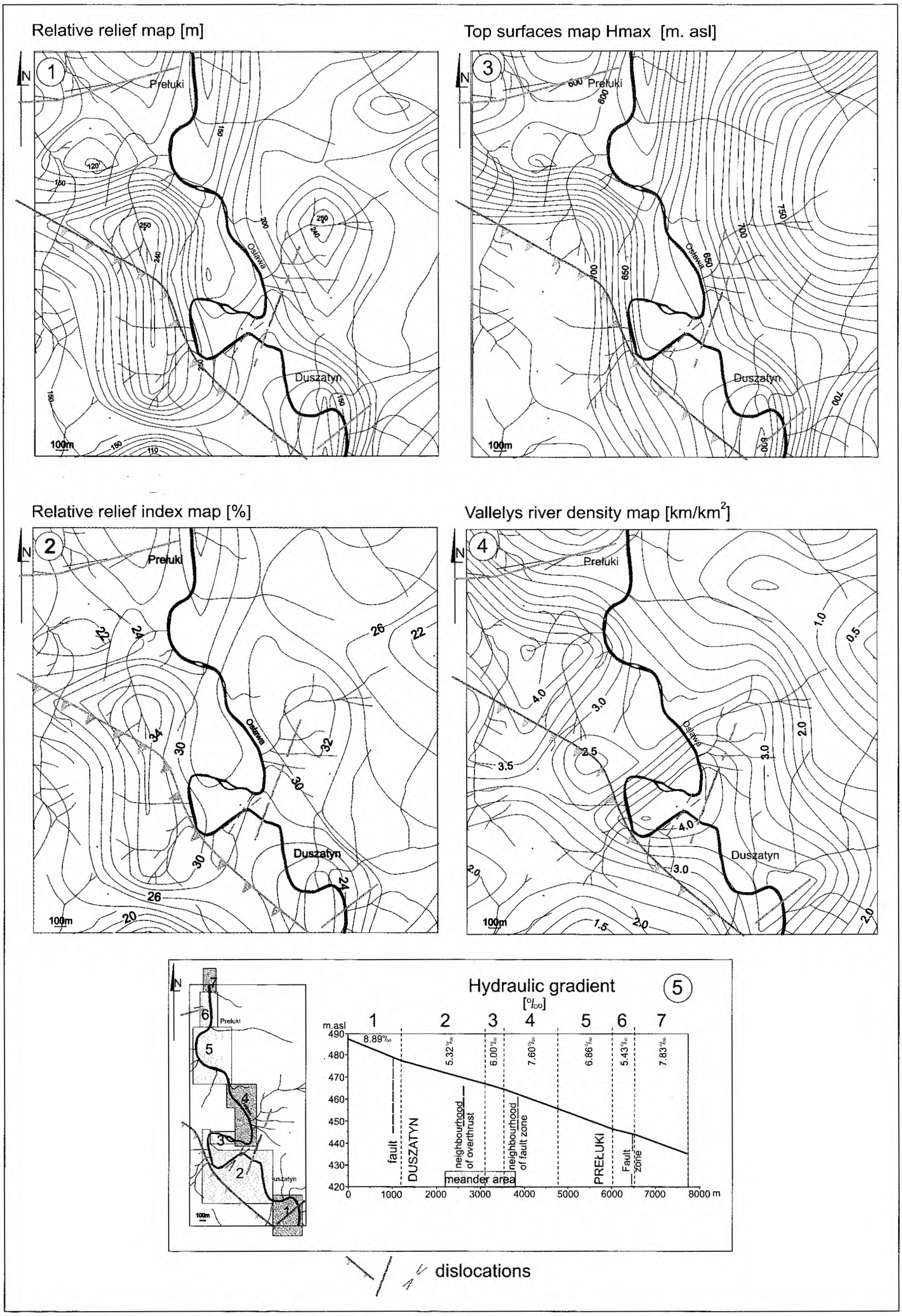

Fig. 5. Contour map of selected morphometric indices: 1 – map of relief energy (relative altitude; contour interval: 10 m); 2 – map of relative relief index (contour interval 2 %); 3 – top-surface (upper envelopping surface) map (contour interval: 10 m); 4 – map of the density of the Osława River tributary valleys (contour interval: 0.25 km/km^2); 5 – a fragment of the longitudinal profile of the Osława River, showing hydraulic gradients [‰]

stream of the meander, the river has a rocky bed, cut into flysch strata of the Sub-Cergowa Marls, and attaining a distinctly high hydraulic gradient of 7.60‰ (Fig. 5.5).

An analysis of joint sets occurring in the rocks exposed in the meander area points to some differences between strata of the upthrown (footwall) and downthrown (hanging wall) sides of the normal fault (see: Fig. 3B – sum of joints for the upthrown and downthrown parts of the fault). In the footwall of the fault and in the near-fault zone, the diagonal joint set D_2, trending ca. N80° E, is represented by the occurrence of vertical joints (Fig. 3A–B: diagrams 1–4). In the hanging wall, in turn, one can see the rotation about horizontal axis of this set ca. 10° to the south (Fig. 3A–B, diagrams: 5–9). Joints of the D_1 diagonal set are also slighty rotated (Fig. 3A: see diagrams 5–6), as is the fault surface itself (Fig. 3B – diagrams: 2, 8). The joint system attitudes appear to indicate the pivotal character of movement of the downthrown side of the fault, probably caused by stress exerted by an active overthust from the SW: the bedding planes dip here ca. 10° to the south. This type of movement is also suggested by geomorphological features. Within the meander neck, ca. 8 m above the present-day river bed upstream of the meander, there occurs a flat surface of ca. 1 ha in area, bearing relics of fluvial gravel (Fig. 6.1a, c). This surface, representing a fragment of an old terrace of the river, is inclined at ca. 8–10° to the SW, i.e. contrary to the general direction of the river flow (Fig. 6.1a).

The complex of dislocations delimiting the area of the river bend could foster block-rotational type of vertical movements of the area framed by these faults. Its northern segment could be uplifted a little bit more intensive than the southern one (with the meander). Apart from tectonic analysis, it is suggested by the maps of morphometric trends of the study area, as well as by differences of the hydraulic gradient of the Osława River in the meandering segment. Therefore, formation of the river bend could have been also controlled by neotectonics.

ALLUVIAL SEDIMENTS

Within the inner part of the Osława River meander there occur alluvial sediments, up to 8 m thick (Fig. 6, site 2). The lower unit of these sediments is represented by gravels composed of rock fragments showing differentiated roundness: besides well-rounded pebbles, subangular and angular clasts of sandstones, marls, and menilite hornstones occur, indicating a very short fluvial transport connected with quick delivery of the material from the slopes (Fig. 6.2: a–b). A 0.25-0.7-m-thick horizon of grey-blue clayey silt occurs above the gravel; the silt thickness increasing towards the south (Fig. 6.2a). The silt probably represents the sediment of a lake, formed due to damming the Osława River by a landslide, developed either on the northern slope of the denudational spur or on the slope above the lower bend of the meander (Fig. 4). A sample of wood taken from the lower part of the lacustrine sediments was dated by ^{14}C method at 11,430 ±70 BP (11,900–11,700 and 11,600–11,150 cal BC; Ki-10149, Kiev Radiocarbon Laboratory, Ukraine). It determines the beginning of deposition of the sediments in the Alleröd Interstadial or a little bit earlier (the Older Dryas Stadial?). Pollen analysis (made by V. Zernitskaya from the Institute of Geological Sciences, Belarus Academy of Sciences, Mińsk, Belarus) shows small amount of pollen of composition typical for the Vistulian Late Glacial.

The lacustrine sediments are overlain by yellow and yellow-brown, clayey-sandy silt, up to 3 m thick. It contains numerous angular clasts of sandstones and hornstones, 1–2 cm in size, typical for slope sediments (the share of fraction >1 mm is ca. 50%; cf. Fig. 6.2a). At some places, three horizons, 20–50 cm thick, of grey-blue clayey silts can be observed. They were probably deposited at the time of restricted delivery of rock fragments. Their colour, similar to the lowermost silt layer, suggests chemical processes of bivalent iron ions and deposition in subaqueous environment.

Deposition of these sediments caused total covering of the river valley in the meander area and raising of its floor by ca. 8 m. The upper sediment surface forms a characteristic flat area, ca. 4–5 m in size, situated above the western bank of the river. Now the river cuts both its alluvia and the bedrock.

The second area bearing remnants of alluvial sediments is an extensive flat surface in the neck of the meander above the railway cut, which represents an erosional-accumulational terrace (Fig. 1.a). Well-rounded sandstone gravels occur on the small area close to the cut, forming a 25–30-cm-thick horizon (Fig. 6.1c). Remnants of fluvial pebbles occur as well on flattened segments of the slope of the spur, above railway cut (Fig. 6. 1.b).

DISCUSSION

Consequent bedding attitude, favourable for the development of a sliding meander, and larger surficial extent of the soft Menilite Shales before erosional entrenchment and exhumation of the bedrock, suggest normal development the river bend. It could have been stimulated by lithological properties and structural style of the bedrock, as well as neotectonic uplift.

Extensive depression (typical for river valley) and erosional-accumulational flat surface bearing remnants of fluvial gravel in the neck of the meander (see Fig. 2 – geological cross-section) indicate that once in the past river used to flow straight to the north, across the neck, and subsequently along the exposures of the soft sub-Cergowa Marls. It resulted in the formation of the depressed neck and erosional-accumulational terrace (Fig. 6.1.a). It means that the river bend could not have been formed due to normal meandering connected with coeval river entrenchment related to neotectonic uplift, because the palaeo-valley in the neck is separated from the present-day valley by a denudational spur that builds a relatively high mount (Fig. 6.1). Hence, it is unlikely that the river could have "jumped" over the mount.

In the following discussion, alternative hypotheses of the development of the Osława River valley will be taken into account, assuming normal development of the meander before the formation of the depression in the neck. Accord-

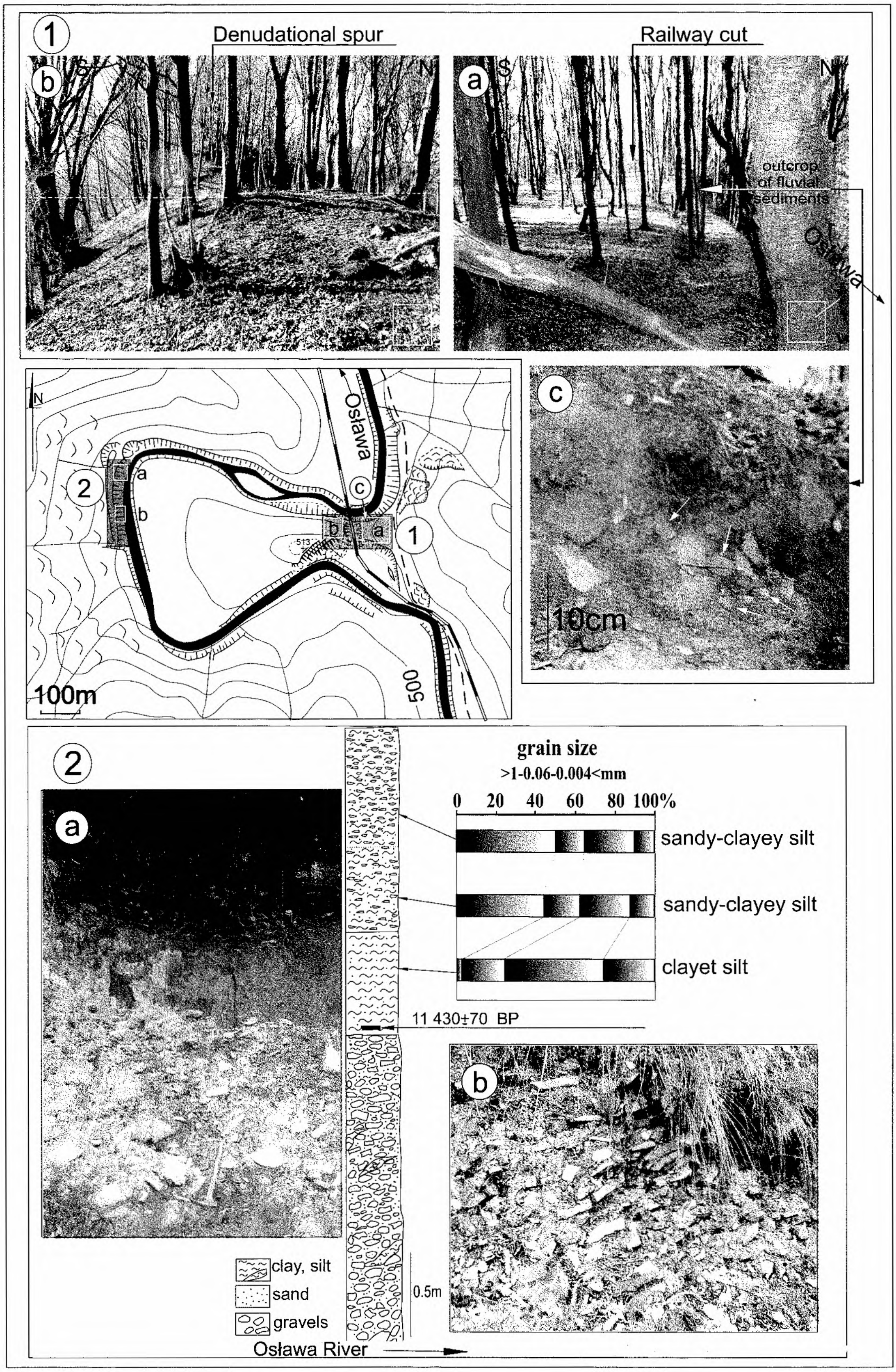

Fig. 6. Diagnostic landforms and deposits in the Osława river meander: 1 – system of old terraces at the neck of the meander: a – flat surface of old terrace with fluvial pebbles (c) cropping out on the terrace surface (arrow shows position of pebbles on the terrace); b – steps of old terraces on the denudational spur. 2 – alluvial sediments in the inner part of the Osława River: a – pebbles covered with lacustrine sediments dated by ^{14}C; b – angular and subangular rubble typical for short fluvial transport. Lacustrine and slope sediments analysed using areometric (Buyucos-Casagrande) methods, classification of sediments based on Shepard's (1954) classification, using Wentworth's (1922) grain-size scale. For other explanations – see Figs. 2 and 4

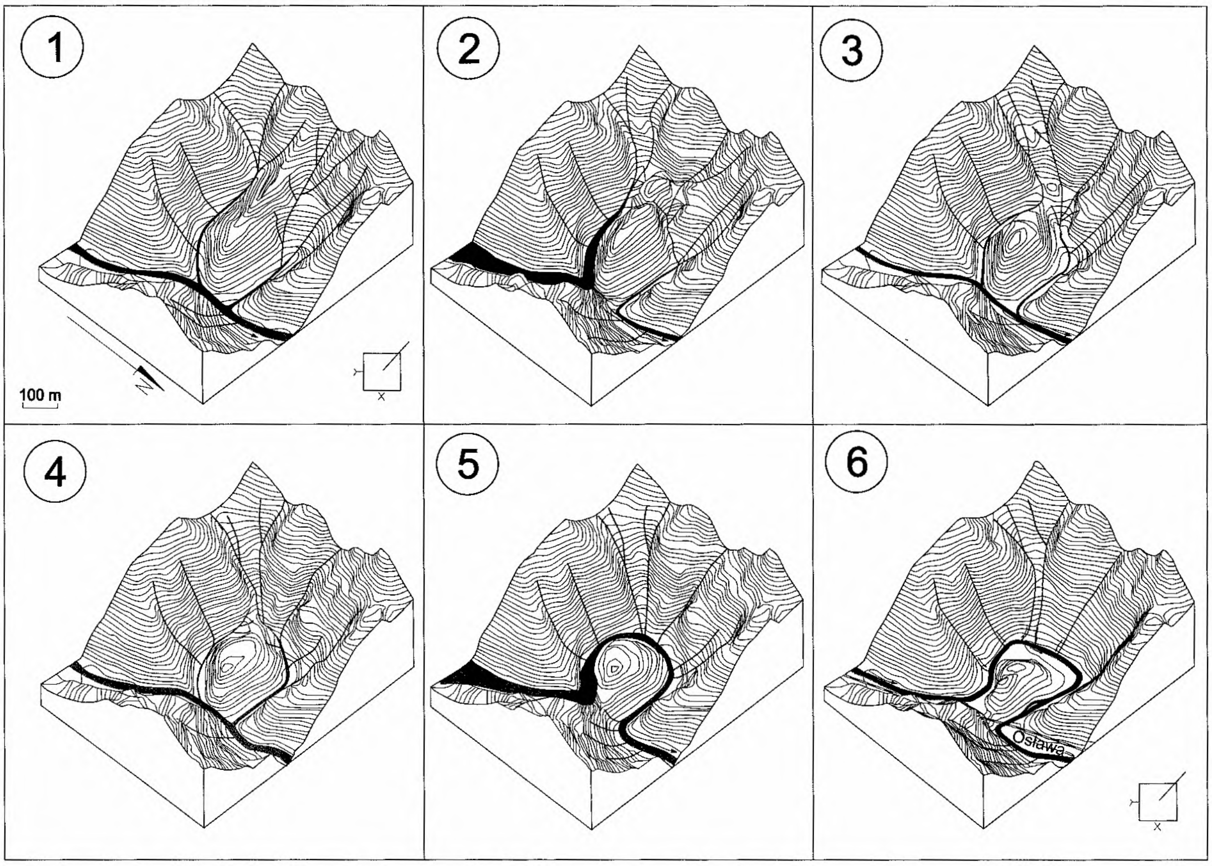

Fig. 7. Reconstruction of the development of the Osława River meander, based on idealistic orthogonal projection of the hypsometry in *Z* value

ing to one hypothesis, the valley was blocked by landslides on the southern slope of the denudational spur (Fig. 1 – zone 2), and the river, much less truncated into the bedrock than now, flowed straight across the neck owing to a rise of the water table. However, in this case, the hydraulic gradient over a very short distance must have been very high, and now it is estimated at ca. 100‰ along the neck. Such a very dynamic hydraulic system must have been conserved in the poorly-resistant sub-Cergowa Marls, because it is impossible that the river could have returned to the "old" valley, characterized by the present-day hydraulic gradient of ca. 5–6‰.

The second hypothesis assumes an high level of filling up of the valley by ca. 8-m-thick alluvium, deposited during the last glacial stage (cf. Fig. 6.2). The river, flowing on alluvium in a periglacial environment, due to damming by landslides could have changed the channel and flow straight, notching the neck of the meander. Immediate entrenchment and removal of alluvium during thawing and deterioration of permafrost at the end of the Vistulian, and blockage of the valley by a landslide could have resulted in returning of the river to the "old", meandering valley. But – as in the first case – high hydraulic gradient across the neck must have caused deep entrenchment into the bedrock, what decisively made it impossible to return the river channel to the "old" hydraulic system.

Therefore, the Osława River bend could have not developed owing to a normal meandering process, stimulated by favourable geological structure and neotectonic uplift. The position of the palaeo-valley indicates that in the past the river flowed straight to the north – the direction typical for the sections of the valley located above and below the meander, and being parallel to the diagonal joint set D_1. The topography, depth of entrenchment, and orientation of valleys of the left-hand tributaries of the Osława River in the meander segment suggest that, formerly, two independent stream valleys could have framed the present-day spur at both the northern and southern sides (Fig. 7.1). The orientation of these steams is closely related to that of the diagonal joint set D_2 (ca. N80°E), whereas their narrow valleys could have been formed as antecendent cuts, coeval with the neotectonic uplift of the area (*vide* Zuchiewicz, 1984, 1995b). The interfluve between these streams presumably embraced the ridge and top of the denudational spur.

Common occurrence of landslides within the fault zone, now situated above the Duszatyn-Prełuki road (Fig. 4), resulted in periodical delivery of considerable amount of colluvial material, which dammed the river and raised the water table (Fig. 7.2). Strong water flow over the rock material blocking the valley could have formed a cascade in the vicinity of the present-day railway bridge. Consequently, headward erosion in the zone of potholes developed in the soft sub-Cergowa Marls could have led to lowering of the river bed and the water table in this place (Fig. 7.2). The lowering of the main river bed to the north, i.e., downstream of the present-day meander, due to erosion controlled by unequal neotectonic uplift of the area, has stimulated simultaneous lowering of the erosional base of the northern set of tributaries, influencing thereby dynamic fluvial processes in their valleys (Fig. 7.3). In consequence of lateral erosion, a more dynamic northern stream, forming a deeper valley in the soft Menilite Shales, could have captured the stream next to it from the south (Fig. 7. 3–4). In case of subsequent significant blockage of the valley by landslides formed in the fault zone, the main river could have changed the channel and, joining its tributary in the capture zone, flowed down this valley, forming a meander encircling the present-day denudational spur (Fig. 7.5). In this way, a regressive-type river cut could have been formed. In the following stages, an antecendent water-gap could have developed, owing to both vertical and lateral erosion combined with coeval strong neotectonic uplift of the meander area (Figs: 5; 7.5–6). The river eroding the soft Menilite Shales formed here a wide valley.

In one of the subsequent stages of geomorphic evolution of the area, the valley of the Osława River valley became filled up in part with fluvial sediments. Although C^{14} dating of a single sample from the lower part of the silt layer overlying fluvial gravels does not allow for a comprehensive palaeoclimatic interpretation, it does indicate that accumulation of the gravel, finished in the Alleröd Interstadial or in the Older Dryas Stadial, proceeded under cold climate of the Late Vistulian due to intensive transport of disintegrated rock material from the slopes into stream valleys (cf. Starkel, 1995, 2002; Wójcik, 1997, 2003). This is indicated by the presence of numerous angular and subangular clasts within the gravels, as well as by significant proportion of finer sandy and silty matrix in this sediment (Fig. 6.2). It is likely that the delivery of this material to the Osława River valley was related to the development of talus cones, formed by left tributaries transporting colluvial material of numerous landslides developed in the active thrust area (Fig. 3A). Deposition of silts upon gravels, probably caused by blockage of the valley by a landslide that dammed the river, began at the end of the Last Glacial, since the lowermost part of the silt layer is dated at ca 11.4 ka BP. Preliminary grain-size analysis of this sediment indicates that its predominant component is clayey silt that forms distinct horizons in the sequence, and, in places, it is slightly enriched in sand and coarser granules (proportion of coarser fractions amounts to 50%; Fig. 6). Pollen analysis of the lowermost part of the silt layer suggests "cold" character of plant assemblages, represented by Pinus (also *Pinus cembra*), Juniperus, Larix, and Picea. It is, thus, not unlikely that "pure" silt could have been deposited during a climatic cooling (Older Dryas, Younger Dryas?). Apparent enrichment in coarser detrital material, occurring in places, could be referred to a gradual deterioration of permafrost, associated with climactic warming at the end of the Vistulian, and the transport of solifluction covers into the valley. At this stage of study, it is hard to determine the time of incision of the alluvia by the Osława River. In the Ropa River valley and the valleys of the Jasło-Sanok Depression, this process was initiated at the end of the Vistulian (Wójcik, 1997, 2003).

CONCLUSIONS

The specific shape of the Osława River meander and its denudational spur (Fig. 1) has been controlled by diffences in lithology of the bedrock, attitude of prevailing joint systems, as well as the occurrence of fault zones which border the area. Reactivated faults have significantly influenced upon the nature of vertical movements of the area, causing unequal neotectonic uplift of particular elements. It seems likely that the segment situated to the north of the meander could have been uplifted faster than that located in the southern part of the area. Apart from geological conditions, a considerable role in the development of the river bend has been played by landslides which, due to periodical blockage of the valley, affected the fluvial system, stimulating formation of the final shape of the meander, created due to the activity of two independent left-hand tributaries of the Osława River. An analysis of events and landforms caused by neotectonic movements, including overhanging valleys of the left-hand Osława River tributaries, as well as radiocarbon datings of fluvial deposits deeply incised by the river, may confirm an young age of neotectonic uplift of the Osława River meander area.

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Streszczenie

GEOLOGICZNE UWARUNKOWANIA ROZWOJU ZAKOLA OSŁAWY W DUSZATYNIE (BIESZCZADY ZACHODNIE, POLSKIE KARPATY ZEWNĘTRZNE)

Włodzimierz Margielewski

W dolinie rzeki Osławy w Duszatynie (Bieszczady Zachodnie) powstało rozległe, niemal zamknięte zakole meandrowe, wewnątrz którego znajduje się ostaniec denudacyjny, wznoszący się około 50 m ponad dno doliny. Obszar ten jest usytuowany w strefie występowania dwóch struktur jednostki dukielskiej: fałdu brzeżnego i fałdu Komańczy-Wisłoka Wielkiego (Fig. 1; por. też Ślączka, 1964, 1968). Skałami budującymi obszar zakola są warstwy hieroglifowe (górny eocen), ponad którymi występują gruboławicowe piaskowce z Mszanki z łupkami liściastymi i rogowcami w stropie. Margle podcergowskie zalegające powyżej budują szyję zakola, zaś ostaniec denudacyjny powstał w gruboławicowych piaskowcach cergowskich. Zewnętrzne partie zakola zostały utworzone w łupkach menilitowych i występują już w sąsiedztwie nasuniętych fałdów (Fig. 2).

Analiza spękań utworów występujących na obszarze zakola wskazuje, że dominującymi kierunkami są dwa regularne zespoły spękań skośnych o charakterze spękań przewodnich: D_1 o kierunku 10–30° oraz D_2 o kierunku ca. 80–90°. Towarzyszą im słabiej zaznaczone zespoły poprzeczne T (60°) oraz podłużne L (150–160°) (Fig. 3A; por. także Margielewski, 2002b). W obrębie skalistej skarpy głównej osuwiska występującego ponad zakolem Osławy odsłaniają się liczne powierzchnie zlustrowane w piaskowcach z Mszanki (Fig. 4). Strefa dyslokacyjna posiada tu orientację 20–30°, a towarzyszy jej dyspersja kierunków spękań. Zakole Osławy powstało w obrębie skrzydła zrzuconego tego uskoku.

Nietypowy dla obszarów górskich "meandrowy" kształt doliny rzecznej Osławy jest uwarunkowany różnicami w odporności skał podłoża, kierunkami anizotropii tektonicznej (w tym uskoków), jak też ruchami neotektonicznymi, związanymi z charakterystycznym rozkładem stref dyslokacyjnych (Fig. 5). Analiza rozkładu spękań skał w obrębie zakola, jak też map wskaźnikowych wskazuje na nierównomierne tempo neotektonicznego dźwigania obszaru zakola. Szybciej dźwigane były obszary sąsiadujące z zakolem od zachodu (wzdłuż nasunięcia), od wschodu (uskok normalny) i północy (Fig. 2). Silniejsze dźwiganie obszaru na północ od zakola, powodujące rotację "bloku" zakola (ograniczonego dyslokacjami) o około 8–10° na SW, było spowodowane działalnością aktywnej strefy nasunięcia fałdu Komańczy-Wisłoka Wielkiego na fałd brzeżny w SW części obszaru (Fig. 2, 3).

Istotny wpływ na powstanie omawianej formy posiadały ruchy masowe, rozwijające się na obszarze strefy uskokowej (Fig. 1; strefy 1–3; Fig. 4). Stwierdzone w obrębie nasady zakola żwiry rzeczne (8 m powyżej współczesnego dna doliny rzeki przed zakolem; Fig. 6.1c) wskazują, iż rzeka pierwotnie płynęła prostolinijnie ku północy i prawdopodobnie posiadała w tym regionie dwa równoległe, lewobrzeżne zespoły dopływów (Fig. 7.1). Okresowe tamowanie doliny rzecznej koluwiami osuwisk rozwijanych na obszarze występowania strefy dyslokacyjnej (Fig. 4) prowadziło do piętrzenia wód rzeki powyżej współczesnego zakola, powodując różnice w tempie wcinania się jej w podłoże. Silniejsza erozja wgłębna jednego z dopływów powodowała, że z czasem mógł on w formie kaptażu przejąć drugi z dopływów (Fig. 7.4). Zakole mogło zostać uformowane w trakcie tworzenia przełomu przelewowego o założeniach regresyjnych (Fig. 7. 5–6). Jego ostateczny kształt jest efektem procesów erozyjno-akumulacyjnych, zachodzących w obrębie doliny rzecznej w warunkach nierównomiernego dźwigania neotektonicznego obszaru i formowania się przełomu antecedentnego (Zuchiewicz, 1995a).

W obrębie zewnętrznej części zakola w lewym, wysokim brzegu rzeki (Fig. 1.3), odsłania się poziom żwirów rzecznych miąższości ca. 3–4 m, przykrytych osadami jeziornymi (muł ilasty) i stokowymi (Fig. 6. 2). Wskazuje to, iż nastąpiło niegdyś całkowite zasypanie doliny rzecznej w obrębie zakola. Osady jeziorne o miąższości 0,7 m są prawdopodobnie efektem zatamowania doliny rzecznej koluwiami i powstania jeziora zaporowego już w obrębie zakola. Fragment drewna pobrany ze spągu osadów jeziornych datowano radiowęglowo na 11, 430±70 lat BP (Ki-10149). Analiza palinologiczna próbki pobranej z ich spągowych partii potwierdziła późnoglacjalny wiek osadów jeziornych, deponowanych w "zimnych" warunkach. Datowania wskazują więc, iż zatamowanie nastąpiło w późnym glacjale (starszym dryasie?) piętra Wisły. Już wówczas zakole Osławy było w pełni ukształtowane i częściowo zasypane żwirami rzecznymi, których agradacja mogła zachodzić w warunkach peryglacjalnych u schyłku ostatniego zlodowacenia. Rozcięcie aluwiów Osławy i sięgnięcie do skalnego podłoża nastąpiło już w holocenie, przy współudziale dźwigania neotektonicznego (Zuchiewicz, 1995a, b). Datowanie radiowęglowe wskazuje na młody wiek ruchów neotektonicznych.