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Above-water accumulative forms within the shore zone of the reservoir showing significant seasonal water level fluctuations based on the Pakoski reservoir[1]

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Abstract: The Pakoski reservoir was created in 1975 as a result of damming the lakes located within the Western Valley of the Noteć River. This reservoir operates in yearly cycles with water level fluctuations of up to 3.6 m. The researches carried off by the author in the years 1998–2003 indicate that the thirty-year exploitation period has not ended the intense reshaping phase of the shore zone of the reservoir. Both intensive shore abrasion and various accumulative forms support the above statement. These forms include the small ones of distinctively initial character, such as accumulative spurs or berms, as well as the complex ones whose shaping process has almost finished and the area of which exceeds a few hundred square metres. Due to constant lowering of the water level, accumulative forms occur within the entire width of the shore-platform which is being dried. In most cases these are whole groups of smaller forms related to one another. A beach can constitute a good example, as it predominantly combines a few, most often 5 to 6, adjoining beach ridges separated with small lagoons.

Key words: artificial water reservoir, water level fluctuations, accumulation, accumulative form, morphogenetic classification of forms

Introduction

Creating an artificial water reservoir, either due to damming of the already existing water region or flooding a part of a river valley, leads to transformation or formation of it's shore zone. The signs of the development are abrasive and accumulative processes within the shore zone. The process of accumulation of deposits results from the decrease of the energy of the currents transporting them. This leads to their deposition along the selected shore sections and a build-up of the shore-platform. Initially, the effects of the above process are horizontal as the existing shallow waters widen towards the water region. Later, the upward build-up also occurs, which results in creating accumulative forms. Intensity of these processes depends on many factors, including the geological structure and the relief of the reservoir's surroundings, the existing deposits and the primary angle of the flooded slopes, as well as the hydrodynamic conditions of the reservoir, such as the size of the water level oscillations, the rate of the reservoir's damming, and the existence and the duration of the periods of water stagnancy at a given level (Banach, 1992, 1994; Ovčinnikov et al., 2002). The shore zone of the water regions showing insignificant water level oscillations, after the initial period of intensive development, stabilises reaching the state of relative maturity (Finarov, 1986; Spanila & Simeonova, 1993). When the stage of transverse transport of the deposits ends, followed by the ending of the transport along the shore, accumulative forms appear within the shore zone. Initially, these are very simple open forms accompanying the shoreline, followed by more complex ones, separating the individual bays from the main water region. This process leads to levelling of the shoreline (Lopuch, 2002; Širokov , Lopuch & Levkevič, 1992). Taking into consideration the reservoirs showing significant water level fluctuations, the issue is more complex and the above pattern is of no use (Ovčinnikov, 1996, Ovčinnikov et al., 2002).

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Morphometry of the Pakoski reservoir and the characteristics of its immediate surroundings

The Pakoski reservoir is the water region which operates in yearly cycles. It was created on the Western Noteć River in 1975 as a result of 4.5-metre damming of the waters of two lakes: bipartite Lake Pakoskie, i.e. Lake Northern (2.85 s km) and Lake Southern (4.65 s km), as well as Lake Bronisławskie (0.4 s km) located 2 kilometres to the south. The reservoir shows distinctly elongated character. It is located within the meridional subglacial channel, which separates two uplands: the Kuiavian one (90 - 93 m a. s. l.) and the Gnieźnieńska one (110 - 120 m a. s. l.) (Gnieźnieńskie Lakeland, Kondracki, 1994). The depth of the upland dissection in relation to the bottom of the channel ranges from 20 to 50 m, and at some places the very form is filled with 5- to 10-metre thickness of the lake deposits: gyttja and peat. The channel slopes are asymmetrical. The western ones are higher and gentler, and reach the width of about 750 m, while the eastern ones are narrower (about 250 m) and often in the form of a steep few-metre cliff. The slopes of the reservoir are mainly built of boulder clays, in places covered with or interbedded by sands or loamy sands. In the southern part of the reservoir, in its immediate surroundings, peat occurs. The damming process resulted in flooding of not only the terraces and channel slopes accompanying the lake basins, but also the floodplain of the Noteć River between the lakes and up the 2.5-kilomerte section above the lakes (Fig. 1). The area of the water region increased from 8.1 s km to 13.02 s km, i.e. over 60%-increase, while its capacity grew from 40.60 million c m to 86.46 million c m, i.e. over 110%-increase. The other parameters include: the length - 20.1 km, the mean width - 0.74 km, and the mean depth - 9.2 m. The reservoir is divided into four parts by artificial causeways used as roads or railway lines, which existed long before the lake damming. Starting from the north, the system includes the following lakes of free water exchange: Lake Northern Pakoskie, Lake Southern Pakoskie, Lake Bronisławskie and Lake Kunowskie.

The original water level of Lakes Pakoskie just before their damming was about 75 m a. s. l., and had occurred at that altitude since the mid-19th century. Throughout its entire history, however, the above level, as well as the range of the shore zone, had been changing (Niewiarowski 1976). The water level of the lake existing within the channel about 10.5 thousand years ago had changed from 75 to 80, or even 81, metres a. s. l. W. Niewiarowski (1976) distinguished three periods of higher water level during the lake existence. The first one was the end of the sub-boreal period (about 4 ka BP) when the water level was 76 m a. s. l.; the second one was the turn of the 1st c. BC and the 1st c. AD when the water level was 79-80, or even 81, m a. s. l.; the third one followed the period of low water level in the Middle Ages and lasted from the end of the 11th c. to the late 19th c. with the water at the level of 77.5-78.0 m a. s. l. The digging of the Noteć Canal in 1774, as well as carrying out melioration works within Kuiavian Upland in the mid-19th c, resulted in lowering of the water level in the lakes of the region. Water level oscillations in the lake before its damming ranged from 0.5 to 0.6 m. Thus, the lake water level before creating the Pakoski reservoir stemmed from the very intensive anthropopression over the area, and, in fact, cannot be accepted as the natural one.

Water management at the Pakoski reservoir

Both character and intensity of the processes reshaping the shore zone of the reservoir are directly influenced not only by its parameters but, predominantly, by the way the water economy is run at the reservoir.

The functions performed by the Pakoski reservoir are, most of all, retention and flood control. It is filled up during the winter-spring season. Snowmelt water is stored there in order to protect the Noteć valley down the reservoir against flooding. The stored water is used for industrial aims and, during the summer-autumn season, for field irrigation and for compensation of

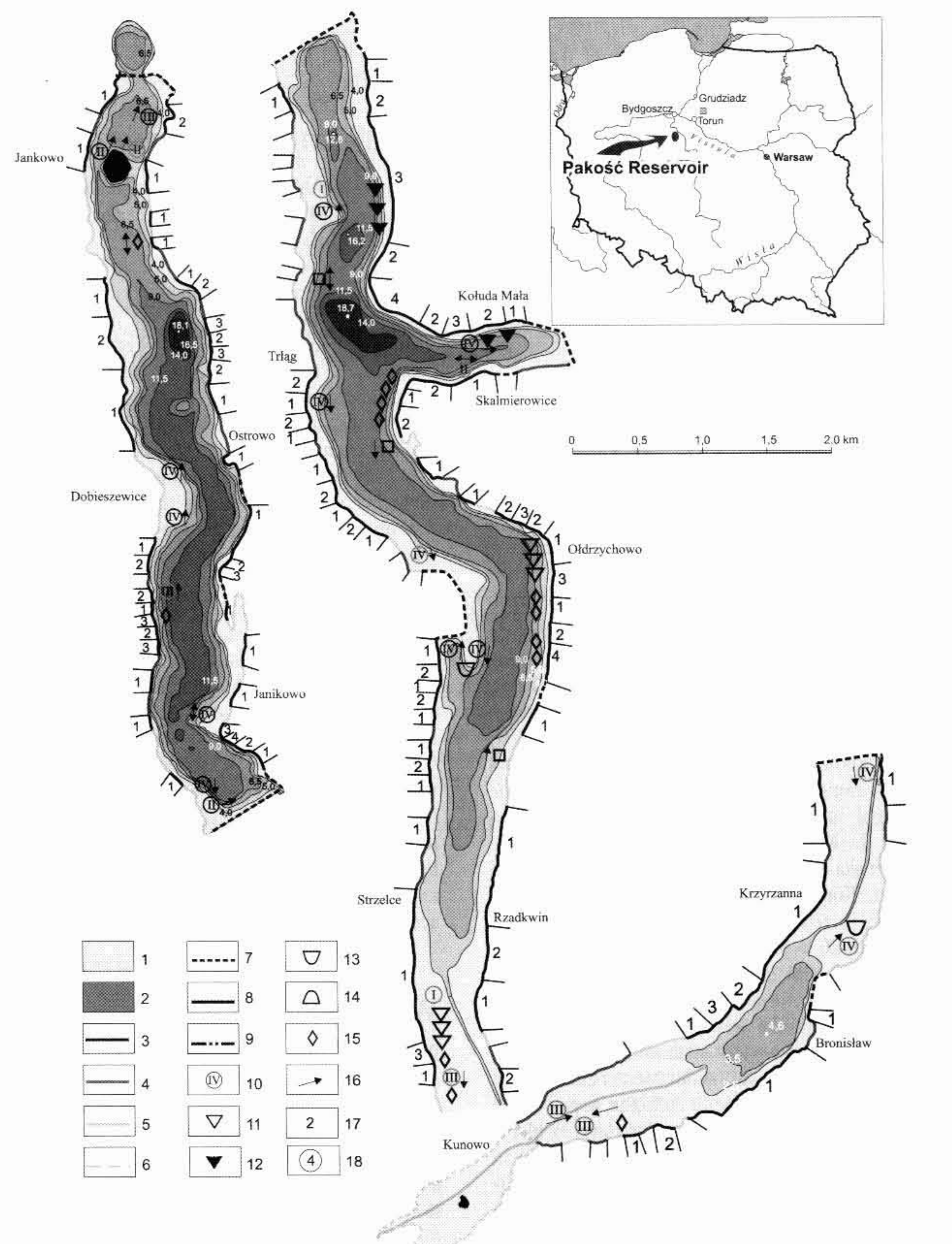

Fig. 1. Classification of the Pakość Reservoir shores – with colors
1-reservoir area at maximum water level, 2-lake area before water rise; shore: 3- abrasive, 4- neutral, 5- accumulative, 6- bioorganic, 7- artificial; 8- road, 9- railway; accumulative forms: 10- spit, Roman numerals inside signature denote form's size: I- 0-5 m, II- 5-10 m, III- 10-15 m, IV- >15 m, red colour- stabilize form, black colour- seasonal form, 11- natural spur, 12- constrain spur, 13- lateral sand bar, 14- bay mouth bar, 15- swash bar, 16- direction of form increase, 17- height of active cliffs: 1- 0-0,5 m, 2- 0,5-1,0 m, 3- 1,0-1,5 m, 4- >1,5 m, 18- cross section by coastal platform monitored in years 1999-2003

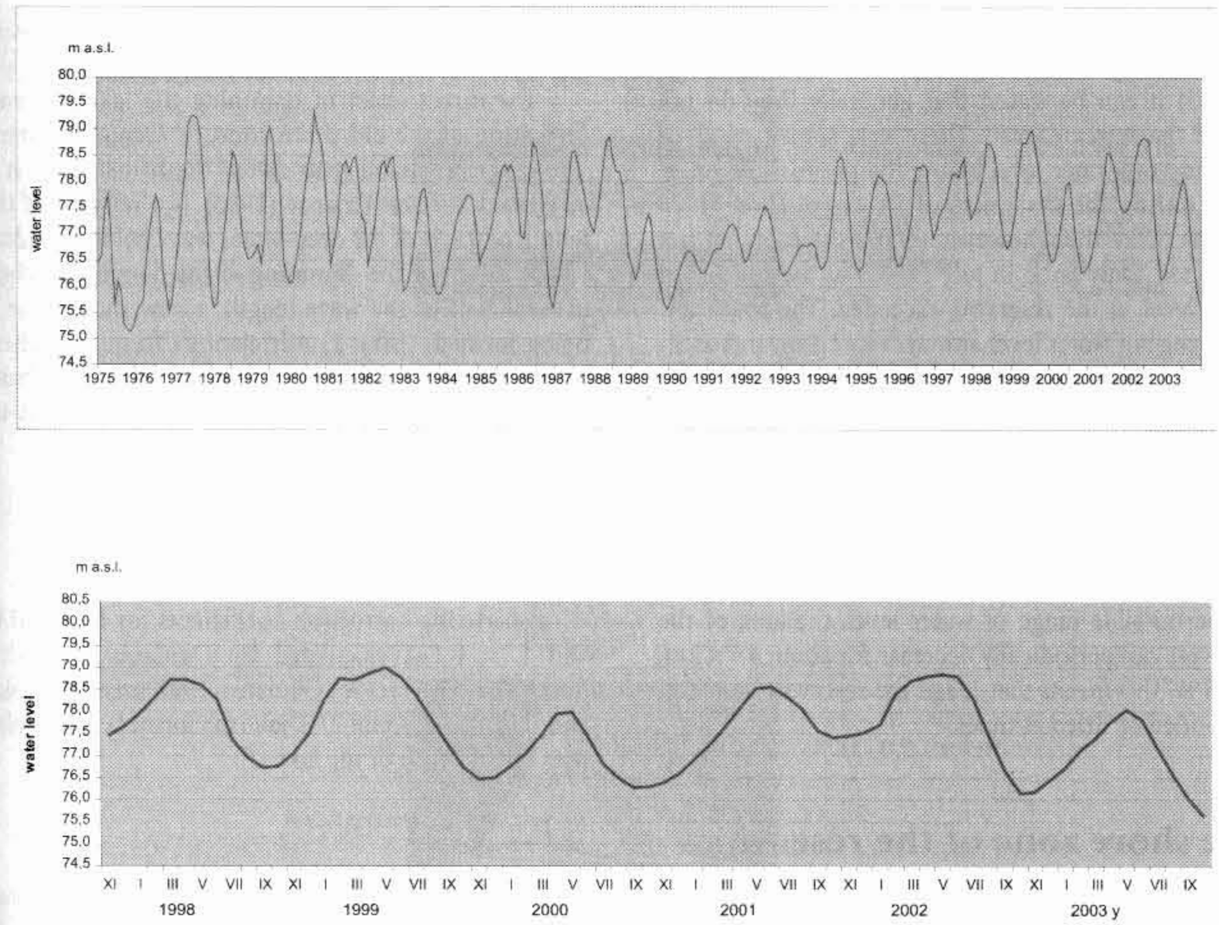

Fig. 2. Water levels in 1975-2003 (up) and average month's water levels in the Pakość Reservoir in years 1998-2003

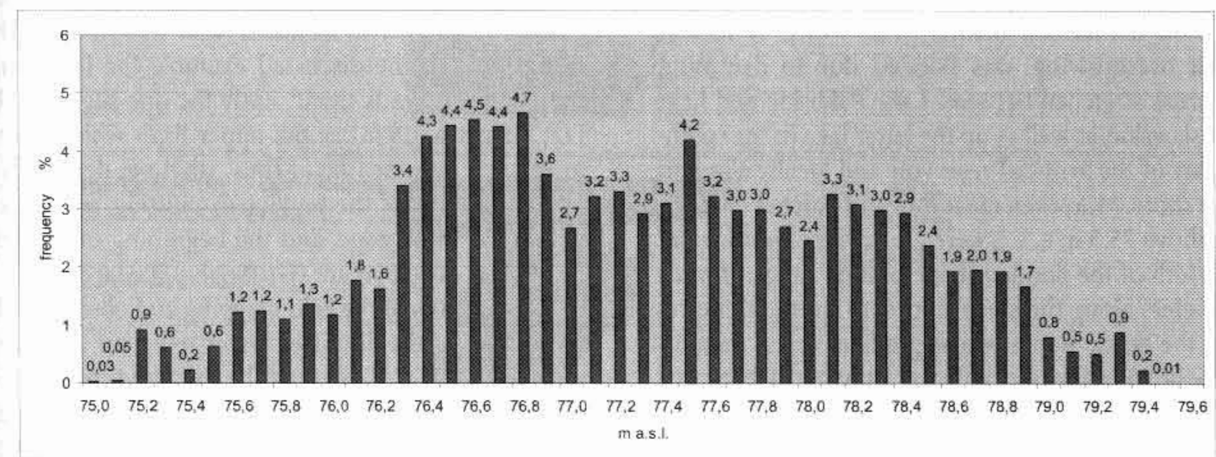

Fig. 3. Histogram of daily water levels of the Pakość Reservoir in 1975-2003 years

low-water states of the Noteć River down the reservoir. Due to low water quality, this water area is hardly used for recreational purposes. The functions fulfilled by the reservoir, as well as the fact that almost half of the stored water (48%) constitutes utilitarian capacity, are the reasons of considerable water level oscillations (Fig. 2). In accordance with the reservoir exploitation rules, water level can fluctuate from 79.4 a 75.5 m a. s. l., i.e. within the 3.9-m range. The reservoir operating cycles lack periods of keeping water at a certain level for long. Both during lifting and lowering phases, water level changes at constant pace of about 1-3 cm a day.

Basing on the analysis of water levels in the reservoir throughout its entire exploitation period (1975 - 2003) it can be stated that generally they do not exceed the extreme levels. There were some periods of lowering the water level below the permissible minimum during the first years of its exploitation (1975 - 1980). Since then, however, such a situation has not happened. Only once, in July 1980, was the maximum water level in the reservoir exceeded. The mean annual range of water level amounts to 2.4 m, and oscillates between 0.65 m (1993) and 3.59 m (1980). The daily water levels, recorded at the reservoir since its opening, when classified into 10-cm intervals, show clearly a higher rate of medium levels of 76.4 – 76.9 m a. s. l. They make up for almost 24 % of all water levels (Fig. 3). Thus, these levels are the most influential for the shore zone being reshaped. At the maximum of the permissible range of water level, the area of the reservoir can periodically decrease for about 4.7 s. km, i.e. 36 %. This means that 1/3 of the reservoir bowl can be flooded or dried at times.

The shore zone of the reservoir

The term "shore zone" defines the area spreading from the edge of the above-water cliff or the accumulative form limiting the range of waves (a ridge), to the foot of the slope of the shore-platform. As it has been mentioned before, peat, which is reliable to fast overgrowing, was flooded due to damming. Peat areas stretched between Lake Pakoskie and Lake Bronisławskie, as well as up the latter lake in the southern part of the artificial reservoir and locally along its entire shore. Moreover, meadows and patches of farmland above 75.5 m a. s. l. were also covered with water. The width of the flooded stripe of land ranged from a few meters along the steep slopes, to over 100 metres along the gentle slopes whose gradient is less than 6°-7°. The bowl of the reservoir was only partly prepared for flooding. What is left are the trunks of the cut-down trees. Now they block the open water area, and are an important factor influencing character and intensity of the processes taking place within the zone. They are conducive to creating accumulative forms directly above them. While the reservoir was being formed, about 90 thousand trees, mainly willows, alders and limes, were planted in its immediate vicinity. Presently, they are 5 – 6 m high. They are accompanied by 1.5 - 2-metre self-sown bushes. At higher water levels this zone is flooded up to over 1 metre. Together with the under-water tree-trunks they protect the shores both thanks to their root system and due to lowering wave energy at the flooded trees and bushes.

The direct effect of damming the lake is transformation of the old shore zone, or creating it anew. The criterion enabling to define the situation, as it is suggested by D.P. Finarov (1986), is a relation of the length of 0.1 % of the deep-water wave before flooding to the height of the damming. If the damming height exceeds half of the wave length, a new shore zone is being formed. Using 1) Adriejanov's formulas, where height (H) and wave length are calculated on the basis of the wind velocity in m/s (V) and the wave run-up in km (D):

$$H = 0.0208\, V^{4/5} D^{1/3};$$
$$L = 0.304 V D^{1/2},$$

considering correction coefficients for H = 0.0112 and L = 0.132 calculated by Okulanis for Lakes Raduńsko–Ostrzyckie (Okulanis, 1981) of similar size and morphology, and 2) Djakova's formula which also uses mean depth of the lake (F):

$$H = 0.0186\, V^{0.71} D^{0.24} F^{0.54},$$

it can be concluded that at maximum recorded values of the considered parameters, i.e. the wind velocity of 15 m/s, the distance of the wave run-up of 5.5 km, and the mean water area depth before damming at 5.6 m, the waves were 0.5 m high (the average value calculated from the two formulas) and 4.64 m long. This means that in the discussed example the lake damming value exceeds significantly the one suggested by D.P. Finarova (1986) as the upper limit which allows to call it a dammed lake. Thus, what we deal with is a total flooding of the previously existing, completely developed shore zone, and the beginning of the new cycle of its development (Grobelska, 2002a; 2002b).

On the basis of the field mapping and observing the shore zone of the discussed water reservoir at various water levels, as well as using the existing typologies of the shores of artificial reservoirs (Banach, 1994), it can be concluded that after nearly 30-year-long exploitation period of this reservoir its shore zone proves to be still very active. As much as 80.7 % of the non-strengthened shores show abrasive (60.6 %) or accumulative character. The abrasive shores are often accompanied by cliffs of various height. They are cut out in loamy and sandy clays, and can reach from a few centimetres to over 5 meters (Grobelska, 2000; 2002b). The cliff sections are alternated with the accumulative shores, where the abraded and transported material is accumulated in the form of various accumulative forms.

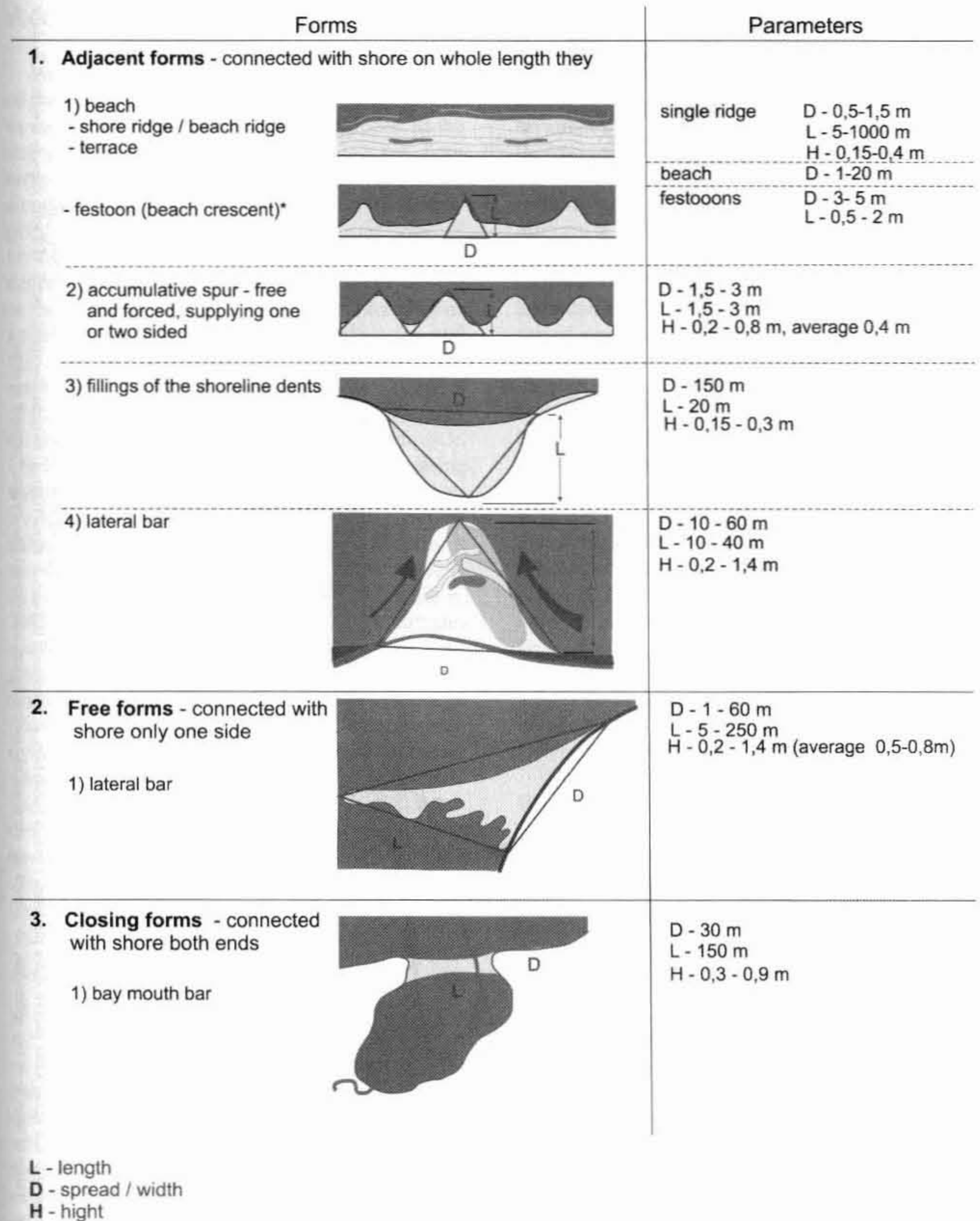

Fig. 4 Accumulative forms on the Pakość Reservoir

distance from one another. Thus, the beach there lacks its homogenous uninterrupted character.

The observed beach ridges most often reached the width of 0.5-1.5 m, and the height of 0.15-0.4 m. The depth of the accumulated deposits amounts to 0.10-0.6 m. The slope gradient of the ridge varies, and depends on granulometry of the material and hydrometeorological situation in the reservoir while the ridges were being formed. The more coarse-grained the deposits the proximal slope gradient higher (Gradziński et al., 1986). The waving works differently. According to L. Kurowski (2002b), who investigated transformation of the beach at the Baltic seacoast, with the increase of the waving the gradient of the proximal slope lowers. Moreover, during the periods of reshaping the reservoir due to constant lowering of the water level, the ridges along the shallow-water shores have a weakly developed step marking out the range of the outer beach. The situation differs along the deep-water shores, which most often show abrasive character. The beach there is not, in most cases, fully formed, and has only the proximal slope developed. It is not built of a ridge, or ridges, but of a nearly horizontal terrace (shelf), or terraces, rolling gently towards the reservoir. It ends with a distinct morphological step a few to 30 cm high. In the periods of the water level going up the existing beach is being remodelled, both along the deep-water and the shallow-water shore sections. Moving of the wash zone towards the inner part of the platform, which is activated by intensive waving, results in destroying, or even total annihilation of the existing beach regardless of its form - a classical ridge or a shelf. At the limit of the wave range a distinct step is being formed. It is 0.3-0.4 m high and is often accompanied by an erosive recess (Kurowski, 2002b). The height of this step is often limited by the maximum depth of the deposits accumulated on the platform. At the distal slope of the beach small, elongated lowerings called "swales" (Otvos, 2000) occur. They are often beach lagoons filled in with water, and are 5-50 meters long and 5-10 meters wide. If they are supplied with the ground water they show seasonal character and exist until the consecutive water level rise above the altitude of the surrounding shore ridge, which leads to their annihilation. However, if the lagoon does not have any extra water supply besides the water which got there during the creation process, the water area exists for only a dozen days or so (Photo 2). As a result it becomes a wet lowering. Within the larger forms of the above type, of a dozen s. m or so, and similarly to the forms observed by L. Kurowski at the Baltic seaside (Kurowski, 2002b), one can observe a small inlet channel, a few cm wide and deep, with a developed delta at its mouth to the lagoon. The size of this form varies and ranges from a dozen cm or so to over 1 s m. Moreover, besides the above inlet channels there are also outflow channels (return channels, Kurowski, 2002b) of similar size, which are not accompanied by any positive forms at their mouths. The bottom of the very lowering is covered with a series of fine-grained deposits, predominantly sandy loams, a few centimetres deep.

Sporadically, along short sections of the shallow-water shore, the ridge which is being created has a characteristic shape of beach crescents (festoons). This is a result of waves running up perpendicularly along the straight sections of the shore (Sirokov, Lopuch & Levkevič, 1992; Lopuch, 2002). At the Pakoski reservoir such forms are not large - their width amounts to 3-5 m, while their length to 2-5 m. They form sequences a few to a few dozen meters long, and are found within the entire width of the uncovered part of the shallow-water (Photo 3).

Besides of the typical mineral shore ridges described above, there are also mineral and organic, or exclusively organic ones within the shore zone of the Pakoski reservoir (Photo 4). These common forms are created along the limit of the wave range, and the material building them is a mixture of mineral deposits and parts of plants, mainly leaves and sticks. Their forming is conduced by overlapping of high water levels, which occur at this reservoir during the winter and spring season, with abundance of dead organic matter floating on the water, and coming from the flooded bushes surrounding the reservoir. These forms get created along the abrasive sections of the shore, above the low cliffs or at the foot of the high ones, as well as along the accumulative sections of the shore. These ridges are prolonged and straight, rarely crescent, and are a few metres long. The ridges form sequences from a few to a few hundred metres. Their width amounts, in most cases, to 0.5 m, while their height - to 0.3 m. Although their durability varies, 1-year life-span predominates which is the period separating the two consecutive high water levels at the reservoir. During growing season these forms are overgrown with vegetation, and that is why they are difficult to recognize in the terrain.

An accumulative spur

The mineral material deposited on the platform surface often takes a form of accumulative spurs. These are seasonal unfixed forms in the shape of a triangle (Fig. 4) with the fixed basis turned towards the land. The sizes of such forms at the Pakoski reservoir are not large. Both their width and length do not exceed 1.5-3 m, while the thickness of the accumulated deposits amounts from 0.2 to 0.8 m and grows distinctively towards the reservoir. Two types of these forms can be distinguished. The first one includes the free forms, which often appear in cycles. They are created along the straight shallow-water sections of the shore. Their occurrence depends on relatively high thickness of the accumulated deposits, i.e. over 0.4-0.6 m, which means the middle and the lower part of the shore-platform patch being uncovered. There are no such forms, however, in the high water level zone, i.e. in the upper part of the shore-platform, which is probably connected with the low thickness of the deposits accumulated there. If these spurs appear cyclically, they form a sequence a few dozen metres long. The second type of accumulative spurs are the forced ones. Their existence is connected with tree logs, present in the shore zone of the reservoir, which come from the trees cut down during the preparation stage before filling in the bowl of the reservoir. These logs are now a kind of a fastener, at the base of which gravel and sandy material is accumulated (Photo 4). Such forms coexist with the ones described before, but they also occur at lower altitudes. Predominantly, these are single, isolated forms. Only sporadically do larger sets of them exist.

Fillings of the shoreline dents

Both shore ridges, with time transformed into beach ridges, and accumulative spurs are characteristic for shallow-water straight shore sections. With the development of the shore zone groups of these forms get also created in the shoreline dents, which leads to straightening of the shoreline. At the Pakoski reservoir such cases are rarely observed. The dents which get filled in are not large - their length amounts to 150 m. They are located along the shallow-water shores, where the slope gradient of the shore-platform does not exceed a few grades. At the present stage of the shore zone development these dents, usually separating abrasive sections of the shore, are filled in only partially. The deposits are accumulated within the upper and middle parts of the uncovered shore-platform, at the altitudes of 76.3 - 76.8 m a. s. l., which corresponds with predominant water levels in the reservoir (Fig. 3). This zone of an insignificant slope gradient of 3–5°, stretches within the expanse of less than 20 m. The deposits accumulated here form a discontinuous layer of diverse thickness and granulometry. These are sandy and gravel deposits 0.15-0.3 m thick within the ridges, and sandy loams only 0.1 m thick within the lowerings separating the ridges. Above as well as below this zone, there are no deposits on the platform surface at all, or they exist only sporadically in the form of discontinuous sandy stripe.

A chute bar

The next adjacent accumulative form observed within the shore zone of the Pakoski reservoir is a chute bar. Similarly to a spur, this form's elevational view reminds a triangle, whose base is fixed to the mother shore. Unlike the spur, however, a chute bar is formed at a concavity of the shoreline, and is often conditioned on the existing elevation of the previous substratum separating the abrasive sections of the shore. These form are built up either one-sidedly or two-sidedly out of the consecutive generations of forms which are being created along with the water level going down, such as ridges, spurs or even accumulative spits (Fig. 4). The mentioned forms' length amounts to 10-60 m, while their width - to 10-40 m. The thickness of the deposits building them increases towards the water area with the descending mother substratum. As a result, the deposits' roof and, thereby, the surface of the form is almost flat with the slope gradient less than 1°. Both granulometry and sorting of the form's deposits varies, and ranges from very well washed gravels and coarse sands to sandy loams. Their thickness increases from 0.2 m at the beginning zone, to 1.4 m in the ending one. Although these forms are not fixed with vegetation and get transformed during the periods of high water levels, their thickness is enough for their recreation during the consecutive operation cycles of the reservoir. Similarly to the forms described before, these ones develop at the altitude from 77.0 to minimum 76.4 m a. s. l.

Free forms – spits

Free forms include the ones which are fixed to the mother shore with only one of their ends (Fig. 4). At the Pakoski reservoir these are numerous various spits: from the common simple ones of a small size and seasonal character, to the very large ones of both seasonal and stable character, partly fixed with vegetation. These forms have distinctively prolonged shape, and occur predominantly along the shallow-water shores. Depending on their character and location,

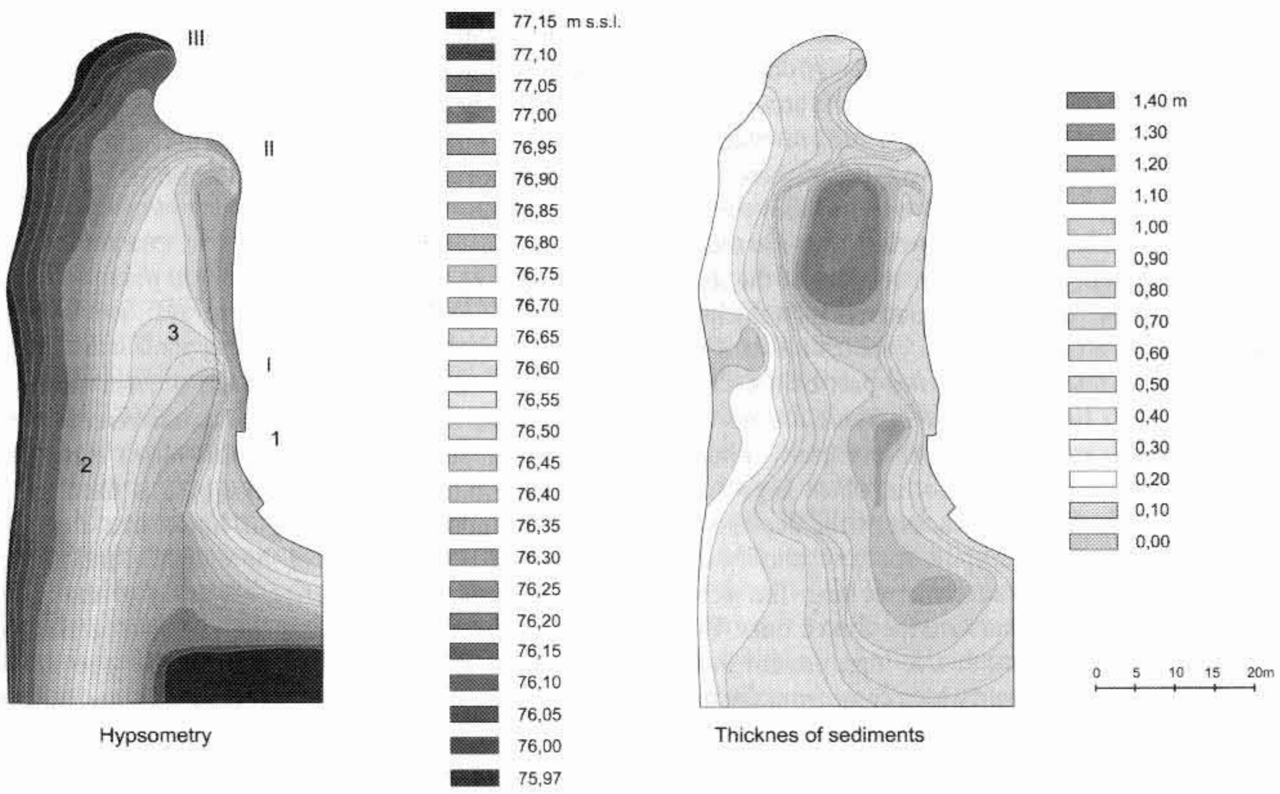

Fig. 6. The spit in Broniewice – hypsometry and thickness of sediments.
Date of measurement – 29.10.2003 y, water in reservoir – 75,97 m a. s. l.

their width amounts to 1-60 m and their length – to 5-250 m. The small forms are created along straight, concave and convex sections of the shore within the entire shore-platform, while the large ones develop only at specific conditions. They are formed as the extension of the straight abrasive section of the shore, whose shoreline changed its direction creating a concavity or a convex (Fig. 4). The largest forms of that type, the spit in Bronisław, developed along the former shore of the totally flooded small Lake Bronisławskie. Being linked to the southern range of the previous lake, this form largely develops perpendicularly to the present reservoir. It builds up the elevation which exists within the old floodplain. Next, it directs along the previous River Noteć valley, the function of which is still the main waterway of this part of the water area. The fundamental parts of the large forms are located at the altitude of the most often water levels, although their development takes place from the lowest observed water levels at the reservoir. Similarly to the forced spurs described above, the retained tree logs are sometimes a kind of a fastener for the emerging spit. Large complex spits are formed of consecutively growing ridges, which get created at the lowering water level in the reservoir due to accumulation of the material transported along the shoreline. The direction of the ridges' growth is connected with the local water circulation within the shore zone. Their deposits, whose thickness amounts to 0.2-1.4 m, is a peculiar layer-cake of the deposits of varied sorting and granulometry. They include pebbles 1-2 cm in diameter, as well as poorly washed sandy loams with few gravels. As these forms are situated at the extension of the shoreline, and not perpendicularly to it, the accumulated deposits very often level the bottom unevenness, and their thickness often decreases towards the end of the form (Fig. 6). Dynamics of the described forms, like their size, also varies and is directly proportional to it. The larger the form the higher its stability, and vice versa. Small forms of a few-metres length have no chances to be preserved during the high water levels. They get annihilated as a result of washing out. If compared with the whole time span of the reservoir functioning, the entire few-year period of time during which the research was carried out had definitely higher rate of high water levels (Fig). Due to that, the small spits did not reappear in the consecutive seasons, and the only possible sign of their past existence were the shore ridges. However, the five large forms of over a few hundred square metres stayed generally untouched at the high water levels. Only their endings, i.e. their arms, got remodelled. Moreover, the cross-section of

these forms reveals distinct asymmetry. The land-facing slope is narrower and steeper, with the gradient of up to 50°, and is diversified with the consecutive arms of the form. The water-facing slope, however, is almost horizontal, with the gradient of up to 5° and the levelled shape (Fig. 6).

Closing forms – a bar

The main feature of the closing forms is the fact that they are fixed to the shore with both their ends. This leads to separating a part of the water area from its main area. Within the shore zone of the Pakoski reservoir there is only one well developed form of that type. It is located on the right, eastern shore of the water area in its middle part. The bar is over 150 m long and 30 m wide, and separates a bay supplied by ground waters. During the periods of medium and low water levels, when the bar gets dry, the lagoon has a constant connection with the water area through a small watercourse. The cross-section of the sand bar reveals that the thickness of its deposits ranges from 0.9 m in the zone adjacent directly to the separated small water area, to less than 0.3 m at the reservoir-facing side. Predominantly, the deposits include well washed gravels and coarse sands with the layers of fine-grained and loamy sands. This bar grows up from south towards north, and only its ending gets remodelled during high water levels. Its main part has already been fixed with bushy vegetation, the expansion of which is effectively limited by high water levels during the most part of the growing season.

Closing forms at shallow artificial water reservoirs of insignificant water level fluctuations emerge after about 25-30 years of their exploitation. According to some researchers, their presence proves that the reservoir's shore zone, stable and mature, is at the last stage of development (Širokov, Lopuch & Levkievič, 1992; Lopuch, 2000). Such an interrelation is not recorded at the reservoirs of considerable water level oscillations, which was pointed out by G. I. Ovčinnikov who based his research on the River Angara Cascade (Ovčinnikov et al., 2002). This dependence probably results from a high mobility level of the outwash and in-wash zone on the shore-platform surface. The above view is also supported by the investigations carried out at the Pakoski reservoir. After nearly 30 years of its exploitation, the character of its shore zone does not prove the shaping processes are fading. Both abrasive and accumulative processes are dynamic here.

Conclusions

In a single cycle of the Pakoski reservoir operating, within its shore zone coexist and develop accumulative forms of various sizes and durability. They include small seasonal accumulative spurs as well as fixed multistage spits of over a few hundred s m. This proves that the shaping process has not finished yet. The above forms are located over the entire dried shore-platform zone, and predominate at the altitude of the most often water levels, i.e. 76.3-76.9 m a. s. l. That level range makes up 26 % of all day-and-night water levels in the reservoir throughout its entire existence. The observed forms have characteristic peculiar features. One of the most important features is their complexity and multistage development. Large forms are mainly built up of the smaller ones. This is a result of constant lowering of the water level, which leads to movement of the outwash and in-wash zone around the platform. This feature is most distinct in the case of the beach, which is built here out of a few parallel ridges, often separated with small water areas. As such, it resembles similar forms observed on the seacoasts within the tidal zone, or at the lakes of the previously raised water level. In here this is a seasonal form not fixed with vegetation. Moreover, it is characteristic that with the water level going down the observed forms get "stretched" all over the platform. Unlike the accumulative forms at the reservoirs of insignificant water level oscillations, thus, the thickness of their deposits does not rise. On the contrary, it often lowers towards the waterline. Analysing the morphological situation of the existing accumulative forms, however, it can be observed that a larger concentration of them definitely accompanies shallow-water shores, rather than the deep-water ones. Additionally, the small seasonal forms exist in various conditions, while the large ones, which survive throughout consecutive seasons, are located at the shoreline curves accompanied by elevations in the mother substratum, and separating the abrasive sections of the shoreline.

Translated by Aleksandra Zaparucha

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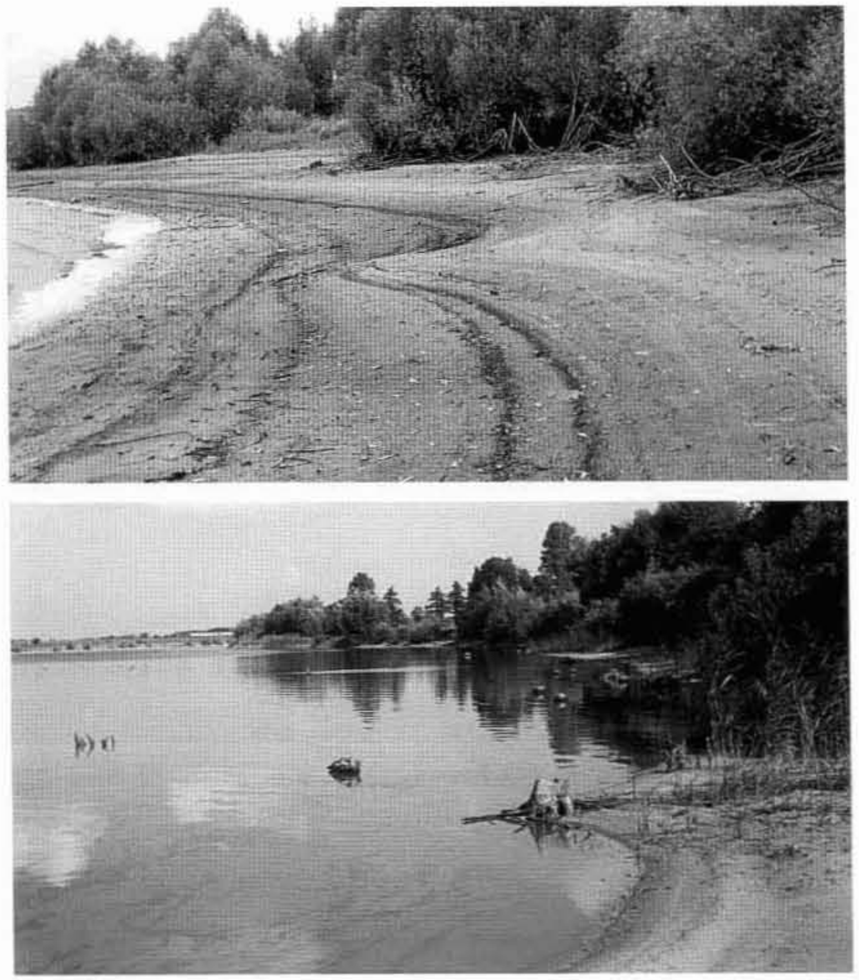
Phot. 1. The shore ridge

Phot. 2. The beach plain. Generation beach ridges with beach lagoon between it.

Phot. 3. The beach crescents (festoons)



Phot. 4. Free and forced accumulative spurs

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Distribution of small, water-filled depressions as a component of the analysis of icesheet retreat dynamics in young glacial areas

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Abstract: The young glacial landscape of the northern Europe features numerous post-glacial structures, including drainless relief depressions which are usually filled with water and are called ponds or kettle holes. Their presence in Western Pomerania is associated mainly with a zonal arrangement of glacial forms related to the retreating icesheet front.
Distribution of kettle holes was analysed in a region where their density is highly variable. The study covered mainly the Wełtyń Plateau, the Myślibórz Lakeland, and the northern part of the Gorzów Plateau.
About 11 thousand kettle holes smaller than 1.0 ha, marked on the late 19th century 1:25,000 topographic maps, were included in the analysis.
The analysis of the kettle hole distribution, conducted with the aid of GIS software and spatial analysis statistics, demonstrates that the distribution of kettle hole clusters, the shape of the surrounding vegetation patches, and the kettle hole cluster alignment may be important components of the icesheet retreat reconstruction. The elements mentioned, when factored in the analysis, may contribute to, i.a., understanding of the direction of the ice movement and the sequence of the icesheet front ranges.

Key words: kettle holes, ponds, icesheet retreat dynamics, young glacial areas.

Introduction

The landscape of northern Europe features numerous post-glacial structures, including drainless relief depressions, usually filled with water. They are typical of morainic plateaux and bottom moraines where they are usually present in clusters (Kloss et al., 1987). The origins of the depressions supporting kettle holes date back to the Pleistocene when chunks of the so-called dead ice, completely or partially buried in the bottom moraine deposits, were thawing at a differing rate, and when meltwater activity and inglacial erosion were commonplace (Kosturkiewicz & Musiał, 1982; Drwal & Lange, 1985).

At present, the sites of numerous drainless depressions support small water bodies, called ponds or kettle holes. The division of post-glacial kettle holes is based on their origins. The young glacial landscape is commonly thought to be dominated by primary and secondary kettle holes (Klafs et al., 1973). The primary kettle holes were formed towards the end of the last glaciation, as a result of slow thawing of dead ice chunks covered by morainic deposits (Röpke, 1929). At that time, drainless areas emerged, with depressions left where the ice chunks had been melting (Klafs et al., 1973; Jeschke, 1987; Kalettka, 1996). In addition to the post-glacial primary kettle holes, the young glacial areas feature also small water bodies the structure of which is close to the kettle holes described above, but which did not derive directly from thawed dead ice. They are the so-called secondary kettle holes. Their origins date back to the time when mass woodland felling resulted in an increase in the groundwater table and intensification of water erosion. The dry Pleistocene depressions were permanently filled with water at that time. A detailed classification of post-glacial water kettles was presented by Pieńkowski & Podlasiński (2001).

The presence of both primary and secondary kettle holes is related to the terrain relief, which in turn