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IN-CHANNEL ACCRETIONARY MACROFORMS IN THE MODERN ANASTOMOSING SYSTEM OF THE UPPER NAREW RIVER, NE POLAND

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Abstract: Predomination of sandy bedload is typical of the anastomosing channels of the Narew River. Several types of in-channel accretionary macroforms have been found in these channels: side bars, concave-bank bars, plug bars, point bars, linguoid bars, and mid-channel bars. The first three types are relatively rare, point bars occur only exceptionally, while linguoid bars and mid-channel bars are quite common. The bars usually occur in main channels, which are the master routes of sand transport in the whole anastomosing system of the Narew. The lower parts of the bars are built of coarse- and medium-grained sand, similarly to the sediments in the deeper parts of the channels. Fine-grained sand, locally alternating with organic-rich muddy sand, predominates usually in the upper parts; peat with high content of sand is present in the highest parts of some bars.

All bars are rapidly colonised and stabilised by plants. It is for this reason and due to the low energy of the river that the bar sediments have a high preservation potential. The development of bars is usually not accompanied by lateral migration of channels. Consequently, sediment accretion in bars is one of the factors leading to gradual narrowing of channels. Deposits of some sand-bars, when preserved in fossil record, may probably be represented by characteristic “wings” in the outer parts of ribbon-like sand bodies.

Key words: anastomosing river, sand bars, vegetation, Poland.

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INTRODUCTION

In-channel accretionary macroforms of sand bar type are common in braided and meandering rivers, are well studied, and play an important role in channel sedimentation processes (cf. Miall, 1996). On the other hand, the knowledge about forms of this class found in anastomosing rivers is relatively scarce. Such forms have not been mentioned or only marginally dealt with in many papers dealing with modern anastomosing rivers and their sediments (cf., e.g. Smith & Smith, 1980; Smith, 1986; Smith *et al.*, 1989; Schumann, 1989; Knighton & Nanson, 1993; Nanson & Knighton, 1996; Schumm *et al.*, 1996; Makaske, 1998, 2001; Morozova & Smith, 1999, 2000; Perez-Arculea & Smith, 1999; Makaske *et al.*, 2002). The few exceptions include fairly detailed descriptions of small sand bars from some channels of the anastomosing Okavango system in Botswana (Stanistreet *et al.*, 1993), a schematic reconstruction of side bar formation in the Old Channel in the lower Saskatchewan River (Smith, 1983), and the descriptions of accretionary benches from anastomosing rivers in Channel Country in central Australia (Gibling *et al.*, 1998).

Various types of in-channel accretionary macroforms have been found by the authors during their studies of the anastomosing system of the upper Narew River. An introductory brief information about these forms is contained in

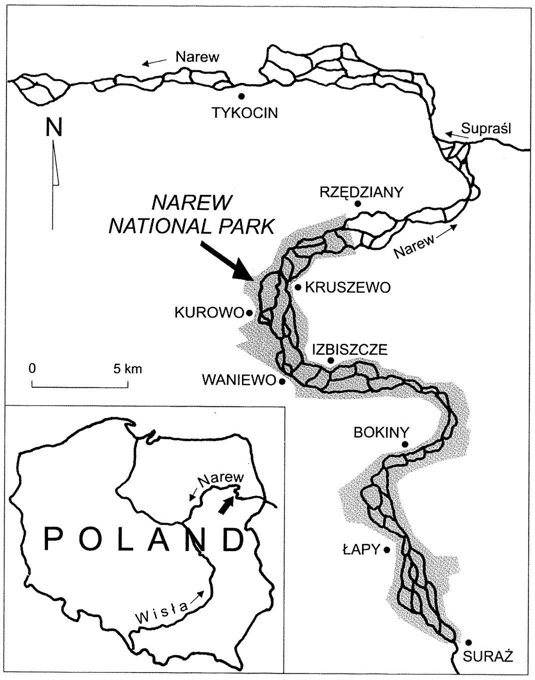


Fig. 1. Schematic map of the upper Narew River between Suraż and Tykocin. The channel network in the reach downstream from Rzędziany is shown as it looked like before the drainage works

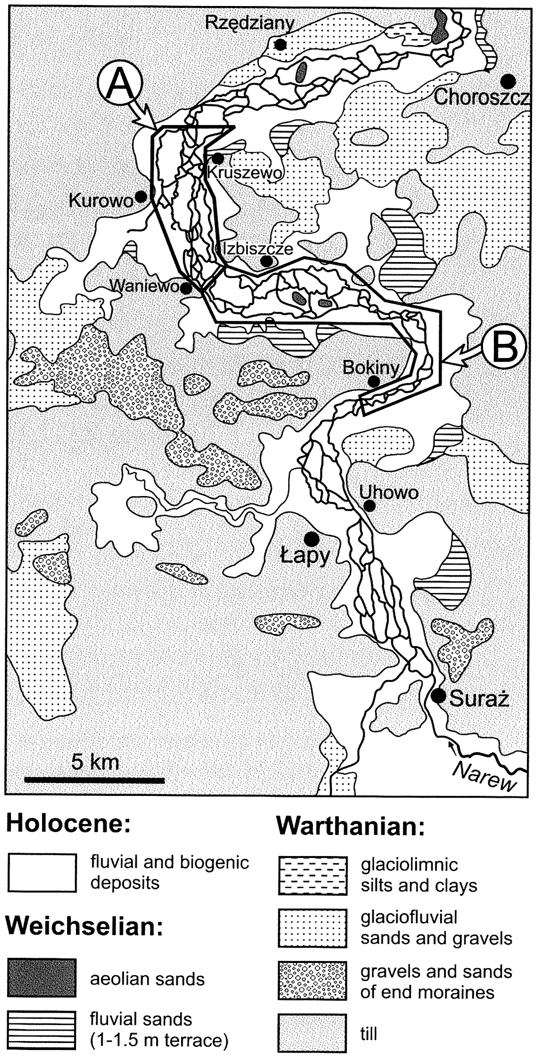


Fig. 2. Geological map of the middle reach of the upper Narew River valley (after Bałuk, 1973, simplified). (A) Area of the detailed study; (B) area of reconnaissance studies

an earlier paper on the Narew system (Gradziński *et al.*, 2003). Here we report a more detailed description of these macroforms and we discuss their role in the development of the Narew anastomosing channels.

LOCATION AND BACKGROUND

The anastomosing reach of the upper Narew between Suraż and Rzędziany is preserved in a nearly pristine form and is 35 km long (Fig. 1). It lies within the Narew National Park (NNP). This reach is referred to below as the Narew anastomosing system (NAS). The river had similar characteristics for another 35 km downstream still in the 1970s, but since then this part of the valley has been strongly altered by drainage works.

The upper Narew flows through a lowland area underlain by Pleistocene sediments, about 200 m thick, mainly glacial till and glaciofluvial sands (cf. Bałuk, 1973; Banaszuk, 1996; Lindner & Astapova, 2000). The upper Narew River is distinctly bedload in character. The river carries almost exclusively sand; suspended clastic load is negligible.

The network of anastomosing channels of the NAS is developed in a relatively wide valley, the bottom of which is occupied by wetlands and bordered by low hills built of Pleistocene sediments (Fig. 2). The average longitudinal gradient of the valley bottom between Suraż and Rzędziany is ca. 0.00022. The almost whole bottom of the valley, except for the river channels, is covered with a Holocene (mostly late Holocene) layer composed mainly of peat and peat-like deposits (Fig. 3). For the sake of simplicity, this layer is further referred to as the peat layer. This layer and the channel sediments are underlain with the so-called basal sand series, 15–25 m thick, considered to represent older, pre-anastomosing fluvial systems (Falkowski, 1970; Churski, 1973; Okruszko & Oświt, 1973; Banaszuk 1996; Gradziński *et al.*, 2000, 2003). The exact age of the basal sand series is not known; it may be either late Pleistocene or early Holocene.

The present authors are of the opinion (see Gradziński *et al.*, 2003), that the upper Narew at the studied reach may be regarded as a typical anastomosing fluvial system of temperate-humid climate, although it stands out with its distinctly bedload-dominated character and the lack of natural levees and crevasse splays. The impact of vegetation is crucial for the evolution of the NAS. Avulsion in the system is a small-scale, gradual, long-term and relatively infrequent process. In our opinion, the formation of the network of anastomosing channels was related mostly to the gradual development of the Holocene peat layer. The relics of the older meandering fluvial system are still partly preserved within the modern anastomosing system as laterally inactive high-sinuosity reaches.

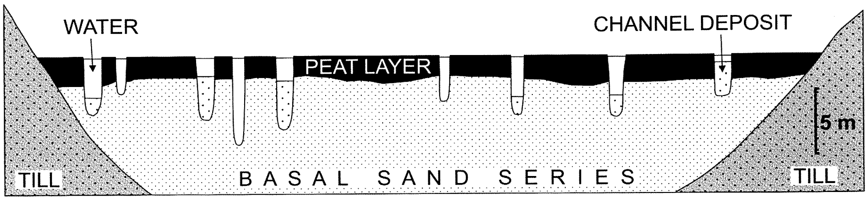


Fig. 3. Schematic cross-section through the Narew River valley near Kurowo. No horizontal scale, valley is ca. 2.5 km wide

METHODS

The anastomosing system of the Narew was studied by the present authors within the scope of a mainly sedimentological project; vegetation was studied by J. Baryła, peat by S. Żurek, and hydrology by R. Soja. The largest part of the data used in this paper was obtained during the final stage of our field work, during the period of extremely low water stage (see Fig. 4).

The main field work was carried out in June and September of 1998 and 1999, and in September of 2000; additional data have been obtained during a short visit in August 2001.

Water-level observations in the NAS came from the Kurowo water gauge (Fig. 4). The water level referred in this paper as normal (NWS) corresponds approximately to the average level, which in the NAS is close to the bankfull flow. Water level described as low (LWS) is ca. 30–40 cm lower than NWS. Finally, water level called here extremely low (ELWS) is ca. 75 cm lower than NWS.

Inflatable boats were the main means of transport; they enabled measurements in the channels and collection of core and box samples of bottom sediments. Underwater investigation was supported by a scuba diver and by specially adapted TV equipment. The longitudinal sections of channels were surveyed using an electronic acoustic bottom profiler. Transverse sections of the channels were mainly made by sounding with a lead line dropped from boat.

A total of about 160 cores up to 5 m long were taken using self-designed Plexiglas-tube corer. Another 45 boreholes, up to 6 m deep, were drilled using Eijkelkamp hand-auger set with peat sampler. Additional samples of sediments with undisturbed structure were taken using a wedge-shaped sampler (cf. Chudzikiewicz *et al.*, 1979). Trenches reaching down to the water level were made in September 2000, on the then emergent parts of some sand-bars. Airborne observations and photographs were made using a helicopter flying at altitudes of 50–200 m.

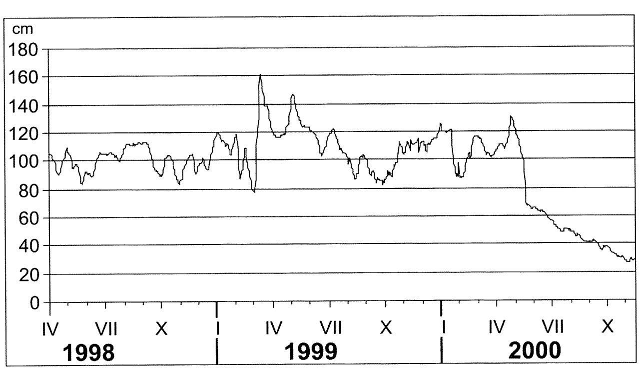


Fig. 4. Water stages in the NAS (water gauge at Kurowo) during the study period

An analysis of a series of successive topographic maps and aerial photographs (the latter from the years 1966, 1980, 1989 and 1997) was of limited use. Only the larger forms belonging to linguoid and mid-channel bars were discernible on the maps and photographs.

Sand grain-size in drill-cores and box-cores was determined in the field using a transparent grain-size comparator. Granulometric analyses were made in Sedimentological Laboratory of the University of Silesia. Samples of peat and peat-like deposits were dated by radiocarbon method at the Institute of Geological Sciences of the Academy of Sciences of Belarus in Minsk.

CHARACTERISTICS OF THE NAS

The area of the upper Narew River has a temperate humid climate. The mean annual rainfall is about 560 mm. The period of maximum precipitation is from June to August. The NAS usually has one high water stage in the spring, due to snow melting, and one low water stage from July to October (Fig. 4). The mean annual discharge at the Suraż gauging station is 13.3 m^3/s, while the maximum recorded discharge was 250 m^3/s. As compared with the Suraż gauging station, the NAS area displays distinct lowering and flattening of flood peaks and prolonged periods of flooding.

The river in the NAS area forms an irregular network of interconnected channels with flat interchannel areas between them (Fig. 5). The vast majority of the channels are active, even at LWS. Individual active channels vary in size and discharge. The larger ones, which show higher discharges than the others, are considered the main channels (Fig. 6).

Some of the channels are in various phases of abandonment and are heavily overgrown with water plants. Fragments of abandoned channels of various length, shape and depth are preserved locally. They are partly or completely isolated from the active channels. Some parts of the channel network have a character of shallow lakes.

Most channels show relatively low sinuosity (below 1.3), but sporadically exhibit tight bends. Subordinate are highly sinuous channels with regular bends, showing meandering pattern. Both types of channels usually do not display clear traces of lateral migration.

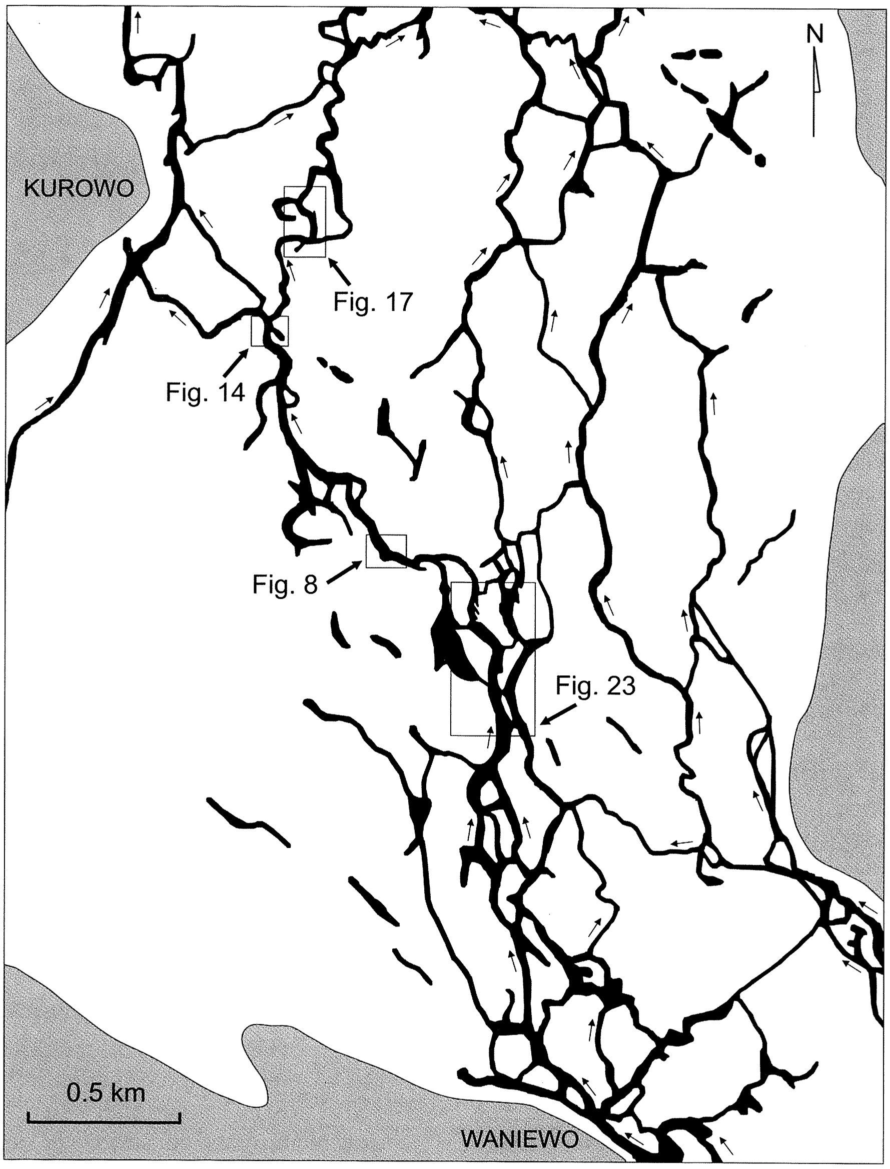


Fig. 5. The Narew River valley between Waniewo and Kurowo. Interchannel areas are shown in white, elevations bordering the valley – in grey

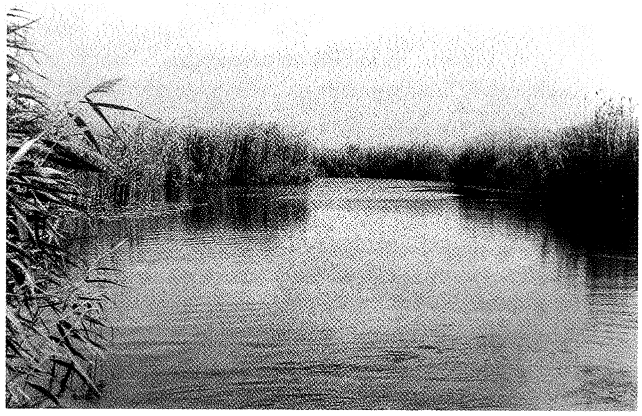


Fig. 6. Upflow view of a main active channel. Reeds are ca. 3 m high

Active channels are usually 5–35 m wide and are all relatively deep. Width/depth ratio falls within the range of 2–10, most frequently between 2 and 4. The slope of water surface in individual channels is generally low, usually between 0.0002 and 0.00012. At NWS, the maximum velocity of flow is rather low and usually varies between 10 and 35 cm/s, only exceptionally it is higher (see Gradziński *et al.*, 2003). The stream power values are very low as well, ranging between 2 and 3 W/m^2. During the high water stages, flow velocities are certainly higher but not much, as they are limited by the extensive area of the flooded overbank areas.

Cross-sections of active channels are often canal-like, i.e. they have both margins similarly steep and have flat bottom (see Gradziński *et al.*, 2000, fig. 8). Such outlines have been observed along both, straight and bent reaches of many channels. Outlines of cross-sections of some bent reaches are distinctly asymmetric with either the convex or concave bank sloping more gently. Some channels display considerable differences in depth along their thalwegs, even over short distances.

Arrowhead (*Sagittaria sagittifolia*) or yellow water lily (*Nuphar lutea* cf. *submersa*) commonly appear in shallow places.

Channel banks are often so strongly overgrown that precise determination of their position may be difficult. The margins of active channels are overgrown mainly with common reed (*Phragmites australis*). Its stems commonly grow on underwater channel slope, at a depth of one metre or more, forming a belt along the shore, described as a grill-like margin (see Gradziński *et al.*, 2000, 2003). Such margins are often accompanied by floating mats of plants laterally attached to reed stems (see Gradziński *et al.*, 2003, fig. 10C). Most mats consist of yellow-cress (*Rorippa amphibia*), narrow-leaved water parsnip (*Berula erecta*) and cowbane (*Cicuta virosa*).

Channel deposits consist almost entirely of sand. Generally medium- and coarse-grained sand dominates, fine-grained sand is subordinate. Locally, mainly in thalwegs of major channels, coarse and very coarse sand includes admixture of granule-sized particles. Sporadically, rip-up clasts of peat occur.

Clastic fines are subordinate. They usually occur together with plant detritus forming single dark laminae within sand, which enhances stratification of the sandy channel deposits. Less common are dark layers of organic-rich muddy sand, centimetric or a few tens of centimetres thick, rich in plant detritus and debris. Such layers usually alternate with lighter-coloured sand layers. Heterogeneous sediments, composed of layers of both types, are farther described as heterolith (see Fig. 11, E, F and G).

Generally, sediments of the modern channels are similar in lithology to the sediments of the basal sand series. On the other hand, they clearly differ from sediments of the peat layer, which they juxtapose laterally at the channel margin.

Interchannel areas are flat and heavily overgrown. At NWS they are only slightly elevated above the water level in the channels (see Fig. 3), whilst during floods they are inundated, often for weeks or longer. The interchannel areas are vegetated with peat-forming plants. Dominant are common reed (*Phragmites australis*) and sedges (*Carex elata* and *Carex acuta*). Small patches of osier community (*Salicetum pentadro-cinereae*) and single arborescent willows occur locally. These plants are well rooted in the relatively firm but wet, peaty ground. A small proportion of interchannel areas, described by us as quagmires (see Gradziński *et al.*, 2003), are so heavily waterlogged that they are not firm enough for walking during NWS; the area is then a mosaic of small pools of water and clumps of semi-aquatic and aquatic plants.

The Narew system is moderately aggrading. Vertical accretion of the peat layer (1–1.5 mm per year on average) seems to be the main factor controlling the gradual rise of the depositional surface in the whole system – i.e., in the interchannel areas and in the channels as well (Gradziński *et al.*, 2003).

DESCRIPTION OF BARS

In the channels of the studied segments of the NAS, we have distinguished several types of modern accretionary macroforms, for brevity referred to below as bars. The individual types of bars differ in shape and position within channels (Fig. 7). The types of bars include: (1) side bars, (2) concave-bank bars, (3) plug bars, (4) point bars, (5) linguoid bars, and (6) mid-channel bars (see Gradziński *et al.*, 2003). For the sake of simplicity, the bars of the first four types are jointly described as group A, and the other two as group B.

All the bars are rapidly colonised by vegetation, which covers their highest, intermittently emergent parts, as well as the parts permanently covered with shallow water.

The A-group bars are usually of small horizontal dimensions. They are rare in the NAS, relative to the B-group bars. Moreover, they are hardly visible at NWS. Their presence is then indicated only by measurements of channel bottom relief, diver observations, drilling and plant species specific for bars. Only during LWS and ELWS the upper parts of the bars are emergent; the youngest accumulations of sediments are then especially conspicuous, being composed of clean fresh sand laid down during the most recent flood, and not yet colonised by vegetation (see Figs 12A and 22A).

Relatively large are only B-group bars, which are the linguoid and mid-channel ones; their upper parts are usually overgrown with high semi-aquatic plants. It is due to these characteristics and specific shapes that these forms are easily discernible in the field and sometimes even on air photographs (see Figs. 23 and 24).

Side bars

The bars of this type, seen in plan view, have shapes of elongated lenses and are attached to the channel margins (Figs 7 and 8). Their observed widths are of a few metres and the lengths attain 20–30 m. The bar surfaces are usually inclined towards the channels at an angle of 10–15° and pass to similarly inclined underwater slopes. An indistinct shallow depression parallel to the channel axis is present on

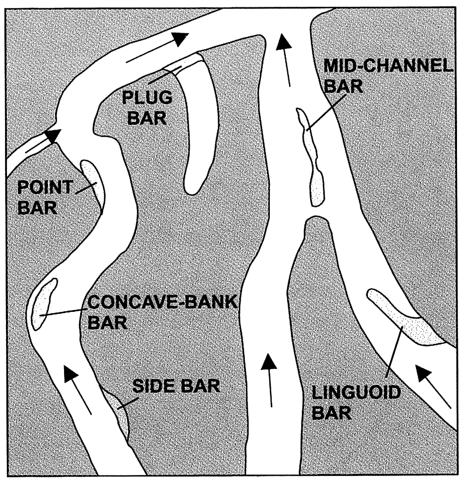


Fig. 7. Scheme showing various types of in-channel macroforms present in the NAS

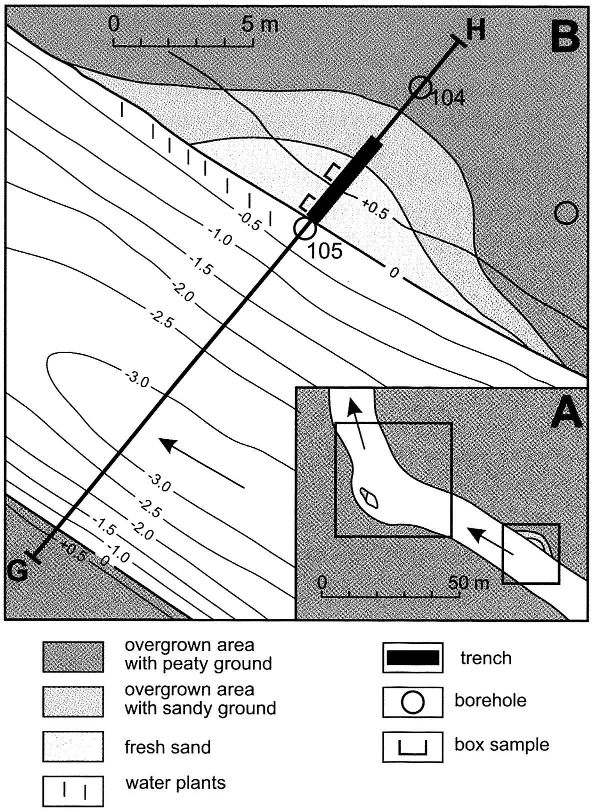


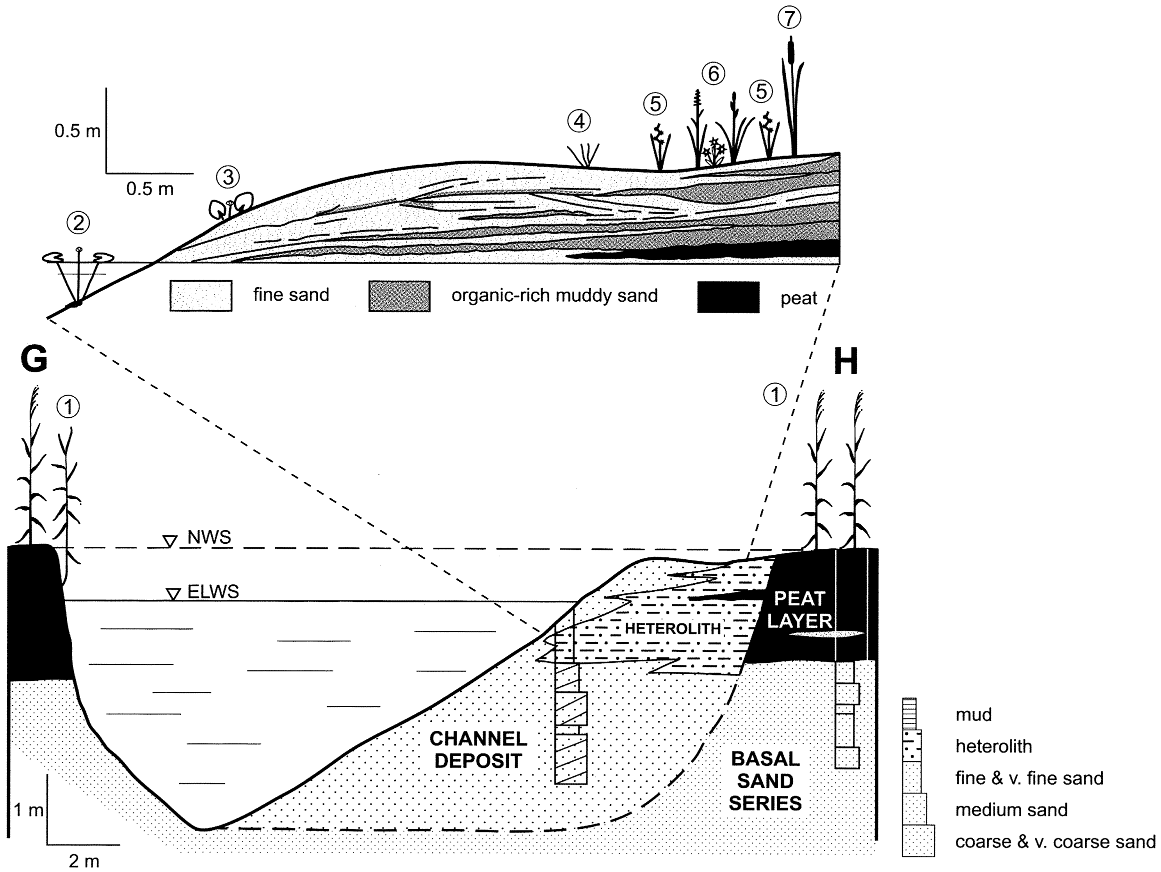
Fig. 8. Map of a fragment of a main channel showing positions of a side bar and a concave-bank bar (**A**); map of the studied side bar (**B**). Contours are in metres relative to an arbitrary selected water level; ELWS, September 2000. For location, see Fig. 5

the surface of some bars, on the side opposite to the channel. The slope of the channel opposite to a bar is usually steep, built of peat layer and usually lacks any traces of erosion. The observed side bars are often located in small, local embayments of otherwise straight reaches of the channels (Fig. 8). The margins directly upstream and downstream of the bars are usually grill-like.

One side bar was studied in detail (Figs 8–10, 12). Its top reaches almost to the level of the adjacent interchannel area overgrown with reed.

During the study, the surface of the bar was covered with clean fresh sand. A trench, boreholes and box-cores have shown that the part of the bar lying below the surface layer of clean sand to a depth of ca. 1.5 m is built of heterolith sediments, that is alternating dark beds of organic-rich muddy sand and beds of fine-grained sand (Fig. 9). The thickness of these beds varies from centimetric to decimetric. The dark beds wedge out toward the channel and some of them amalgamate over a short distance in the opposite di-

Fig. 9. Cross-section through a main channel and a side bar; for location, see Fig. 8. Vegetation marked schematically, not to scale. (1) Common reed (*Phragmites australis*); (2) Yellow water lily (*Nuphar lutea*); (3) Yellow water lily, specimens buried by sand; (4) Young specimens of grasses; (5) Bur reed (*Sparganium erectum*); (6) Grasses (Graminae), sedge (*Carex* sp.), bur marigold (*Bidens* sp.) etc.; (7) Great reed mace (*Typha latifolia*)



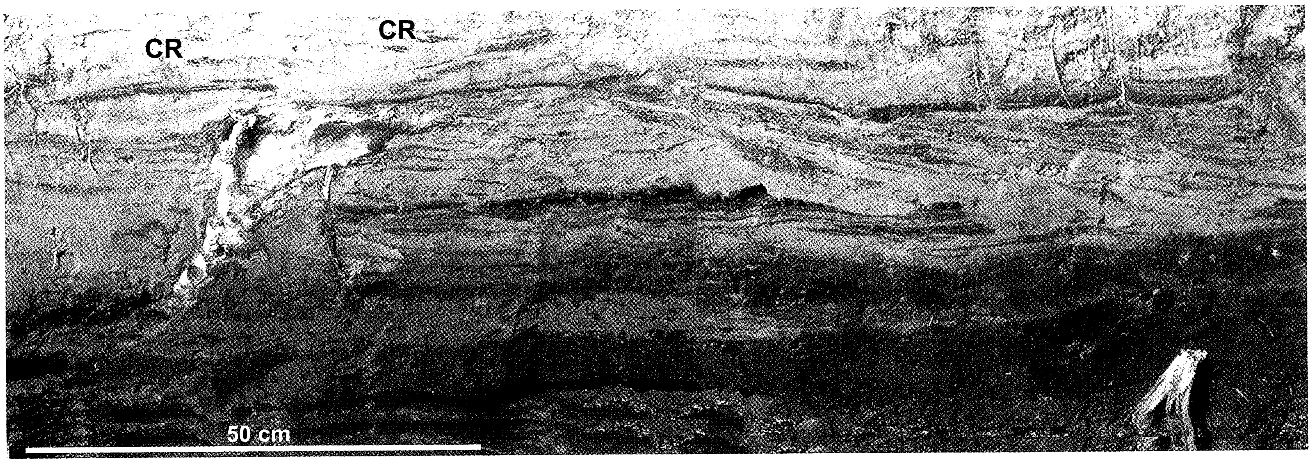


Fig. 10. Photograph showing the middle part of the wall of a trench on a side bar; channel to the left. CR – climbing ripples

rection. A single bed of sandy peat wedges out similarly. Sand in the light beds is fine-grained and usually well sorted.

Bedding in the upper part of the bar is more or less parallel to the upper surface of the bar. Erosional surfaces truncating the underlying sediments at a low angle occur locally. The dark beds are apparently structureless. Internal stratification is locally weakly discernible in the light beds (see Fig. 11E), though it is quite often accentuated by the presence of darker streaks and laminae of plant detritus. Slightly wavy lamination and ripple cross-lamination predominate; here and there, single sets of climbing ripples are visible. Their lee-side laminae are usually inclined away from the channel. Also present are decimetric bundles of laminae, usually inclined at a low angle (up to 10°) away from the channel, similarly as the erosional surfaces at their base. The bar sediments are locally strongly deformed by plant roots and rhizomes.

It is noteworthy that in September 2000, on the emergent surface of this bar single specimens of flowering (!) yellow water lily (*Nuphar lutea*) protruded directly from fresh clean sand (Figs. 9 and 12A), though yellow water lily is a typical water plant rooted in the bottom, whose leaves and flowers normally float on water surface (cf. Fig. 9). The presence of the mentioned specimens on the bar surface proves that the lower parts of the plants were recently and rapidly buried *in situ* by a layer of clear sand several tens of centimetres thick, most probably during the most recent flood. A year later the whole surface of the bar was already densely vegetated, mainly with bur reed (*Sparganium erectum*) and grasses; the specimens of yellow water lily buried earlier were already dying (Fig. 12B).

Concave-bank bars

The bars of this type occur on bends near the outer banks and are slightly crescent-shaped in the plan view (Fig. 13). Their platforms are convex, several metres wide and are separated from the outer bank by a shallow depression. A cross-section of the channel near the bar is slightly asymmetric, with the steep slope at the convex bank.

Drilling on one of the bars revealed that it is built of sand which shows general upward-fining (Fig. 13). It is mainly coarse- and medium-grained sand at the bottom, moderately or moderately well sorted, with predominance of large-scale cross-lamination; fine-grained sand, well sorted, with horizontal and ripple cross-lamination predominates in the highest part of the section. The top of the bar was only slightly emergent during ELSW.

Plug bars

Plug bars occur at extremities of abandoned channels. Some of these bars are underwater shoals and are permanently submerged, while the upper parts of some others are emergent during LWS and ELWS. Trenches were dug across two of the emergent forms, referred to as no. 1 and no. 2.

Plug bar no 1 is an elongated elevation between an active and an abandoned channel (Fig. 14). The middle narrowest part of this bar is under water during NWS and rises 50–60 cm above the water level during ELWS. The upper part of the bar, exposed in trenches, is built of fine-grained, well sorted sand. Generally, stratification is more or less parallel to the upper, convex surface of the bar, though small discrepancies and wavy disturbances of the bundles of laminae are common locally (Fig. 15). Feebly discernible ripple cross-lamination predominates (Fig. 11B) and climbing ripple structures are rare. Stratification is accentuated by few dark, often discontinuous, millimetric layers of plant detritus, sporadically by thin layers of organic-rich muddy sand. The latter are more common in the part of the bar adjacent to the abandoned channel. Measurements of the lee-side laminae inclination in the ripples show palaeocurrent directions downstream (relative to the main channel) or toward the abandoned channel.

Plug bar no 2 is an elongated elevation across an isolated abandoned channel (for location, see Figs 17 and 18). The elevation is 15–20 m wide, and its top reaches to the height of the adjacent interchannel areas. In September 2002 (during ELWS), the bar was almost completely overgrown, mainly by bur reed (*Sparganium erectum*) and great reed mace (*Typha latifolia*). Small patches of fresh clean sand were visible only on the slope inclined towards the ac-

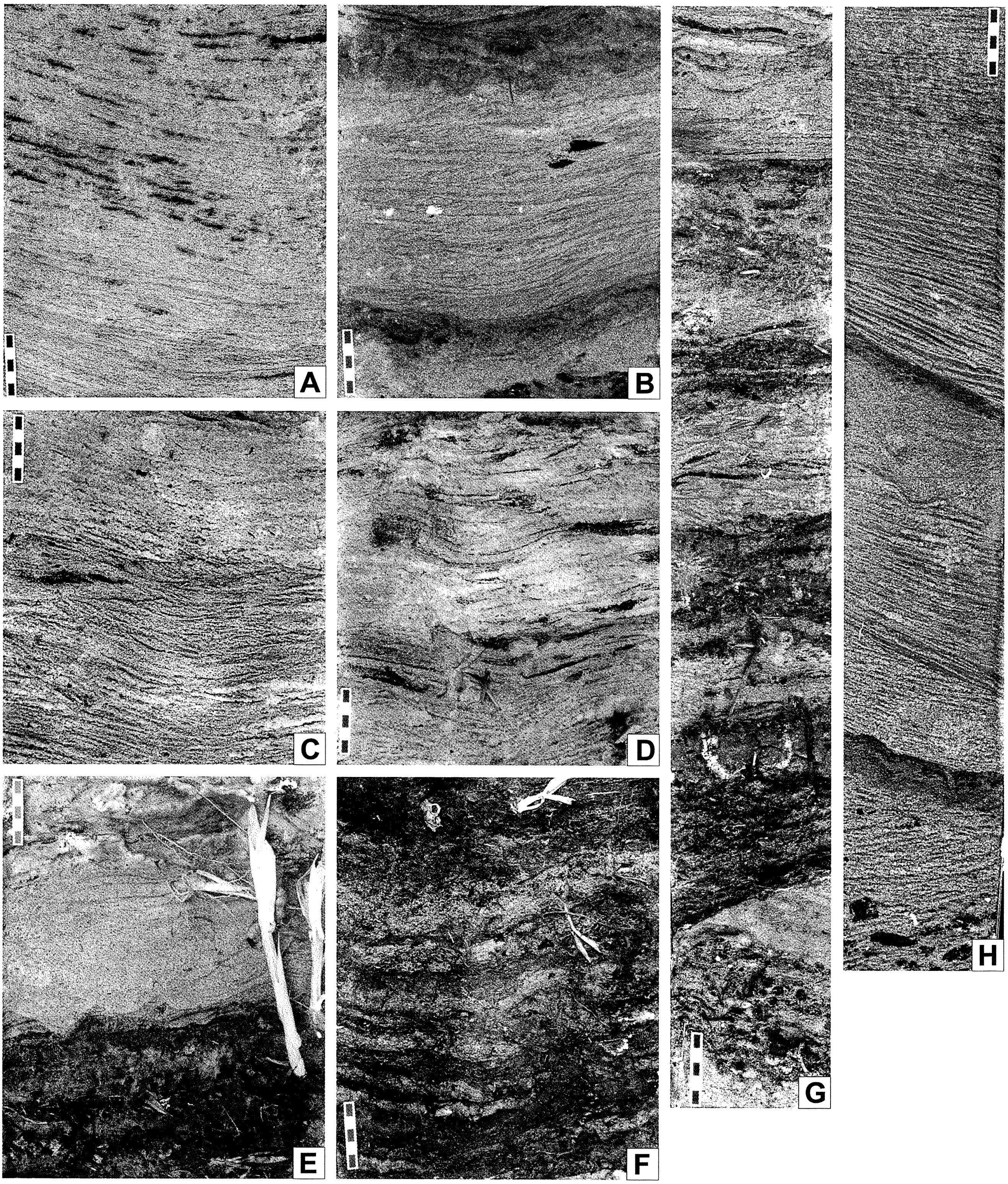


Fig. 11. Resin-hardened samples showing various types of bar sediments. Dark laminae and layers are rich in plant detritus. Scale in cm. (**A**) Inclined stratification in laterally accreting downstream portion of the point bar; (**B**) Small-scale cross-lamination in the upper part of plug bar no 1; (**C**) Small-scale cross-lamination and wavy lamination in the upper part of the point bar; (**D**) Wavy lamination in the middle part of a mid-channel bar section; (**E**) Fresh sand in the highest part of a side bar, underlain by heterolith; (**F**) Thinly bedded heterolith in a side bar; (**G**) Side bar sediments; sand at top, heterolith below; (**H**) Sets of large-scale cross-strata with backflow ripple structures in the lower part; small-scale cross-stratification at the bottom; sample from a downstream part of the point bar

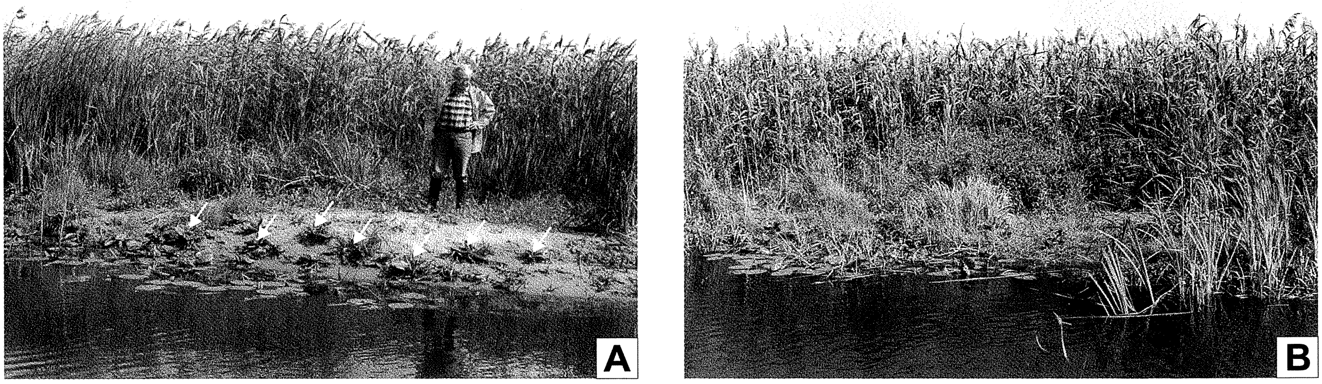


Fig. 12. The studied side bar during ELWS. (**A**) July 2000; arrows point to flowering specimens of yellow water lily (cf. Fig. 8); (**B**) August 2001

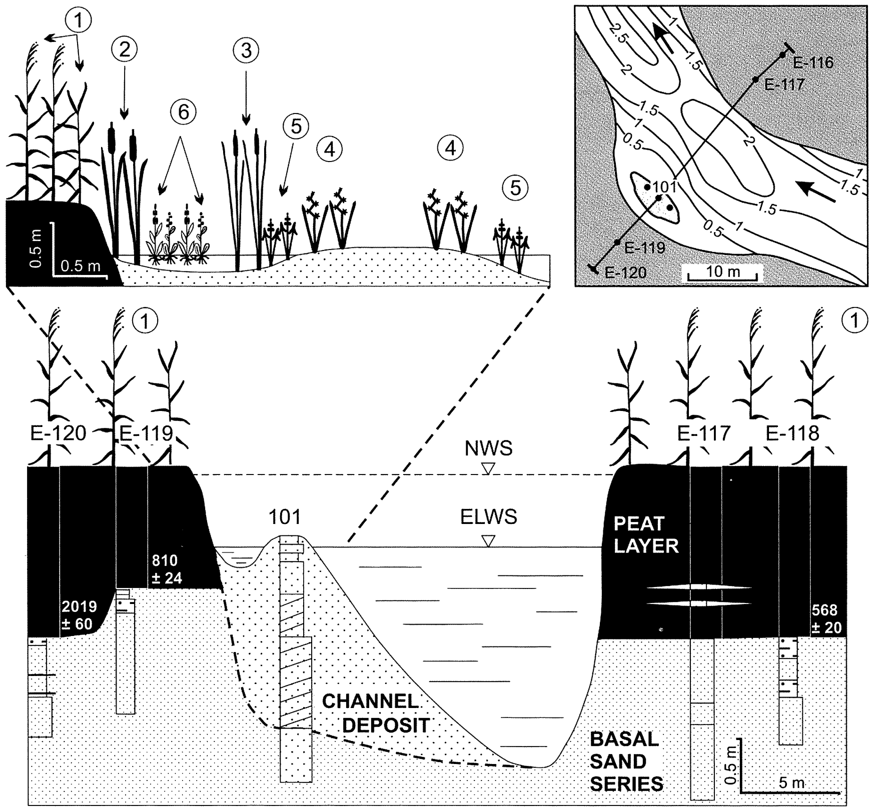


Fig. 13. Cross-section through the main channel and a concave-bank bar; for location, see Fig. 8. Contours are in metres relative to an arbitrary selected water level; ELWS, September 2000. Vegetation marked schematically, not to scale. (1) Common reed (*Phragmites australis*); (2) Great reed mace (*Typha latifolia*); (3) Lesser reed mace (*T. angustifolia*); (4) Bur reed (*Sparganium erectum*); (5) Arrowhead (*Sagittaria sagittifolia*); (6) Marsh woundwort (*Stachys palustris*) and great yellow-cress (*Rorippa amphibia*)

tive channel. A trench parallel to the channel was dug in this part of the bar.

The trench wall reveals two beds of fine-grained well sorted sand, separated with a dark layer composed of organic-rich muddy sand, rich in detritus and coarser plant debris (Fig. 16). Stratification in sand is generally horizontal or slightly wavy; it is locally accentuated by the presence of discontinuous laminae of plant detritus. Ripple-cross lamination is indistinct, lee-sides of the ripples are inclined downstream.

Point bars

Point bars are rare in the NAS. Only one emergent point bar has been observed. It is situated in a segment of the main channel, near the Remiz Island (Figs 17 and 18). This segment was surveyed in detail in years 1998–2000, so that successive changes in its topography have been registered (see Figs 19 and 21).

The shore of the Remiz Island, opposite to the point bar is one of the few places in the NAS where lateral erosion of

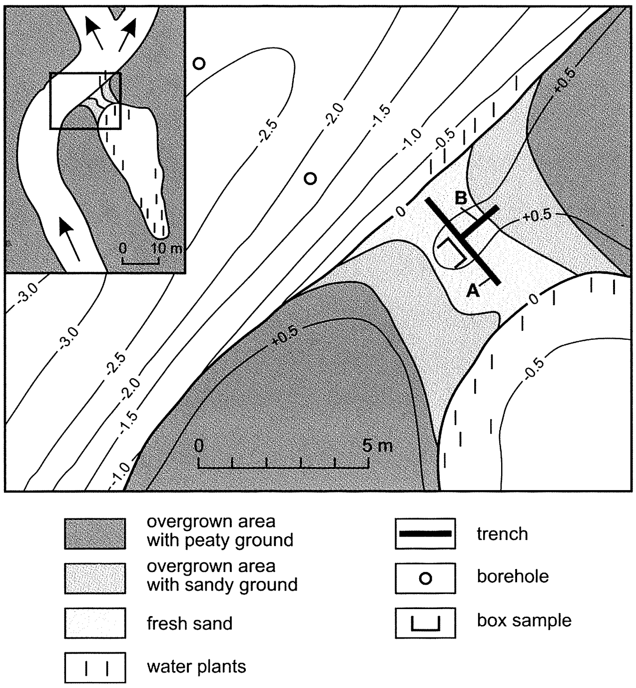


Fig. 14. Map of the studied plug bar no. 1. Contours are in metres relative to an arbitrary selected water level; ELWS, September 2000

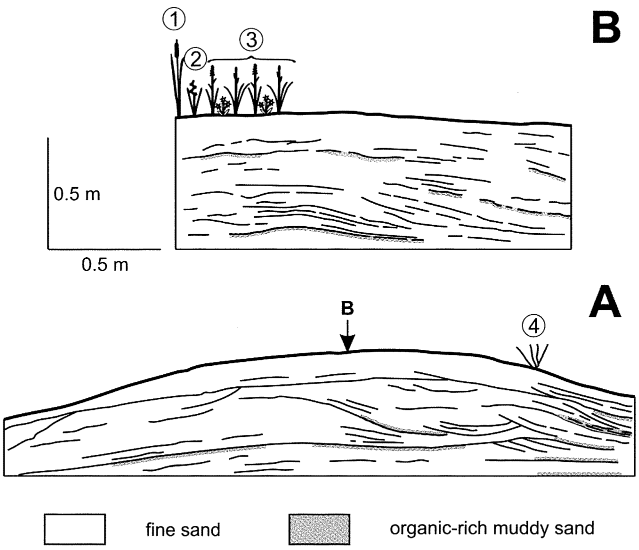


Fig. 15. Walls of excavations on the plug bar no 1 (see Fig. 14). (**A**) Trench perpendicular to the main channel; (**B**) Trench parallel to the main channel. Vegetation marked schematically, not to scale; (1) Great reed mace (*Typha latifolia*), (2) Bur reed (*Sparganium erectum*), (3) Grasses (Graminae), sedge *(Carex* sp.) etc., (4) Young specimens of grasses

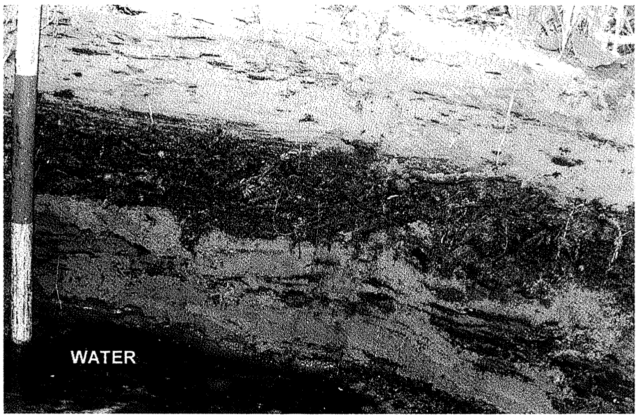


Fig. 16. Wall of excavation in plug bar no. 2 (for location, see Figs. 17 and 18) seen from the direction of the main channel. White and dark segments on the pole are 20 cm each

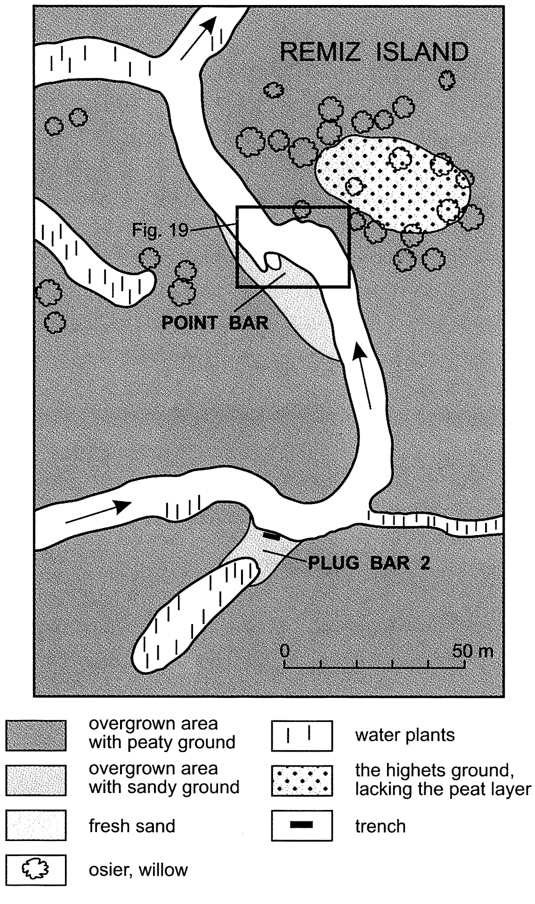


Fig. 17. Map of the Remiz Island vicinity; for location, see Fig. 5. ELWS, September 2000

the peat layer may be observed, and the only one where the process is very rapid. Apart from the channel geometry, erosion is favoured by relatively low thickness of the peat layer underlain by sand. Archaeological artefacts of various age, the oldest ones older than ca. 3000 years (see Gradziński *et al.*, 1998), were found on the channel bottom by our scuba diver. The artefacts undoubtedly have come from the eroded shore, most likely from the layer of sand underlying the peat layer. A large counterclockwise vortex is present nearby over the whole width of the channel (Fig. 19).

The bar is elongated parallel to the convex bank and terminates downstream with a rounded tip (see Figs 19B and

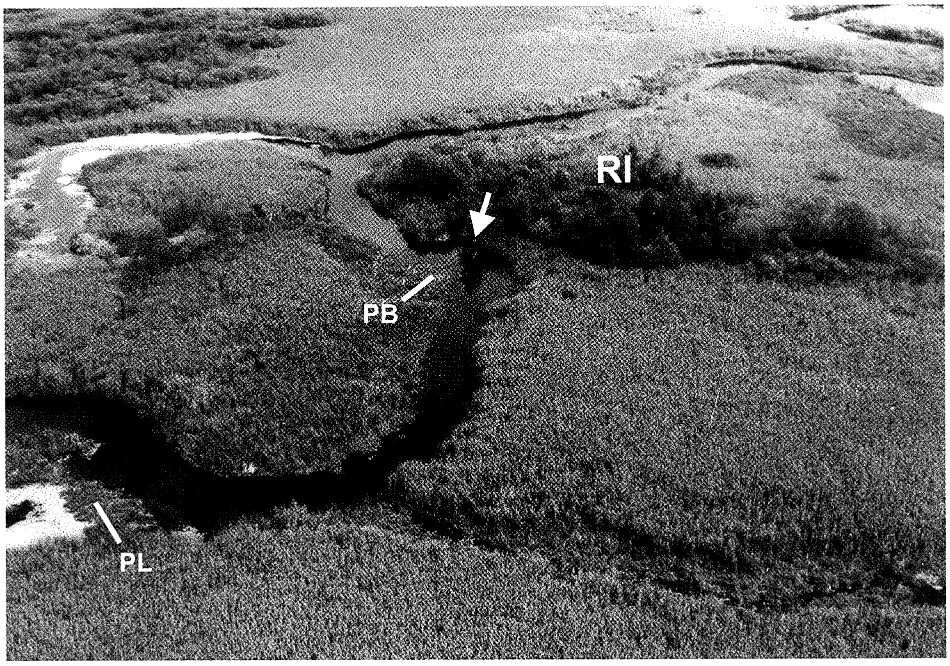


Fig. 18. A fragment of a highly sinuous channel near the Remiz Island; see Fig. 17. Arrow shows the only place where the concave bank is subject to erosion. RI – Remiz Island; PB – point bar; PL – Plug bar no 2. Downflow view. Width of lower foreground is approximately 80 m

22). The bar is heavily overgrown; in September 2000 only its terminal part was devoid of vegetation and covered with clean, fresh sand. Three trenches were then dug in this place and box samples were taken (Fig. 19B).

The part of the bar exposed in the trenches (Fig. 20) is built of fine-grained well-sorted sand with predominant small-scale cross-stratification. Climbing-ripples are common, mainly of type B (cf. Jopling & Walker, 1968). Some parts of these structures are especially well visible due to the concentrations of dark plant detritus on lee-sides of the ripples. The angle of climb varies from a few to 20°, cosets attain 30 cm in thickness and display the same angle of climb from the bottom to the top (pattern I, cf. Allen, 1973). The measurements of lee-side laminae inclinations reveal predominant direction of the currents that laid down the clastic material toward the E and ENE, generally opposite to the main flow in the channel.

The lower part of the bar, directly underlying the sediments exposed in the trenches, is built of fine- and medium-grained sand, well or moderately sorted, with large-scale cross-stratification in which laminae are inclined downstream (Fig. 11H). The whole section of the bar sediments is generally fining-upwards. The upper part of the point bar in its upstream part is built mostly of heterolith, and is strongly disturbed by penetration of plant rhizomes and roots.

Measurements prove that vertical and lateral accretion of the downstream part of the point bar is fast, similarly as erosional retreat of the opposite bank of the channel (Fig. 21). Also rapid is colonisation of the bar by vegetation (Fig. 22).

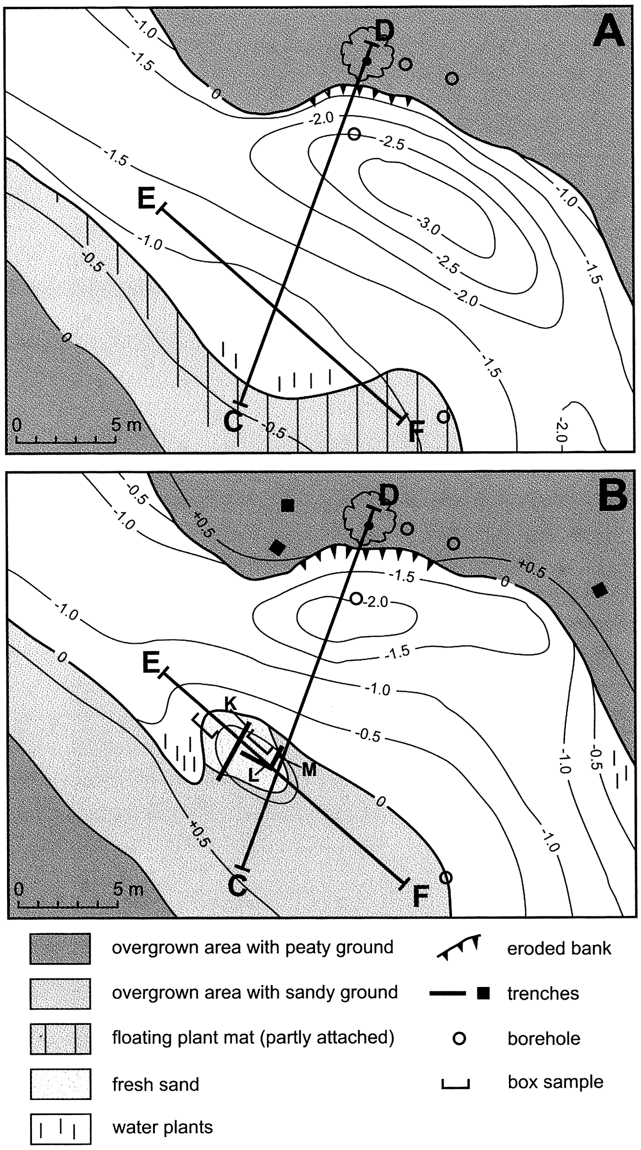


Fig. 19. Maps of the main channel east of the Remiz Island; for location, see Fig. 17. Contours are in metres relatively to an arbitrary selected water level, different for each map. (**A**) In September 1998 (NWS); (**B**) In September 2000 (ELWS)

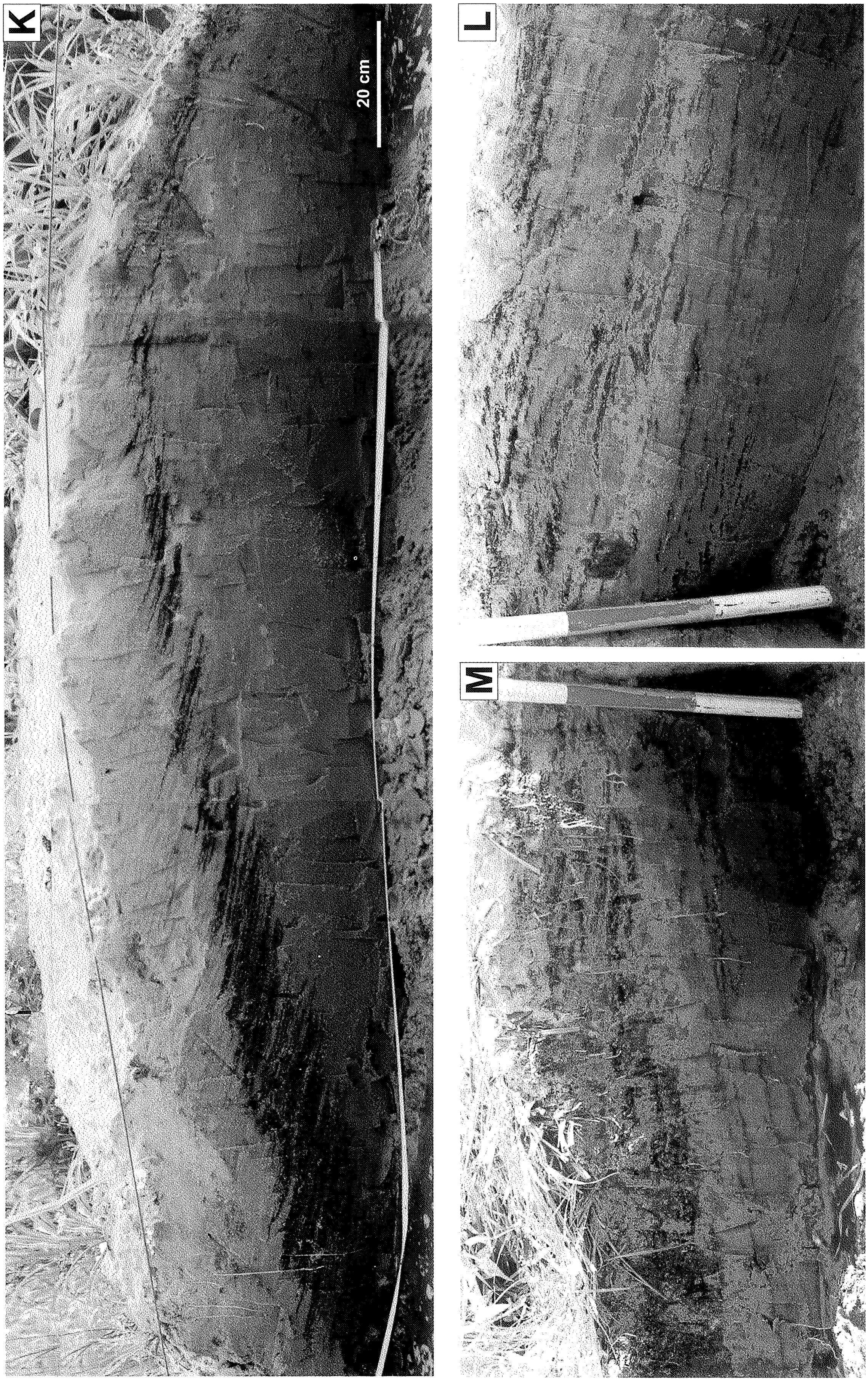


Fig. 20. Photographs of trench walls (K, L, M) on a point bar; for location see Fig. 19B

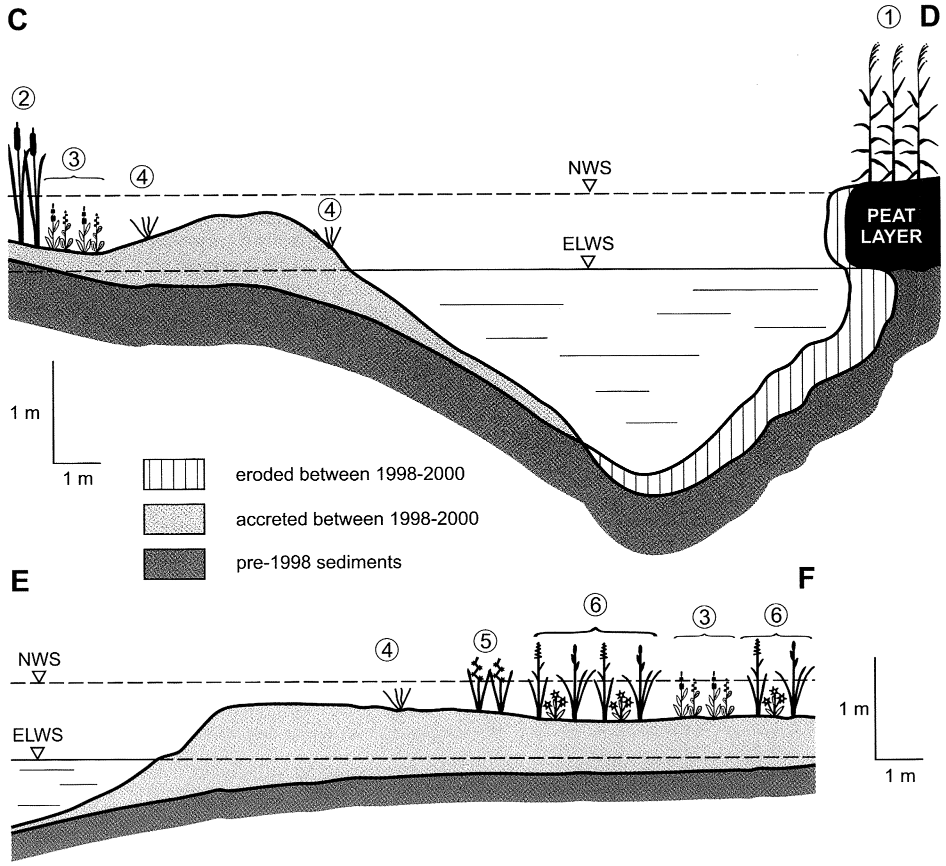


Fig. 21. Cross-sections of channel and point bar near the Remiz Island, showing the results of erosion and accretion between September 1998 and September 2000. For location of cross-sections see Fig. 19. Vegetation marked schematically, not to scale. (1) Common reed (*Phragmites australis*); (2) Great reed mace (*Typha latifolia*); (3) Marsh woundwort (*Stachys palustris*) and great yellow-cres (*Rorippa amphibia*); (4) Young specimens of grasses; (5) Bur reed (*Sparganium erectum*); (6) Grasses (Graminae), sedge (*Carex* sp.), bur marigold (*Bidens* sp.), etc.

Linguoid bars

Linguoid bars resemble in shape peninsulas attached to the channel margin on their upstream sides. Their axes usually run diagonally to the channel margins (Figs. 23 and 24). Individual bars may differ slightly in shape and may attain many tens of metres in length. The bars extend downstream in the form of submerged sandy ridges gradually decreasing in height (Fig. 25). The highest parts of the bars rise approximately to the level of the adjacent interchannel areas.

Top platforms of the linguoid bars are more or less horizontal and at NWS they acquire quagmire characteristics. They are densely overgrown with taxonomically differentiated vegetation, mainly reed mace (*Typha angustifolia*), great reed mace (*Typha latifolia*), water plantain (*Alisma plantago aquatica*), bur reed (*Sparganium erectum*), yellow cress (*Rorippa amphibia*), cowbane (*Cicuta virosa*), and marsh woundwort (*Stachys palustris*). Common reed (*Phragmites australis*) dominates in the extreme upstream parts of some bars.

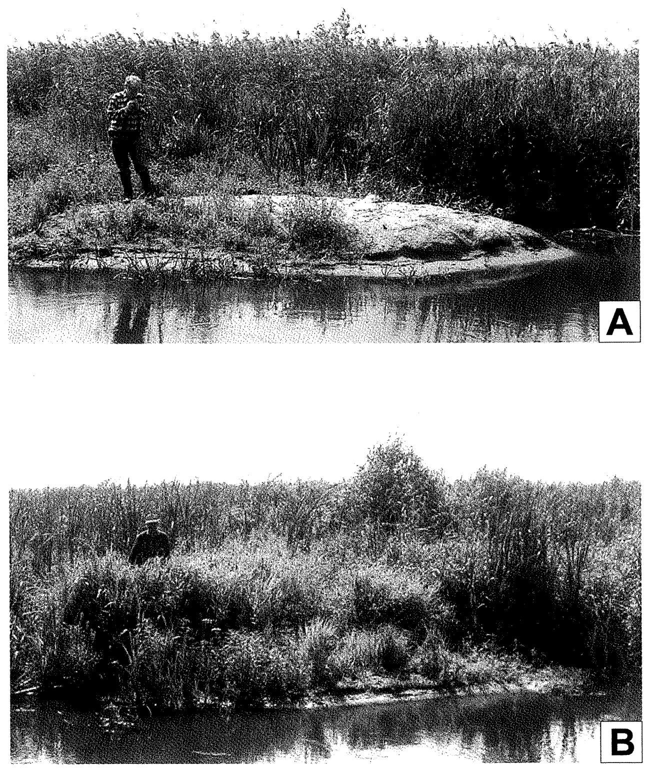


Fig. 22. Colonisation by plants of the downstream part of point bar near the Remiz Island. (**A**) September 2000; (**B**) August 2001. Both photographs at ELWS; westward view, flow to the right

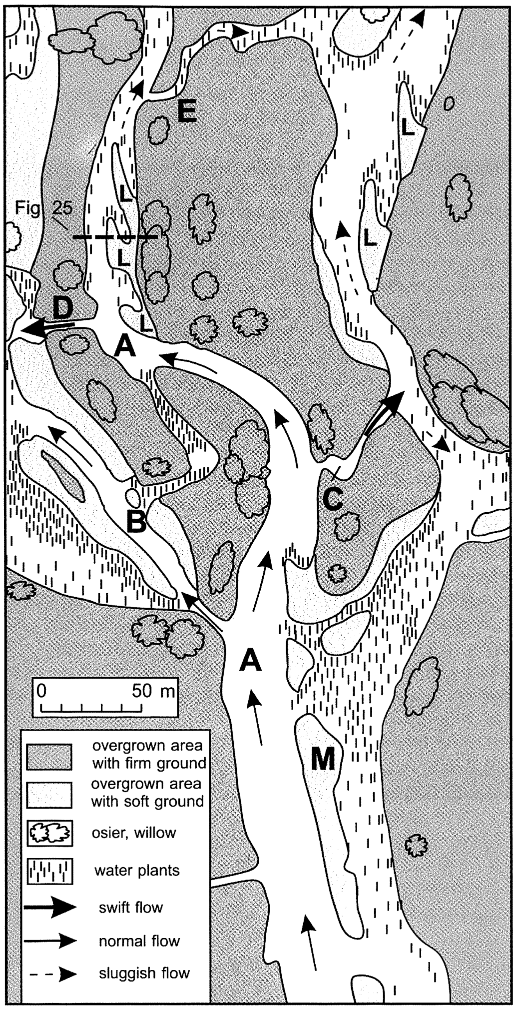


Fig. 23. Map of the dense channel network at the Zielona Budka study area; for location see Fig. 5. (A–E) Channels; (L) Vegetated linguoid bars; (M) Mid-channel bars

Scarce available data indicate that a thin layer of peat with rich sand content is often present under the axial parts of the bars. It is underlain by heterolith, and this, in turn, by a thick package of sand with characteristics of channel deposit (Fig. 25). The higher part of the bar sediment section displays a crude fining-upward sequence.

The linguoid bars occur in slow-current channels, usually near their gently convex margins, less frequently within the straight reaches. The growth of the bars is initiated by protrusions of heavily vegetated channel banks in the places where plants prograde towards the channel axis.

Analysis of air photographs from the Zielona Budka study area proves that the linguoid bars now observed in channel A were there already in 1966 (Fig. 26). It may be, thus, inferred that the bars are relatively old forms, slowly growing in the downstream direction. It should be added that we also know small linguoid bars in the NAS, most likely formed in a shorter period, of the order of a few decades or less.

Mid-channel bars

In plan view, mid-channel bars are elongated approximately parallel to the channel margins. They continue downstream as submerged sandy ridges, similarly as the linguoid bars. They vary in size – some attain 150 m in length. These bars are often segmented by secondary elevations and depressions clearly visible in longitudinal sections. During NWS such bars resemble chains of vegetated isles (Figs 23 and 24). The described bars are similar to linguoid bars in many respects, such as behaving as quagmires during NWS, and are being densely overgrown with similar plants.

Organic-rich muddy sand is the main type of sediment accumulating on the bar surfaces. However, local accumulations of fresh, clean sand may be seen after floods (Fig. 26). Though few data are available, it may be supposed that internal structure of the mid-channel bars is similar to that of linguoid bars (cf. Fig. 25). Analysis of air photographs

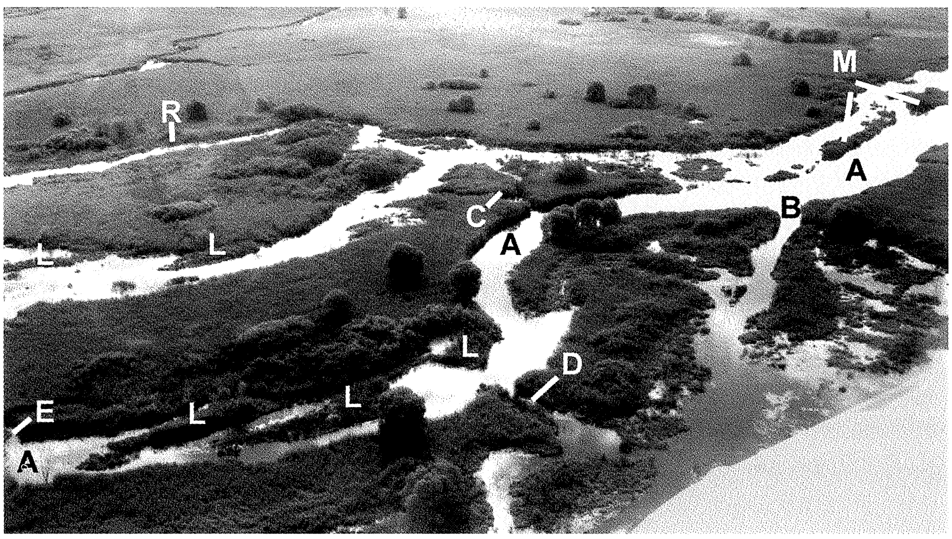


Fig. 24. Photograph of the dense channel network at the Zielona Budka area, view eastward (cf. Fig. 23). (L) Vegetated linguoid bars; (M) Mid-channel bars; (A–E and R) Channels. Flow to the left

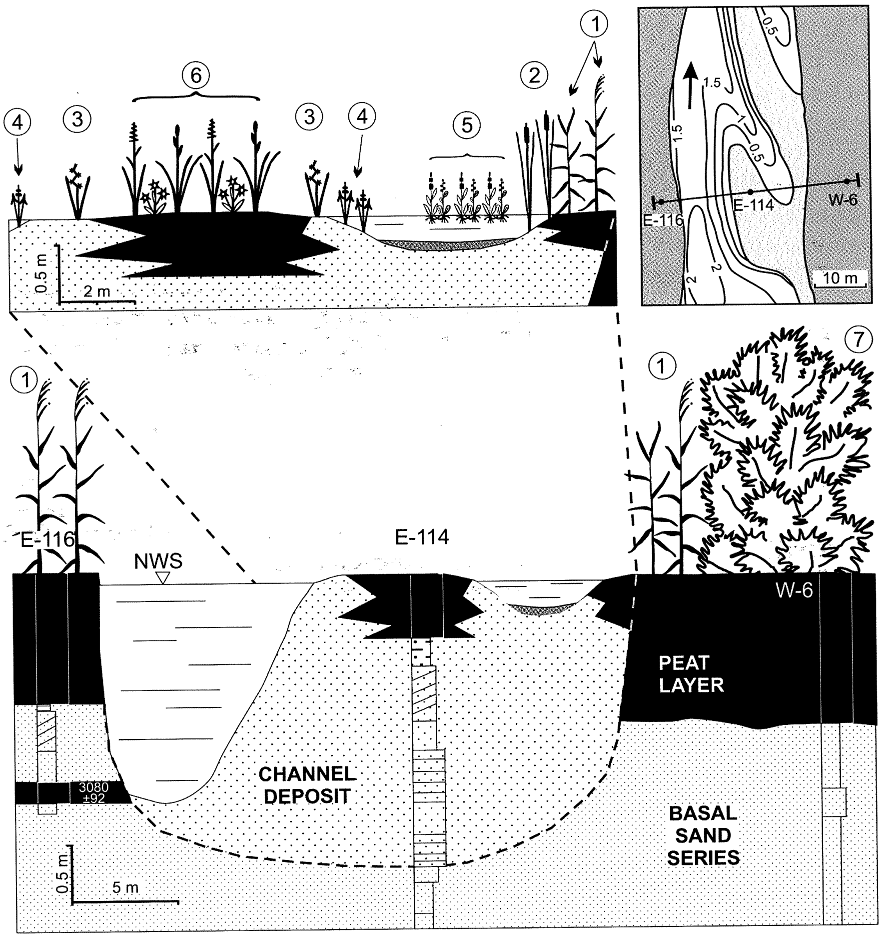


Fig. 25. Cross-section through the lower reach of channel A and vegetated linguoid bar within it; for location see Fig. 23. Vegetation marked schematically, not to scale. (1) Common reed (*Phragmites australis*); (2) Lesser reed mace (*Typha angustifolia*); (3) Bur reed (*Sparganium erectum*); (4) Arrowhead (*Sagittaria sagittifolia*); (5) Marsh woundwort (*Stachys palustris*) and great yellow crest (*Rorippa amphibia*); (6) Grasses (Graminae), sedge (*Carex* sp.), bur marigold (*Bidens* sp.), etc.; (7) Common sallow (*Salix cinerea*)

proves that some of the large forms existed in a similar form as today already in 1966 or 1980. On the other hand, our observations during successive field seasons indicate that some, relatively small, forms are growing at a fast rate. Mid-channel bars occur most commonly in wide channels, usually in their straight reaches. They often grow downstream from a place where two channels coalesce at a sharp angle.

INTERPRETATION AND DISCUSSION

The data collected by us indicate that the presence of sand-bars may be considered one of characteristic features of the anastomosing channels of the Narew River. In NAS, sand dominates in the material forming all types of bars; this

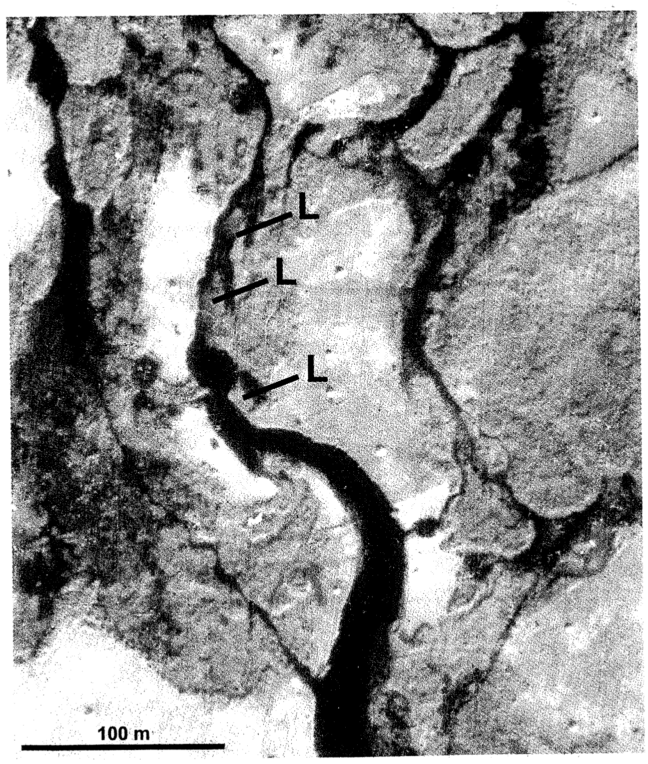


Fig. 26. Air photograph of the Zielona Budka area from 1966 (cf. Figs 22 and 23). Linguoid bars (L) are visible in channel A. Black reflex comes only from plant-free water surfaces. Photograph taken at a low water stage

is due to the fact that the Narew, though transporting only limited amount of sand, is a distinctly sandy-bedload river and is almost devoid of suspended clastic fines. At the same time the Narew River is a distinctly low-energy river. So, sand is transported and deposited mainly during floods. Main channels are the master routes of sand transport in the system. This fact explains why the development of bars is limited almost exclusively to active main channels.

Vegetation plays a major role in deposition within the all observed bars. Its presence markedly increases boundary roughness and reduces flow velocity. The common colonisation of active channel bottoms shallower than 2 m slows down the current and facilitates accretion of mineral sediments, thus initiating a feedback mechanism which leads to local shallowing and waning-flow conditions (cf. McCarthy *et al.*, 1992). Rapid colonisation of the bars by plants prevents easy erosion of the sediment already laid down (cf. Smith, 1976; Hickin, 1984; Harwood & Brown, 1993; Wende & Nanson, 1998); the low stream power reinforces this protective action of plants.

The factors mentioned above are responsible for the general long-term preservation potential of the bar sediments. As the Narew channels are laterally stable (see Gradziński *et al.*, 2003), the development of bars leads to gradual narrowing of the active channels. This process may contribute to the low values of the width/depth ratio of these channels.

The slowing down of stream flow by plants, common in the shallower parts of the active channels, may be considered the main cause of the occurrence of heterolith facies in the higher horizons of many bars. We interpret those heteroliths as sequences genetically related to flood cycles. The beds of relatively clean sand represent sediments of one or a few floods that occurred within a short span of time. The beds of organic-rich muddy sand are formed during the long periods between the floods. Similar heterogeneous sequences, though differing in details, are known from bars of some rivers; examples are given by, e.g. Taylor and Woodyer (1978), Page and Nanson (1982), Nanson and Page (1983), and Wende and Nanson (1998).

The bars grow by joint action of vertical and lateral accretion. Vertical accretion dominates especially in the upper parts of the bars; this is shown by subhorizontal bedding in the heterolith sediments and the occurrence of climbing ripples, both of which are common. Participation of lateral accretion in the growth of the lower parts of some forms is suggested by the elongated downstream shape of many bars and their continuation in the form of submerged ridges (Figs 19B and 25), and by the presence of large-scale cross-stratification in their sediments, usually with low and moderate angle of laminae inclination. No typical downstream-orien- ted avalanche (foreset) fronts have been found in the submerged parts of the bars. The important role of vertical accretion and the lack of foreset fronts in the bars are well explained by the low-energy nature of deposition in the channels. The joint occurrence of channel sediments of vertical and lateral accretion in the anastomosing rivers was described by Makaske (1998) as one of the characteristic features of the anastomosing fluvial systems. The observations from the Narew channels seem to corroborate this view.

The fairly common occurrence of climbing-ripple structures in sediments of the upper parts of some bars indicates partial transport of material in suspension and a steep gradient of flow velocity at the site of deposition. Not infrequently, the measurements of these directional structures indicate (e.g. the side bar mentioned above and the plug bar no 1) a flow directed nearly perpendicularly to the main channel, in the direction away from the channel. At some places, also the sets of inclined laminae dip in the same direction (eg. the side bar mentioned above and the plug bar no 1). With respect to the textural characteristics and the mentioned sedimentary features, the sediments of some bars resemble deposits of natural levees and crevasse splays, which are common in many fluvial systems, including anastomosing ones, but are absent in the NAS. It should be added, however, that structures indicating flow downstream along the main channel are also commonly observed. Generally, cosets of climbing-ripples have been seldom reported from fluvial channel facies; bar-top deposits are normally represented by sand packages with small-scale trough cross-lamination (of "normal" linguoid ripples) or horizontally stratified sand (of upper plane beds). Perhaps the relatively high frequency of climbing-ripple structures jest typical of the low-energy sand-bed anastomosing rivers.

The opposite (upstream) direction was observed in bars in only one case. In the terminal downstream part of a point bar situated opposite to the Remiz Island (see Fig. 19B), in a layer of sand at least 60 cm thick, cosets of climbing ripples migrating in the direction opposite to the main flow in the channel are common (Fig. 20). Their formation in this place should be referred to the presence of a vortex resulting from flow separation at this segment of the channel, near the strongly eroded fragment of the concave bank. A similar situation, that is formation of reversed climbing ripples, has been reported by Hiller and Stavrakis (1982) from the upper portions of a point bar in a gentle bend of the sand-bed Great Fish River in Africa, and also, on a much greater scale, by Davies (1966) from the Duncan point bar in the Mississippi River in Louisiana.

In the NAS, the most numerous and greatest are forms of group B, that is mid-channel bars and linguoid bars. They grow relatively slowly, on a decadal scale. It seems, however, that small, initial forms of both types may form in a much shorter time.

Much less common are the A-group bars, which form at the margins of a main channel or in their direct vicinity. It may not be excluded, however, that in fact the bars of these types are more common than they appear to be. The pioneer vegetation growing on the higher parts of bars may be quickly replaced by peat-forming vegetation typical of interchannel areas; in this way the bar tops lose their individuality and become incorporated into interchannel areas.

Among the A-group bars the most numerous seem to be side bars and concave-bank bars. The latter resemble in many respects the forms described as concave-bank benches by Taylor & Woodyer (1978), Page and Nanson (1982), Nanson and Page (1983), Hickin, (1984), Zieliński (1993) and Gibling *et al.* (1998). Generally, they may be considered as low-energy variants of point bars. On the other hand, typical point bars are exceptionally rare.

The relatively rare occurrence of the A-group bars in the whole NAS may be explained by high lateral stability of the channels. The presence of numerous straight reaches and the common lack of erosion of the concave banks at channel bends, related to the presence of the peat layer and the profuse riparian vegetation, hamper the growth of bars of this group. The low-energy character of the river and its relatively low clastic load reinforce this influence.

The conditions of aggradation prevailing in the whole NAS allow to suggest that the sediments of this system have a rather high preservation potential. If preserved in geological record, the NAS would produce a dense network of interconnected ribbon sand bodies built up of channel facies separated laterally by lithologically contrasting, organic-rich, interchannel sediments. When compared to the facies models of other anastomosing rivers (cf., e.g. Smith & Smith, 1980: Nadon, 1994; Makaske, 2001), the latter would correspond to the overbank facies, represented mainly by clastic fines, while the NAS would lack levee and crevasse-splay deposits (Gradziński *et al.*, 2003).

Some similarities in the sediment architecture exist between the sediments of the NAS and the St. Mary River Formation, interpreted by Nadon (1994) as anastomosing river sediments. The studies of this formation and a critical review of earlier literature were the base of the facies model presented by him. Large sandstone lenses, which are deposits of the main fluvial channel, include characteristic wings, considered by this author as "composed of varying proportions of levee deposits and channel sandstones"; he also postulates that "reworking of levee deposits by channel flows may be a function of the limited root networks present in pre-Tertiary ecosystems" (Nadon, 1994, p. 455). However, the upper surfaces of the large sandstone lenses and the adjoining wings are always flat (Nadon, 1994, figs 8 and 13), which seems to contradict such interpretation. In our opinion, the wings in the St. Mary Formation may correspond to the bar sediments described in this paper.

CONCLUSIONS

(1) Presence of sand bars is one of the characteristic features of the channels in the anastomosing system of the upper Narew River, even though these forms are not common there.

(2) Individual bars differ in shape and in position within channels. The following types of bars have been distinguished: side bars, concave-bank bars, plug bars, point bars, linguoid bars, and mid-channel bars.

(3) Mid-channel bars and linguoid bars are the most frequent types and they attain the largest dimensions. Point bars are observed only exceptionally, while bars of the other three types are rare and usually small.

(4) The bars usually occur in main channels, which are the main routes of clastic transport in the whole system.

(5) All bars are rapidly colonised by plants and stabilised in that way. They have a high preservation potential and their development results in gradual narrowing of the channels.

(6) The bar growth proceeds by combined action of vertical and lateral accretion, with the prevailing role of the former.

(7) The time of formation of the greatest bars is estimated at tens of years, most smaller bars form in shorter time.

(8) The upper parts of the bars are built of fine-grained sand, often also of alternating layers of sand and organic-rich muddy sand. A thin layer of sandy peat is often found in the highest parts of the linguoid and mid-channel bars.

(9) The sand-bar deposits when preserved in fossil record, may have a form of wings in ribbon sand bodies representing deposits of anastomosing channels.

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REFERENCES

Allen, J. R. L., 1973. A classification of climbing-ripple cross-lamination. *Journal of the Geological Society*, 129: 537–541.

Bałuk, A., 1973. *Mapa Geologiczna Polski 1:200,000, Arkusz Łomża.* (In Polish). Wydawnictwa Geologiczne, Warszawa.

Banaszuk, H., 1996. *Palaeogeography, Natural and Anthropogenic Transformations of the Upper Narew River Valley.* (In Polish, English summary). Wydawnictwo Ekonomia i Środowisko, Białystok, 213 pp.

Chudzikiewicz, L., Doktor, M., Gradziński, R., Haczewski, G., Leszczyński, S., Łaptaś, A., Pawełczyk, J., Porębski, S., Rachocki, A. & Turnau, E., 1979. Sedimentation of modern sandy delta in Lake Płociczno (West Pomerania). (In Polish, English summary). *Studia Geologica Polonica*, 62: 1–61.

Churski, T., 1973. Outline of geomorphology of swampy sector of the upper Narew valley. (In Polish, English summary). *Zeszyty Problemowe Postępów Nauk Rolniczych*, 134: 11–30.

Davies, D. K., 1966, Sedimentary structures and subfacies of a Mississippi River point bar. *Journal of Geology*, 74: 234–239.

Falkowski, E., 1970. History and prognosis for the development of bed configurations of selected sections of Polish lowland rivers. (In Polish, English summary). *Biuletyn Geologiczny Uniwersytetu Warszawskiego*, 12: 5–121.

Gibling, M. R., Nanson, G. C. & Maroulis, J. C., 1998. Anastomosing river sedimentation in the Channel Country of central Australia. *Sedimentology*, 45: 595–619.

Gradziński, R., Baryła, J., Danowski, W., Doktor, M., Gmur, D., Gradziński, M., Kędzior, A., Paszkowski, M., Soja, R., Zie-

liński, T. & Żurek, S., 2000. Anastomosing system of the upper Narew River, NE Poland. *Annales Societatis Geologorum Poloniae*, 70: 219–229.
Gradziński, R., Baryła, J., Doktor, M., Gmur, D., Gradziński, M., Kędzior, A., Paszkowski, M., Soja, R., Zieliński, T. & Żurek, S., 2003. Vegetation-controlled modern anastomosing system of the Upper Narew River (NE Poland) and its sediments. *Sedimentary Geology*, 157: 253–276.
Gradziński, R., Doktor, M. & Zaitz, E., 1998. Archaeological finds from the Nerew River channel between Kurowo and Kruszewo (boundary area of the Białystok and Łomża provinces). (In Polish, English summary). *Materiały Archeologiczne*, 31: 157–160.
Harwood, K. & Brown, A. G., 1993. Fluvial processes in a forested anastomosing river: flood partitioning and changing flow patterns. *Earth Surface Processes and Landforms*, 18: 741–748.
Hickin, E. J., 1984. Vegetation and river channel dynamics. *Canadian Geographer*, 28: 11–126.
Hiller, N. & Stavrakis, N., 1982. Reversed currents over a point bar on the Great Fish River. *Transactions of Geological Society of South Africa*, 85: 215–219.
Jopling, V. & Walker, R. G., 1968. Morphology and origin of ripple-drift cross-lamination. *Journal of Sedimentary Petrology*, 38: 971–984.
Knighton, D. & Nanson, G. C., 1993. Anastomosis and the continuum of channel pattern. *Earth Surface Processes and Landforms*, 18: 613–625.
Lindner, L. & Astapowa, S. D., 2000. The age and geological setting of Pleistocene glacigenic beds around the border between Poland and Belarus. *Geological Quarterly*, 44: 187–197.
Makaske, B., 1998. Anastomosing rivers – forms, processes and sediments. *Nederlandse Geografische Studies*, 249: 1–287.
Makaske, B., 2001. Anastomosing rivers: a review of their classification, origin and sedimentary products. *Earth-Science Reviews*, 53: 149–196.
Makaske, B., Smith, D. G. & Berendsen, H. J. A., 2002, Avulsions, channel and floodplain sedimentation rates of the anastomosing upper Columbia River, British Columbia, Canada. *Sedimentology*, 49: 1040–1071.
Miall, A.D., 1996. *The Geology of Fluvial Deposits*. Springer, Berlin, 582 pp.
Morozova, G. S. & Smith, N. D., 1999. Holocene avulsion history of the lower Saskatchewan fluvial system, Cumberland Marshes, Saskatchewan-Manitoba, Canada. In: Smith, N.D. & Rogers, J. (eds.), *Fluvial sedimentology VI. International Association of Sedimentologists, Special Publication*, 28: 231–249.
Morozova, G. S. & Smith, N. D., 2000. Holocene avulsion styles and sedimentation patterns of the Saskatchewan River, Cumberland Marshes, Canada. *Sedimentary Geology*, 130: 81–105.
Nadon, G. C., 1994. The genesis and recognition of anastomosed fluvial deposits: data from the St. Mary River Formation, Southwestern Alberta, Canada. *Journal of Sedimentary Research*, B64: 451–463.
Nanson, G. C. & Knighton A. D., 1996. Anabranching rivers: their cause, character and classification. *Earth Surface Processes and Landforms*, 21: 217–239.
Nanson, G. C. & Page, K., 1983. Lateral accretion of fine-grained concave benches on meandering rivers. In: Collinson, J.D., Lewin, J. (eds.), *Modern and Ancient Fluvial Systems. International Association of Sedimentologists, Special Publication*, 6: 133–143.
Okruszko, H. & Oświt, J., 1973. Natural characteristics of the swampy upper valley as a basis for its reclamation. (In Polish, English summary). *Zeszyty Problemowe Postępów Nauk Rolniczych*, 134: 31–99.
Page, K. J. & Nanson, G. C., 1982. Concave-bank benches and associated floodplain formation. *Earth Surface Processes and Landforms*, 7: 529–543.
Pérez-Arculea, M. & Smith, N. D., 1999. Depositional patterns following the 1870s avulsion of the Saskatchewan River (Cumberland Marshes, Saskatchewan, Canada). *Journal of Sedimentary Research*, 69: 62–73.
Schumann, R. R., 1989. Morphology of Red Creek, Wyoming, an arid-region anastomosing channel system. *Earth Surface Processes and Landforms*, 14: 277–288.
Schumm, S. A., Erskine, W. D. & Tilleard, J. W., 1996. Morphology, hydrology, and evolution of the anastomosing Ovens and King Rivers, Victoria, Australia. *Geological Society of America Bulletin*, 108: 1212–1224.
Smith, D. G., 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. *Geological Society of America Bulletin*, 87: 857–860.
Smith, D. G., 1983. Anastomosed fluvial deposits: modern examples from Western Canada. In: Collinson, J. D. & Lewin, J. (eds.), *Modern and ancient fluvial systems. International Association of Sedimentologists, Special Publication*, 6: 155–168.
Smith, D. G., 1986. Anastomosing river deposits, sedimentation rates and basin subsidence, Magdalena River, northwestern Columbia, South America. *Sedimentary Geology*, 46: 177–196.
Smith, D. G. & Smith, N. D., 1980. Sedimentation in anastomosed river systems: examples from alluvial valleys near Banff, Alberta. *Journal of Sedimentary Petrology*, 50: 157–164.
Smith, N. D., Cross, T. A., Dufficy, J. & Clough, S. R., 1989. Anatomy of avulsion. *Sedimentology*, 36: 1–23.
Stanistreet, I. G., Cairncross, B. & McCarthy, T. S., 1993. Low sinuosity and meandering bedload rivers of the Okavango Fan: channel confinement by vegetated levées without fine sediment. *Sedimentary Geology*, 85: 135–156.
Taylor, G. & Woodyer, K. D., 1978. In: Miall, A.D. (ed.), *Fluvial Sedimentology. Canadian Society of Petroleum Geologists, Memoir*, 5: 257–275.
Wende, R. & Nanson, G. C., 1998. Anabranching rivers: ridge-form alluvial channels in tropical northern Australia. *Geomorphology*, 23: 205–224.
Zieliński, T., 1993. Bed morphology and sediments of the present-day Biała Przemsza alluvial channel (S Poland). *Geologia*, 12–13: 199–233.

Streszczenie

AKRECYJNE MAKROFORMY W KORYTACH ANASTOMOZUJĄCEGO SYSTEMU GÓRNEJ NARWI

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Anastomozujące koryta Narwi cechuje wyraźna dominacja piaszczystego obciążenia dennego. W korytach stwierdzono obecność kilku typów akrecyjnych makroform typu piaszczystych łach: łachy boczne, łachy przy wklęsłych brzegach zakoli, łachy zamykające opuszczone koryta, łachy meandrowe, łachy językowe i łachy śródkorytowe. Trzy pierwsze typy są stosunkowo rzadkie, łachy meandrowe są zjawiskiem wyjątkowym, natomiast łachy dwóch ostatnich typów są dość pospolite. Łachy rozwinięte są z reguły w większych korytach, będących głównymi drogami transportu piasku w całym systemie anastomozującym. Dolne części łach zbudowane są z grubo i średnioziarnistego piasku, analogiczne jak osady głębszych partii koryt. W górnych częściach dominuje piasek drobnoziarnisty, niekiedy przeławicony mułowym piaskiem, bogatym w materiał organiczny; w najwyższych częściach nietórych łach występuje silnie piaszczysty torf.

Wszystkie łachy są bardzo szybko kolonizowane przez roślinność. Dzięki temu oraz dzięki niskiej energetyczności rzeki, ich osady mają duże szanse do trwałego zachowania się. Rozwój łach z reguły nie jest związany z lateralną migracją koryt. Tak więc akrecja osadów łach jest jednym z czynników powodujących stopniowe zawężanie się koryt. Zachowane w stanie kopalnym osady wielu łach zapewne mogą przedstawiać się jako charakterystyczne „skrzydła" w zewnętrznych częściach wydłużonych ciał piaszczystych, reprezentujących osady anastomozujących koryt.