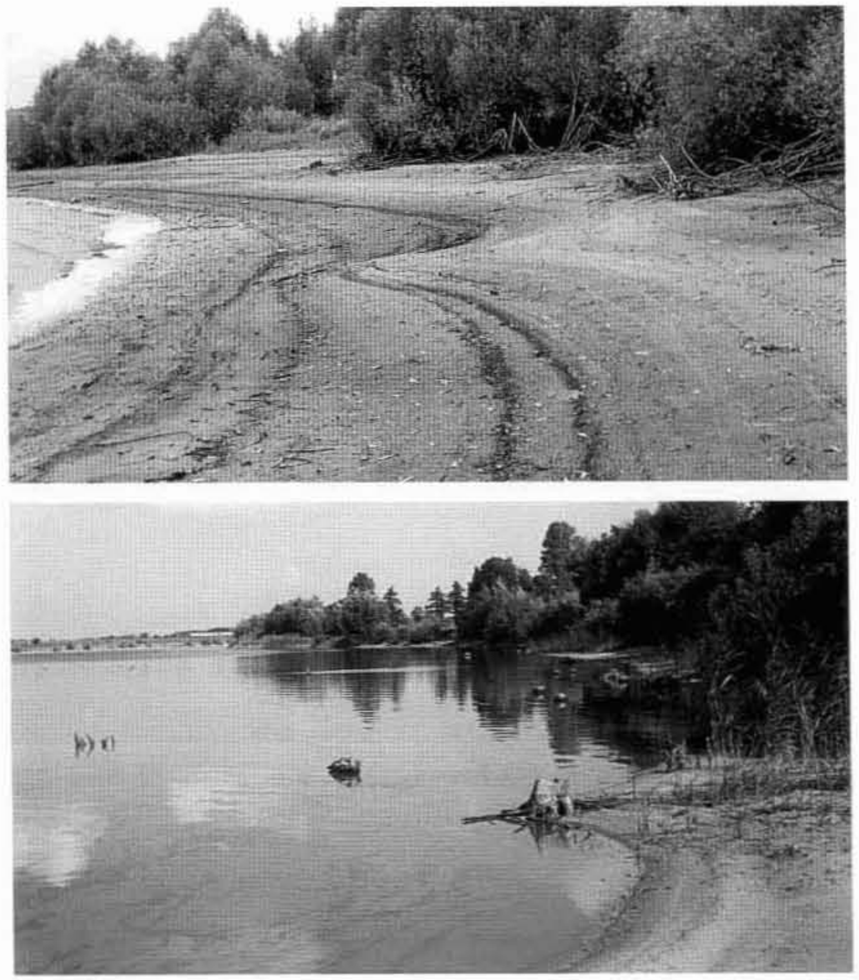
Phot. 3. The beach crescents (festoons)



Phot. 4. Free and forced accumulative spurs

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 depends mainly on the history of the icesheet retreat. The number of kettle holes and their spatial distribution were controlled by the dynamics of the retreating icesheet and, to a lesser extent, by the type and intensity of land use (Grünert & Janke 1981; Pieńkowski, 2000). Kettle holes form diverse clusters, frequently arc-shaped, which is related to, i.a., the distribution of dead ice. Such clusters have been reported from the vicinity of Stralsund (Grünert & Janke 1981) and from the Wełtyń Plateau (Pieńkowski, 1996).

Due to the lack of high-resolution numerical spatial models which could serve as a tool with which to analyse drainless depressions in detail, analysis of kettle hole distribution may provide a direct measure of the type of deglaciation type-dependent terrain relief. Therefore the density and distribution of primary and secondary kettle holes may be considered as one of the components of the analysis of the dynamics and history of icesheet retreat, as presented in this paper.

Materials and methods

Due to a considerable depletion in the number of postglacial kettle holes in the Odra lobe, observed in the last century (Pieńkowski, 1996, 2000) and due to the appearance, in the second half of the 20th century of new mid-field ponds of anthropogenic origin (Kosturkiewicz & Musiał, 1982), the analysis of kettle hole distribution was conducted using the holes marked on the late 19th century 1:25,000 topographic maps published by Königliche Preussiche Landesaufnahme. The analysis presented in this paper involved about 11 thousand kettle holes smaller than 1.0 ha. To exclude man-made water bodies, the focus was on ponds of a regular shape, located in drainless depressions. All the ponds were recorded by the ArcInfo software using the 1965 coordinate system. The kettle hole distribution was analysed using the Idrisi software. Hot Spot analysis (Levine, 1999) was employed to identify areas with a particularly high density of kettle holes. The results were visualised with ellipses covering point objects (kettle holes) assigned to clusters. Fig. 2 shows the ellipses resulting from step two of the search (5-object clusters).

Results and Discussion

The area of study covered mainly the Wełtyń Plateau and the Myślibórz Lakeland, the westernmost

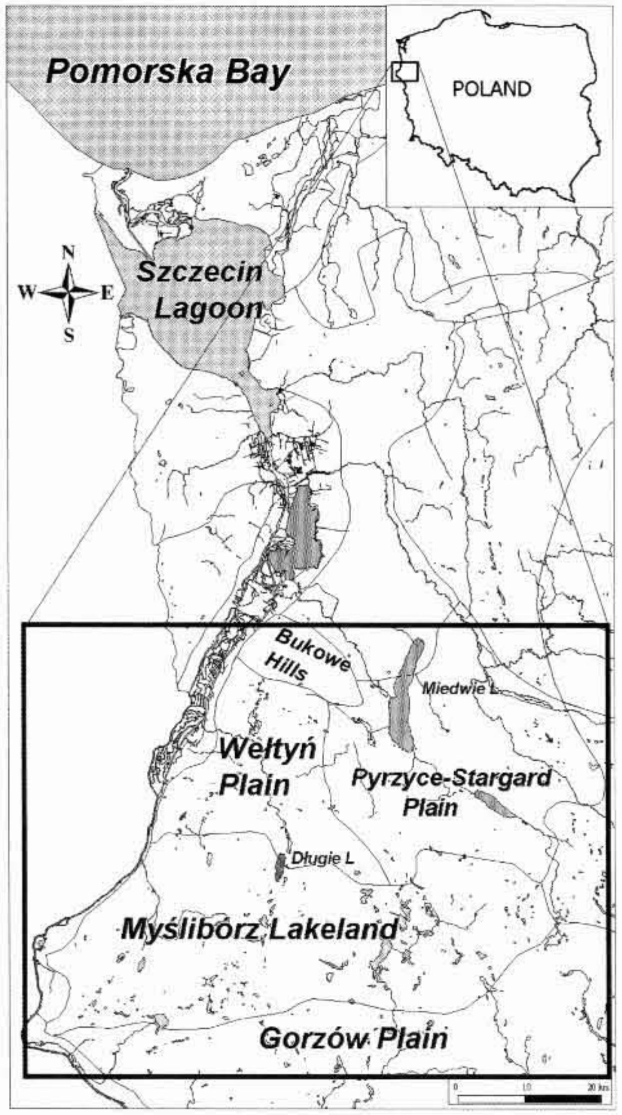

Fig. 1. Location of the area of study

part of the Pomeranian-stage frontal moraine, as well as the northern part of the Gorzów Plateau, a forefront of the frontal moraine ridge (Karczewski, 1968) – Fig. 1.

The area of study was characterised by a highly variable density of kettle holes. At the end of the 19th century, the mean kettle hole density in the Myślibórz Lakeland was 2.8 per km^2. In the mesoregion's uplands and on the outwashes, the kettle hole density reached $6.0 \cdot$and $1.8 \cdot km^{-2}$, respectively. The mean kettle hole density on the Gorzów Plateau was much lower and did not exceed $0.7 \cdot km^{-2}$.

The spatial diversity of kettle hole density is shown in Fig. 2. The high density of those water bodies was typical of, i.a., frontal moraines associated with the maximum stage, and also of an area (almost perpendicular to the frontal moraines) of the River Tywa subglacial trough. The aggregation of small water bodies

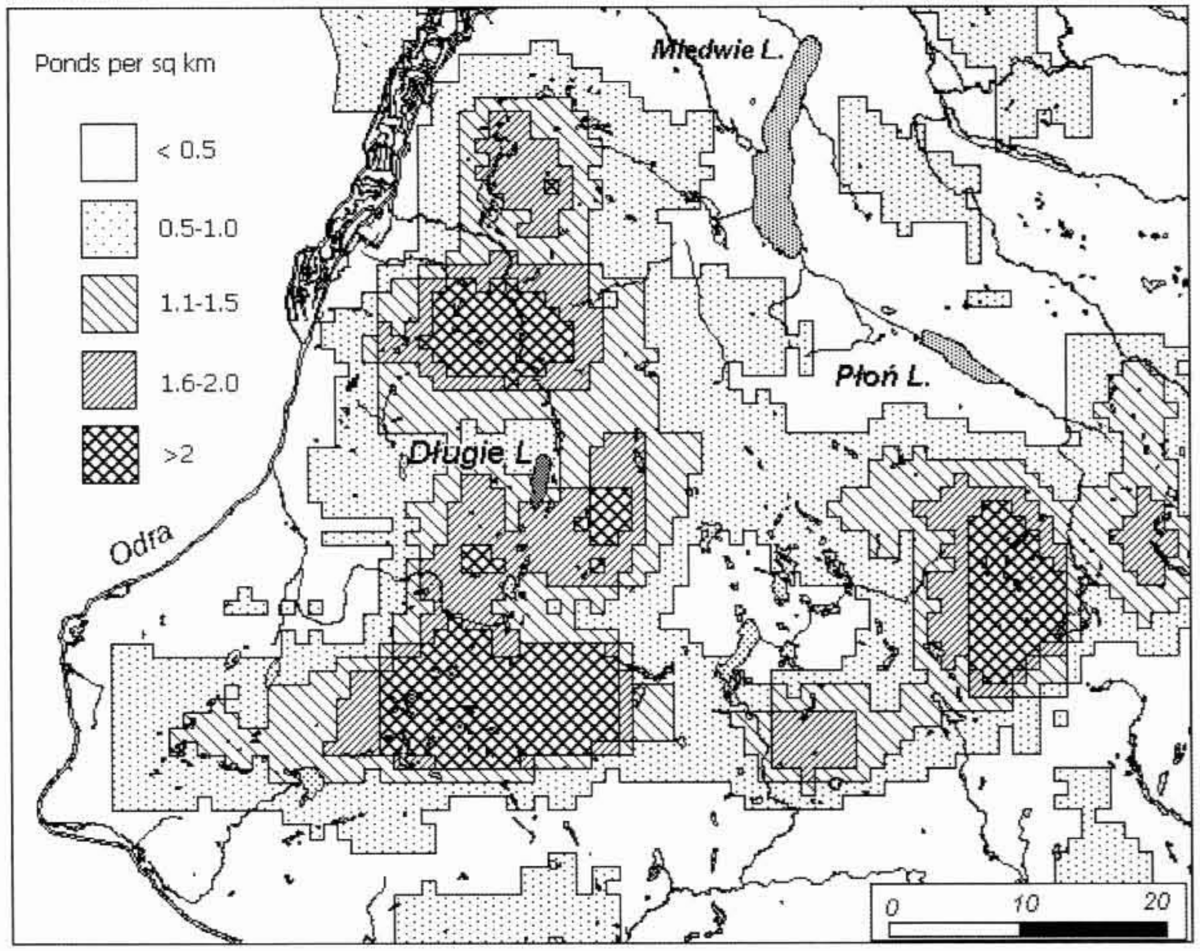

Fig. 2. Diversity of kettle hole clusters in the area of study at the end of the 19th century

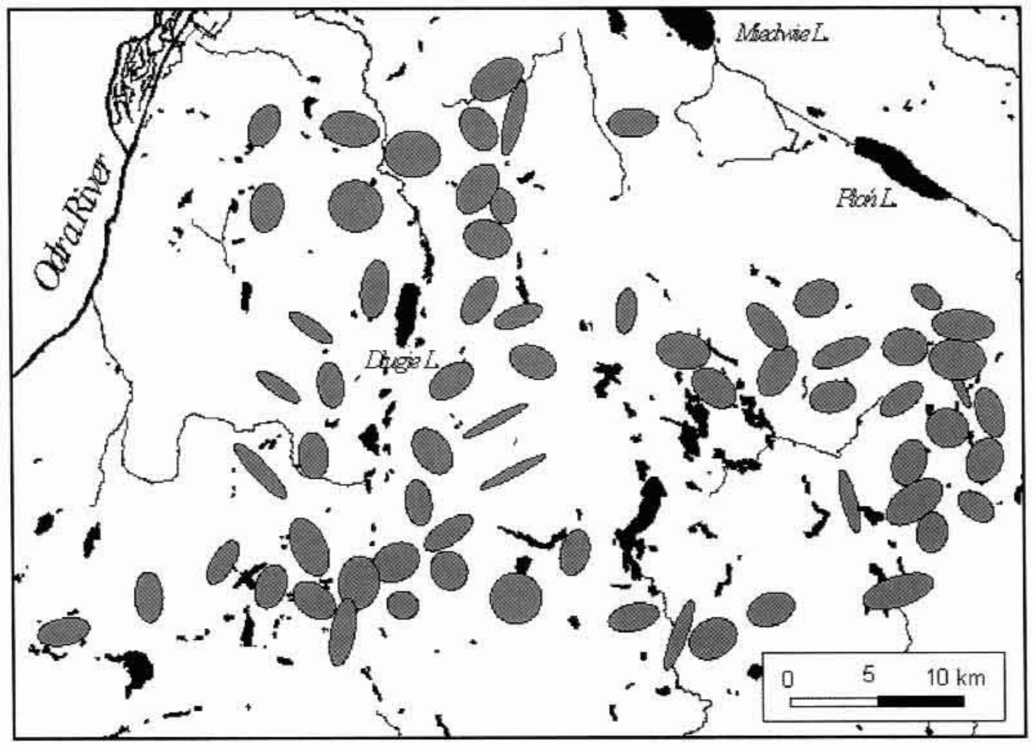

Fig. 3. Sites of the highest density of kettle hole at the end of the 19th of century.

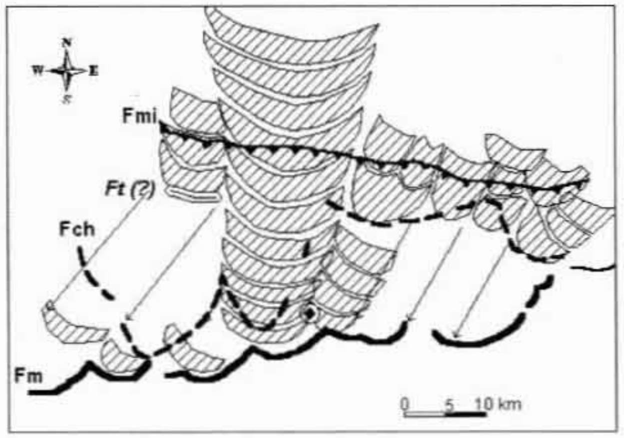

Fig. 4. Hypothetical shapes of icesheet lobes, determined from kettle hole distribution in relation to subphases (according to Kozarski 1965)

Legend: Fm, maximum phase; Fch, Chojna subphase; Fmi, Mielęcin subphase; Ft, presumptive Tetynia subphase; / the site of kettles; → direction of kettle-hole lobe-like alignment.

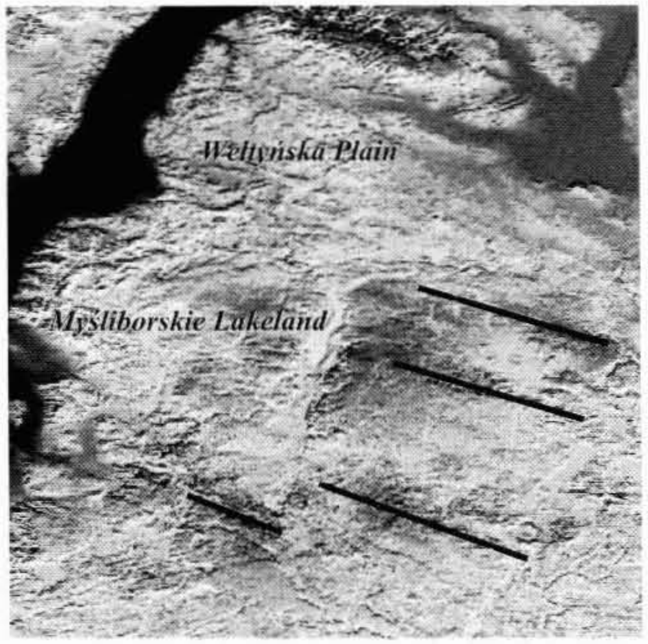

Fig. 5. Numerical representation of the terrain, with hill position indicated

in the Tywa trough is the most pronounced, across the entire area of study, element of the icesheet activity. The density of kettle holes in that area was higher than in areas where the icesheet was stationary, as indicated by the presence of frontal moraines. The shape of the area might be taken as an indication that it was affected by a strongly alimented ice flow (the Tywa lobe?) the front of which was located on the arc of frontal moraine hills belonging, in the opinion of Kozarski (1965), to the Chojna phase and extending along the Brwice-Gogolice Klasztorne line. In addition, both sides of the Tywa trough feature symmetrically arranged clusters of kettle holes. Their location was determined with the "Hot Spot" analysis by plotting ellipses covering the sites of the highest kettle hole densities (Fig. 3). Noteworthy are the elongated clusters of kettle holes, radiating from the circular clusters, perhaps indicative of a lobe-like shape of the area of study.

A detailed analysis of kettle hole clusters within the area of study shows a sequence of regular kettle hole arcs, belonging to the area and situated between the maximum phase and the Beech Hills. The arc mid-points were hypothetically joined together, because kettle holes were absent from the postglacial trough area. The arcs delineated correspond, perhaps, to areas of stagnant ice known from the present-day glaciers (Jania, 1997). Particularly prominent are the arcs, 12-18 km wide, between the frontal moraine arc (Brwice-Gogolice-Klasztorne) and the upland sill (Fig. 4). The position of the kettle holes belonging to the area of study in relation to the neighbouring holes may indicate that the icesheet retreat in the area could have occurred later than the icesheet retreat in the adjacent areas. The later occurrence of deglaciation is supported by the fact that the area of the upland on which the icesheet was staying was not covered by fluvioglacial deposits when the remaining part of the icesheet stopped at the Chojna (Tetynia?) subphase line and formed extensive outwash areas in the south. The area of study would not have been then associated with any of the subphases identified, except for the Chojna subphase the borders of which trace the front and the eastern margin of the icesheet.

The kettle hole arrangement presented is, perhaps, an evidence of a later retreat of the ice flow in the area. The kettle hole distribution would then reflect the position of glaciomorainic ridges formed under conditions of a constant rate of the ice stream (lobe?) retreat, broken by rhythmically occurring periods of icesheet stationing. Lobe-shaped glacial forms of that kind were identified in, i.a., the marginal zone of the Poznań phase (Kasprzak, 1988). The presence, in the Myslibórz Lakeland, of a strongly alimented ice stream characterised by a different retreat rate would then produce difficulties in tracing the subphases down.

The distinct character of the area discussed, relative to the structures known in the remaining part of the Myślibórz Lakeland, is noticeable also when the alignment of kettle hole arcs is analysed. The entire area features more or less marked kettle hole clusters clearly tracing the south-western direction of the ice flow. The chords of the kettle hole cluster arcs run parallel to hill ridges marked on the numerical terrain representation (Fig. 5). Such alignment of the kettle

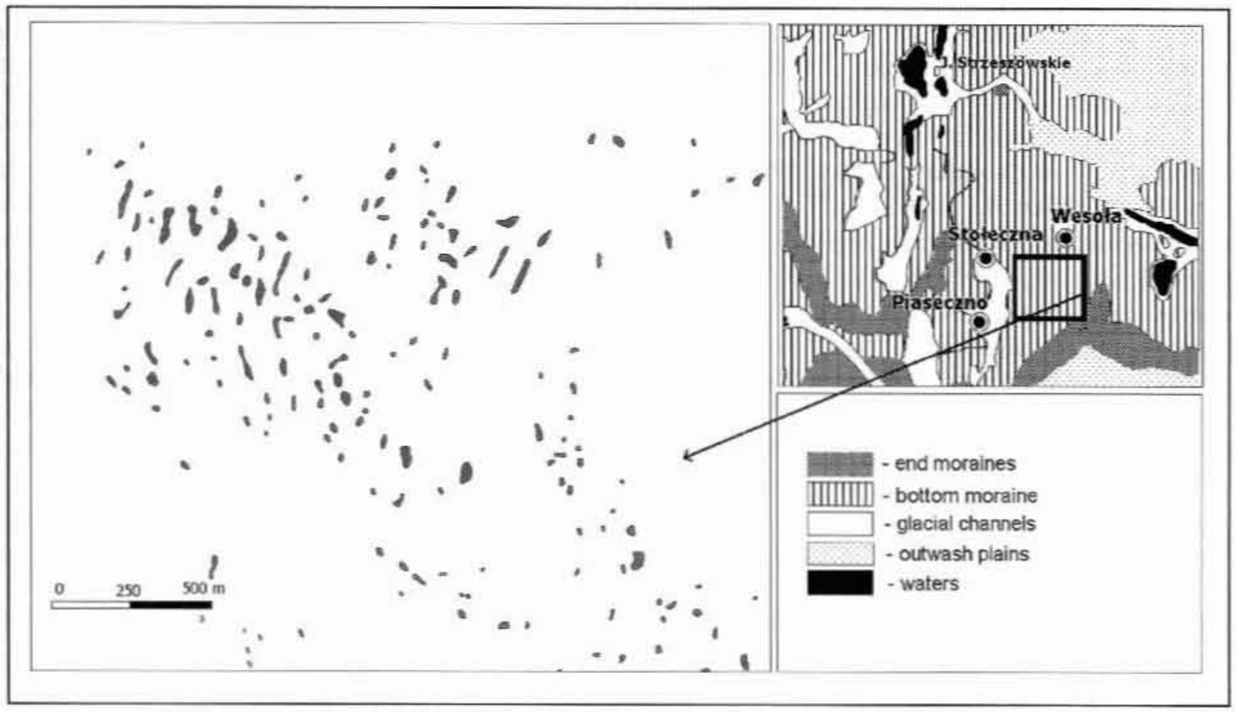

Fig. 6. Distribution of kettles in the vicinity of Piaseczno

holes is suggestive of the icesheet retreat proceeding north-eastwards (or a transgression proceeding south-westwards?) in the Myślibórz Lakeland.

An important component of the analysis of the area discussed will doubtless be the determination of the origin of the kettles situated on the south-eastern side of the frontal moraine arc (Fig. 6). This is an area of the highest kettle hole density not only in the Myślibórz Lakeland, but also the entire Szczecin Lowland (Pieńkowski, 2004). The density of small water bodies in the area at the end of the 19th century was $51 \cdot km^{-2}$. The kettle holes occur in the area of a relatively undifferentiated hypsometry; their drainages are small, and their shores are steep and high (up to 5 m) (Pieńkowski & Podlasiński, 2001). The area of their occurrence overlaps the site of contact between fronts of two ice streams (Fig. 4).

Conclusions

Distribution of kettle holes in young-glacial areas is related to the surface relief which was shaped primarily by the history of the icesheet retreat. Analysis of the kettle hole density may demonstrate the intensity of melting processes and allows to identify structures associated with the retreat, and perhaps also with the transgression, of the icesheet.

Evaluation of the degree of kettle hole clustering, their trending, and the shape of patches supporting the reservoirs in question seem to be an important component of the icesheet retreat analysis in young glacial areas. Taking those elements into consideration will make it possible to explain, i.a., the variability of glacial relief formed during the ice stream retreat.

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Geomorphology of the Tunka rift (South-west Pribaikalye)

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Abstract: The Tunka rift consists of a system of baikal type basins and low-mountain interbasin ridges separating them. In the north it is surrounded by the alpine Tunka ridge and the low Olkha upland, and in the south by the Siberian mountains Western Khamar-Daban with volcanic plateau. This rift may be as a morphotype of dry rift basin of the Baikal type (rift valley) because it has a full set of their typical structural elements and their unified forms. Relief of the rift and its mountain surroundings are composed of five belts: the belt of plains and the belt of tilted piedmonts, the apical belt, the belt of slopes, and the belt of valley bottoms in its mountain frame. Instead of them there is a large group of interzonal land forms.

Key words: structure of relief, Tunka rift valley

Introduction

The Tunka rift stretches over 200 km in a sublatitudinal direction from the Baikal`s south-western termination to lake Khubsugul (fig. 1). It consists of a system of dry valley basins of the baikal type (Florensov, 1960) consisting of a thick (up to 2,5 km) series of Cenozoic deposits alternating with Neogen-Quaternary basal sheets (Logachev & Florensov, 1978) and low-mountain interbasin spurs.

In the east the Tunka rift is begins with a complex combination of low-mountain tectonic steps, horsts, and the small Bystrinskaya basin, constituting of intrarift commissure. Further to the west there is a wide Tora basin. The latter, the largest Tunka and small Tura and Khoitogol basins form the central part of rift valley, and are divided by the low-mountain Elovsky and Nilovsky block spurs. Westward of the Khoitogol basin the rift valley narrows by transforming a commissure between the Tunka and Khubsugul rifts formed by high tectonic steps and the small Mondy basin.

In the north mountain rift frame is represented by a horst of the Tunka ridge of alpine relief type tilted to the north and broken to the rift valley by a high (up to 2000 m), steep tectonic scarp and a tilted uplifted step of the Olkha highland of the Siberian platform margin. In the south the rift is framed by the Western Khamar-Daban dome of the Siberian relief type.

It is reasonable to treat the relief of these geomorphologic regions as belts. Five belts of relief in the Tunka rift and its mountain frame emerge. The belt of plains and the belt of tilted peidmonts are distinguished in a relief of basins, but in their mountain frame the summit belt, the belt of slopes and the belt of valley bottoms are distinguished. Besides, there is a large group of land forms spread among the belts.

Rift valley

Bottoms of basins

The bottoms of the Tora, Tunka, Khoitogol and Tura basins consist of low accumulative plains. The alluvial plain formed by the Irkut river and its largest affluents is the main one. It is formed by low and high flood plains (the widest levels in morphological structure of the alluvial plain), and by two cyclic terraces. The alluvium of the Tunka rift terraces are characterized by a constrictive structure.