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ON THE LOWER VISTULA VALLEY DEVELOPMENT IN THE LIGHT OF GEOMORPHOLOGICAL AND SEDIMENTOLOGICAL INVESTIGATIONS

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Abstract. The paper concerns the Lower Vistula River valley relief development from the Late Glacial until the present, based on the author's geological and geomorphological mapping of this area. Relations between the older (originating prior to the last glacial advance) foundations of the valley and deposition modes within its edges during the last glaciation are described. Particular attention has been paid to traces of dead-ice blocks which had a huge impact upon the development of glaciofluvial and glacial terraces during the Late Glacial. Description of the Vistula River floodplain that reflects a morphological effect of an increasing human impact upon natural environment, its development, landforms and sediment properties, are presented in detail. Their analysis leads to the conclusion that the present-day floodplain resembles partly an initial stage of the anastomosing rivers.

Key words: relief evolution, dead-ice landforms, floodplain, Lower Vistula River valley, Late Glacial, Holocene.

Abstrakt. Na podstawie szczegółowego kartowania geomorfologicznego i geologicznego przedstawiono uwagi o rozwoju rzeźby doliny dolnej Wisły od schyłku ostatniego glacjału do czasów dzisiejszych. Na podstawie badań sedymentologicznych osadów wysnuto tezę o silnym uwarunkowaniu ich depozycji od starszych założeń doliny widocznych już w sposobie depozycji osadów glacjolimnicznych ze schyłku ostatniego zlodowacenia. Szczególną uwagę zwrócono na rolę brył martwego lodu warunkujących rozwój tarasów fluwioglacjalnych i fluwialnych. Omówiono rozwój sedymentologiczny równiny zalewowej Wisły, będącej morfologicznym efektem coraz silniejszego wpływu człowieka na środowisko naturalne. Wskazano na dużą stabilność koryta Wisły i pewne cechy osadów mogące świadczyć o inicjalnym stadium kształtowania się rzeki typu zbliżonego do anastomozującego.

Słowa kluczowe: ewolucja rzeźby, formy martwego lodu, równia zalewowa, dolina dolnej Wisły, późny glacjał, holocen.

INTRODUCTION

The Vistula River, taking into account the outflow, is the biggest one with a fully developed system of valley terraces in the Baltic Region. It is considered to have a constrained channel system (Falkowski, 1990). The area occupied by the Holocene floodplain channel deposits is rather small and therefore, the Vistulian deposits are not concordant with the present-day hydrodynamic channel conditions (no equilibrium meandering fluvial pattern is achieved). The sedimentation within the valley bottom resembles in some way an initial stage of the anastomosing fluvial system i.e. presence of large biogenic wetlands, fine flood deposits and fairly stable main channel belt (Smith, Smith, 1980; North *et al.*, 2007) Therefore, the investigations upon the Vistula River sediments, especially the flood deposits, can help in better understanding a development of anastomosing fluvial systems in the formerly glaciated areas in Europe.

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METHODS

Detailed geomorphologic and geological mapping were used as the main investigation methods. The analysed reach of the valley comprises the western part of the Toruń Basin, Fordon Gap, Unisław Basin, Świecie Basin and the southern part of the Grudziądz Basin between Pędzewo in the south and Szynych in the north. The Świecie Basin was chosen as a test area (about 25 km reach of the river course), which exemplifies a spatial distribution relations between various types of flood sediments (see further illustrations). For a description of the area about 8000 hand-made boreholes, 4000 among them from the test area of Świecie were used. They were supplemented by the sedimentary structures and the texture observations in over 250 outcrops and pits.

RESULTS

DISTINCTIVE FEATURES OF THE LOWER VISTULA VALLEY

The Vistula River valley is a polygenetic one (Drozdowski, 1979, 1982; Brykczyński, 1986). Its lower part downstream from Bydgoszcz as far as the Żuławy Delta Plain makes a large gorge through the morainic plateaux and recessional end moraines of the Poznań and Pomeranian phases (Mojski, 2005). The Lower Vistula River valley has a well developed system of terraces. In the Grudziądz Basin 10 such terraces are distinguished (11 terraces along the whole Lower Vistula River region). A development of the terrace system was so quick that as early as on the onset of the Holocene, the shape of the valley was very similar to the present one (Drozdowski, Berglund, 1976). On the terraces XI to IX (see Fig. 1) the outflow was directed to the south, on the terraces VIII to VI a bifurcation occurred when the Vistula headed simultaneously to the west to the Toruń-Eberswalde streamway and to the north to the Gulf of Gdańsk. Starting with the terrace VI the outflow has been established in the northern route (Galon, 1953; Niewiarowski, 1968). The floodplain is generally subdivided into two or three topographic levels (Galon, 1934; Niewiarowski, 1987; Babiński, 1990; Kordowski, 1999, 2001). The first two are natural, the youngest one is anthropogenic, developed due to a consistent river regulation at the end of 19th century.

RELIEF EVOLUTION AND SEDIMENTATION OF DEPOSITS DURING THE LATE GLACIAL AND THE HOLOCENE

Valley depression caused modifications of the movement direction in the ice sheet sole. The tills thus coming into being in its surroundings were distinctly more sandy than those from far-distant plains (Fig. 2). Shapes of grain-size cumulative curves resemble the ones of the older fluvial and glaciofluvial sediments, incorporated into the ice body. Frequency diagrams indicate strong bimodality or polymodality. The fines, are to be connected with shearing processes in the ice sheet, whereas a sandy mode is to be associated with incorporation into the ice of older, mostly fluvial, local deposits, accumulated prior to the last glacial advance. The clasts are enriched in local rocks, mainly glauconitic sandstones and Mesozoic limestones. The Vistula valley edges modified the extent and the course of minor ice sheet oscillations, what can be examined in the southern part of the Grudziądz Basin and in the northern part of the Chełmno Upland (Niewiarowski, 1961; Drozdowski, 1974).

During a retreat of the ice sheet numerous small terminoglacial lakes emerged but, unlike in the morainic plains, the varves have not been well developed. Instead of a slow deposition from suspension, density and grain flows were more important. The valley depression favoured formation of dead--ice blocks, hence common existence of tiny kame terraces, various kettle holes and debris flow tongues occur (Figs 3–5). In the larger ice crevasses the sandy infilling landforms were formed.

The meltwaters from the ice sheet passed across the valley heading towards the Chełmno Upland. After partial melting of the ice-dam in the valley, a process of glaciofluvial and fluvial terraces development has become.

Subsequently to final development of the terrace system at the valley bottom, vast valley lakes and mires commonly occurred, in which a thick deposition of calcareous gyttjas took place (Figs 6, 7). These sediments have buried the Late Glacial fluvial braided structures present at the valley bottom (Figs 8, 9). In the Unisław Basin the subaqueous fans prograded into the existing depressions occupied by the lakes. A beginning of the organic accumulation was dated by Niewiarowski (1987) at 10 250 ^{14}C BP. Gyttjas and peats are enriched in non-carbonate material (~30%), indicating a fluvial influence. They are also rich in carbonates, about 25% on the average. The rest is constituted by organic matter. According to Bartkowiak (2008), the carbonates are overwhelmingly amorphous (67.5–98.6%), therefore indicating an enhanced solubility.

FLOODPLAIN SEDIMENTS AS INDICATORS OF POSSIBLE EARLY STAGE INITIATION OF RIVER ANASTOMOSIS

About 3400 14C BP (the oldest radiocarbon dating from the sample in alder leaves peat in Podwiesk), the evolution of the cover of flood sediments has begun (Figs 7–11).

The average thickness of flood deposits, estimated on the basis of the analysis of over 6000 boreholes, is equal to about 2.23 m and reaches 7 m maximum (Maksiak, 1983). A common grain size composition is: clay 6%, silt 60%, sands

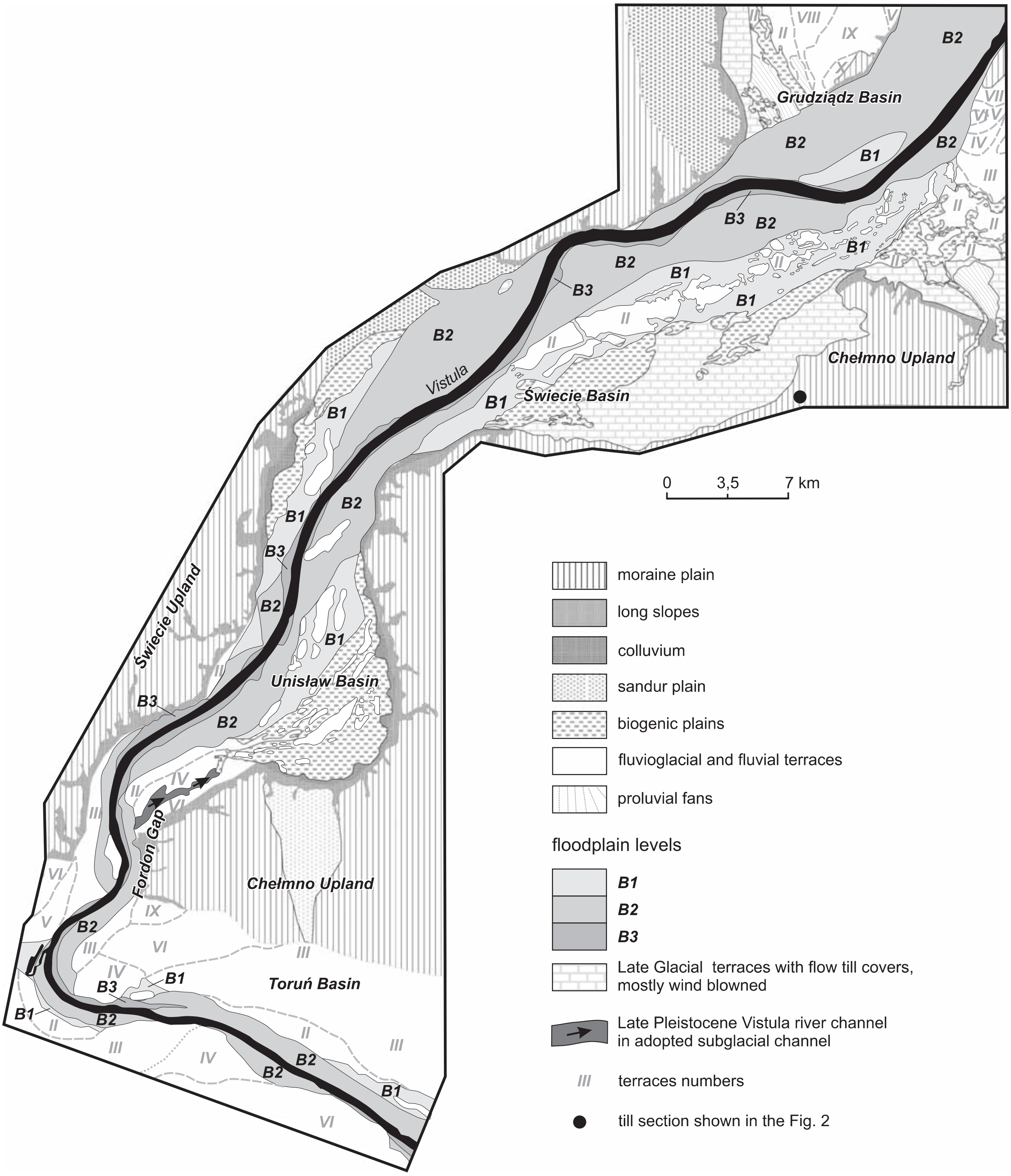

Fig. 1. Geomorphologic outline of the Lower Vistula River valley

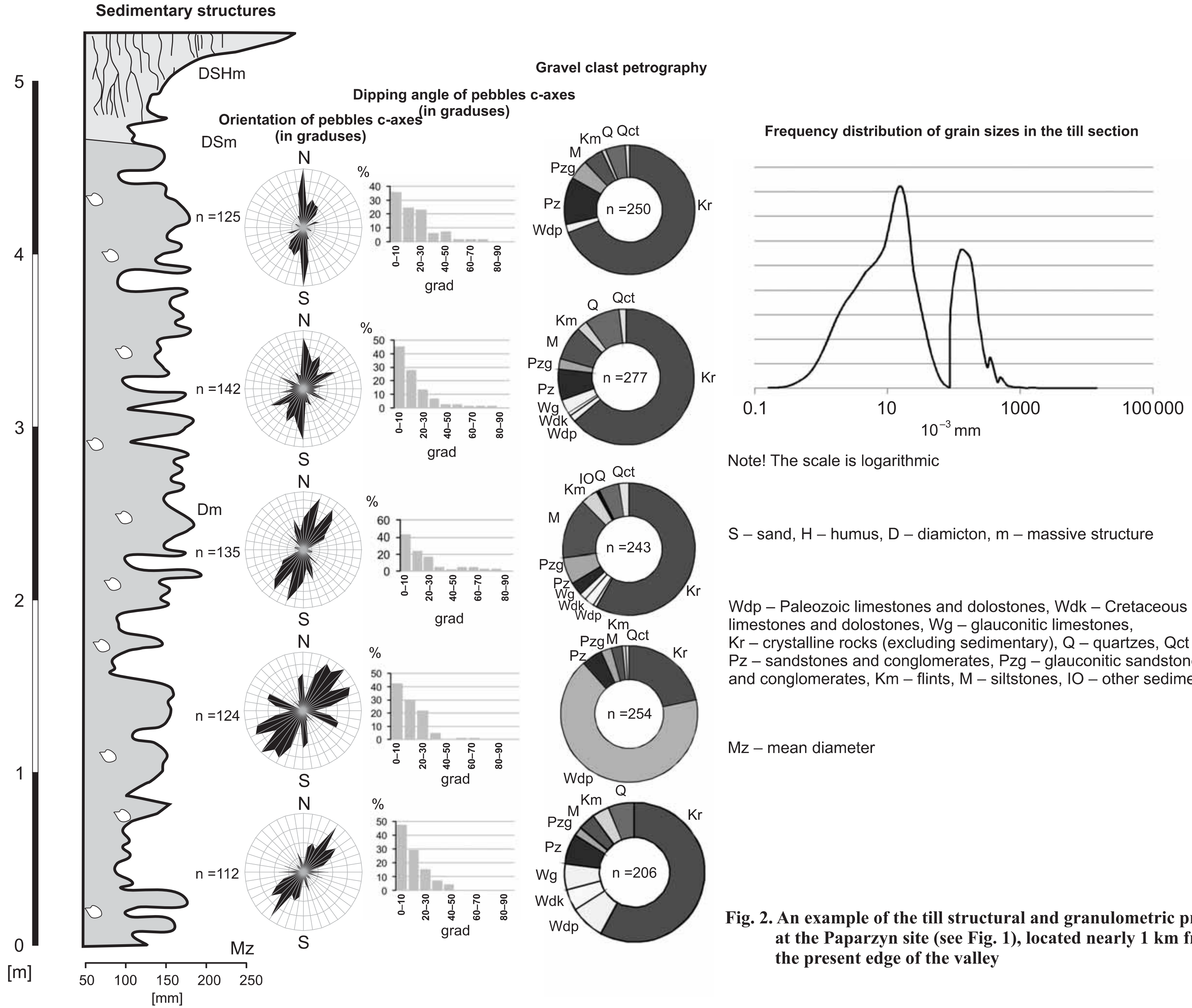

Fig. 2. An example of the till structural and granulometric properties at the Paparzyn site (see Fig. 1), located nearly 1 km from the present edge of the valley

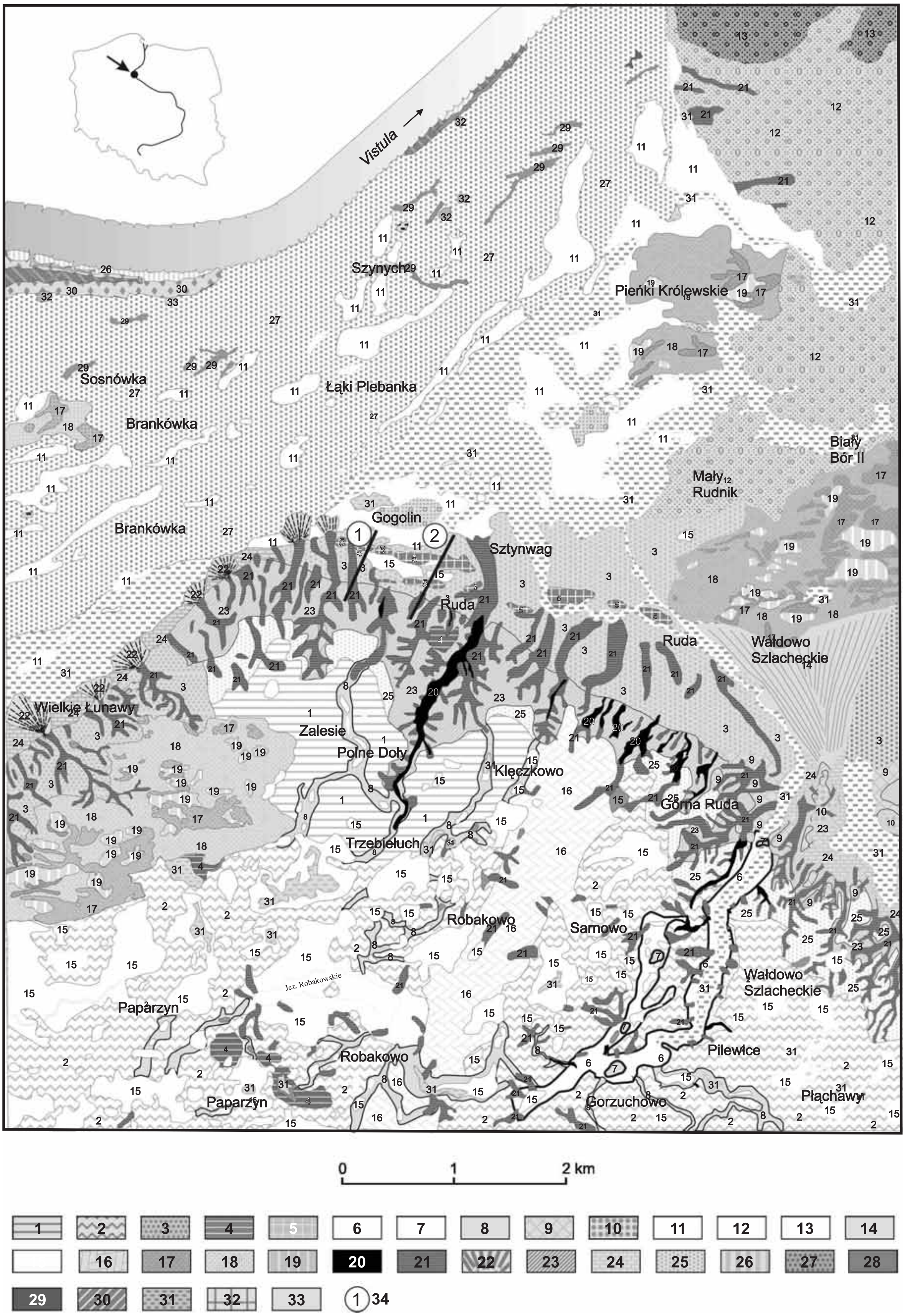

Fig. 3. The geomorphologic map of the southern part of the Grudziądz Basin. The map presents crevasse-infillings in a very low geomorphologic position (signature 5). Geological cross-sections from Fig. 4 are also presented

1 – flat morainic plain, 2 – undulated morainic plain, 3 – kame terraces and covers, 4 – kames and local areas of glaciolacustrine accumulation without distinct morphological edges, 5 – eskers and other crevasse-infilling deposits, 6 – subglacial channels, 7 – elevations and thresholds on the floor of subglacial channels, 8 – small meltwater channels, 9 – revealed outliers of fluvial plains, 10 – revealed outliers of glaciofluvial plains, 11 – terrace I, 12 – terrace II, 13 – terrace III, 14 – proluvial fans, 15 – dead-ice kettles, 16 – probable magadrumlins?, 17 – aeolian dunes, 18 – wind blown sand covers, 19 – deflation moulds, 20 – young erosional incisions, 21 – moulds and hollows originated as a result of denudation, 22 – proluvial fans, 23 – long slopes, 24 – zone of slope aggradation, 25 – zone of slope degradation, 26 – natural levees, 27 – upper flooplain, 28 – lower floodplain, 29 – crevasses, 30 – abandoned river branches, 31 – biogenic plains, 32 – farm embankments, 33 – pits, 34 – cross-sections presented in Fig. 4

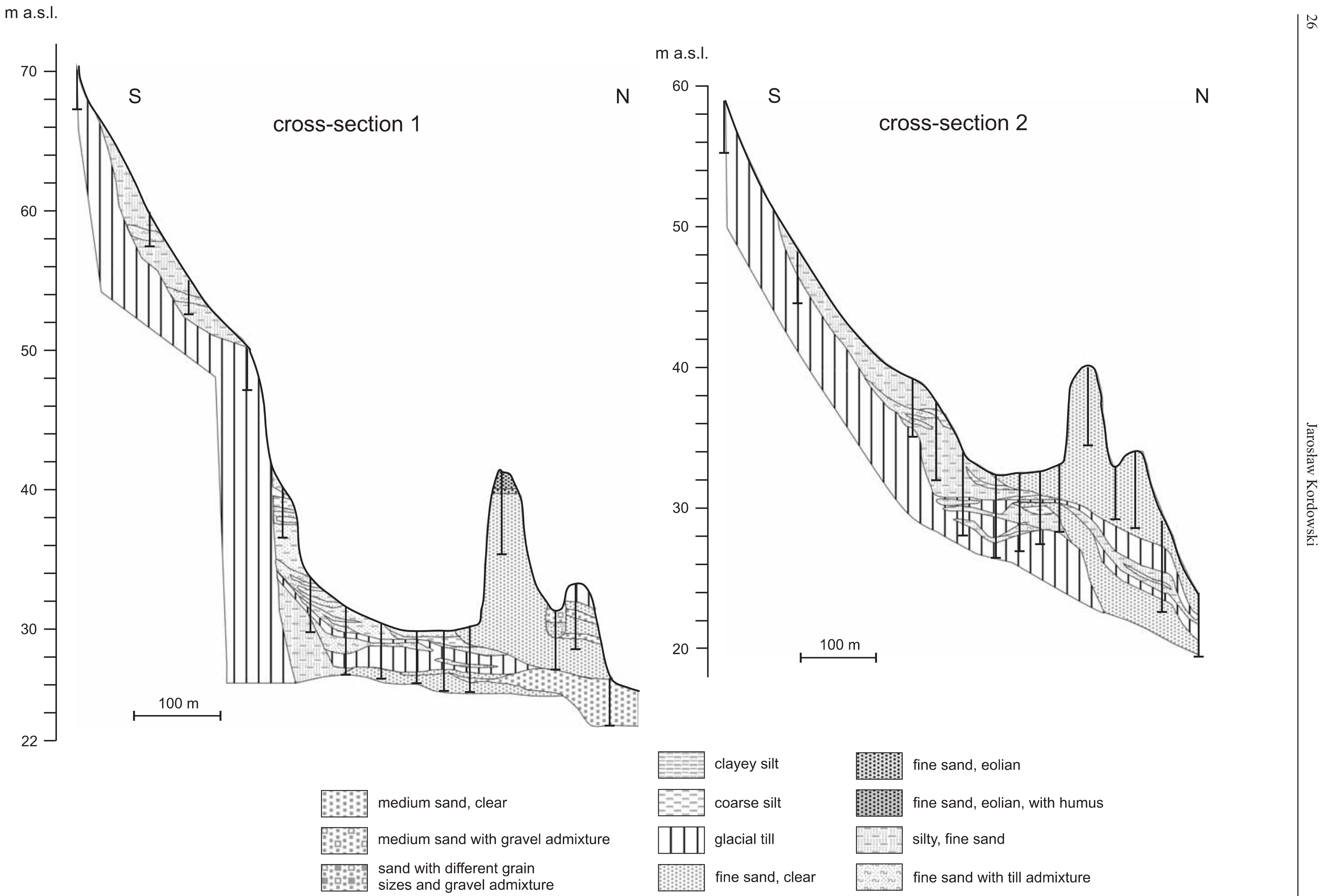

Fig. 4. Geological cross-sections through crevasse infilling in the Grudziądz Basin. The form is straight-lined, 12 m high. The length is about 1.5 km but its eastern part is buried under the sediments of fluvial fans developed at the mouth of Młynkówka subglacial channel at the edge of the Chełmno Upland

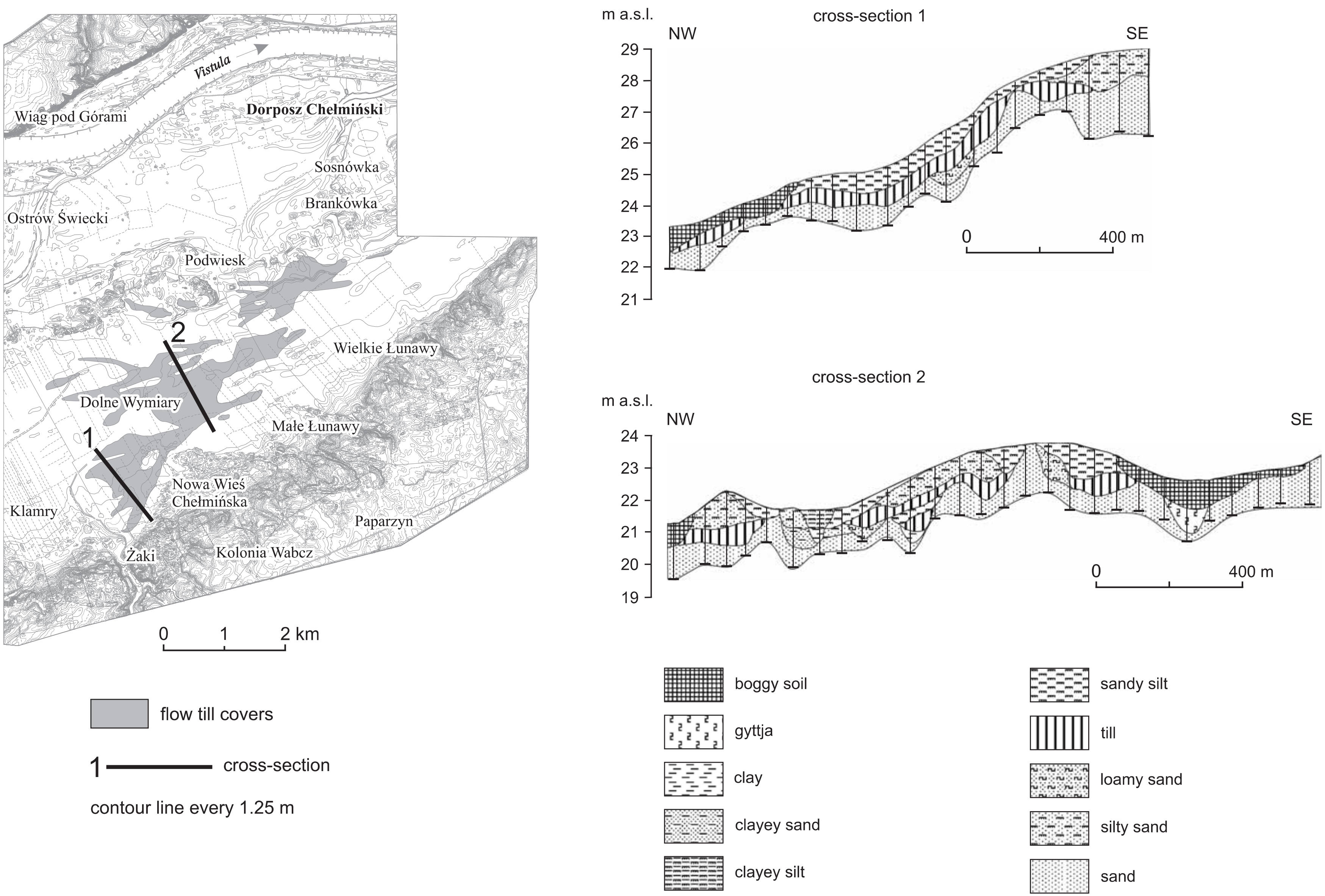

Fig. 5. An example of the debris flow tongues with cross-sections at Nowa Wieś Chełmińska in the north-eastern part of the Świecie Basin

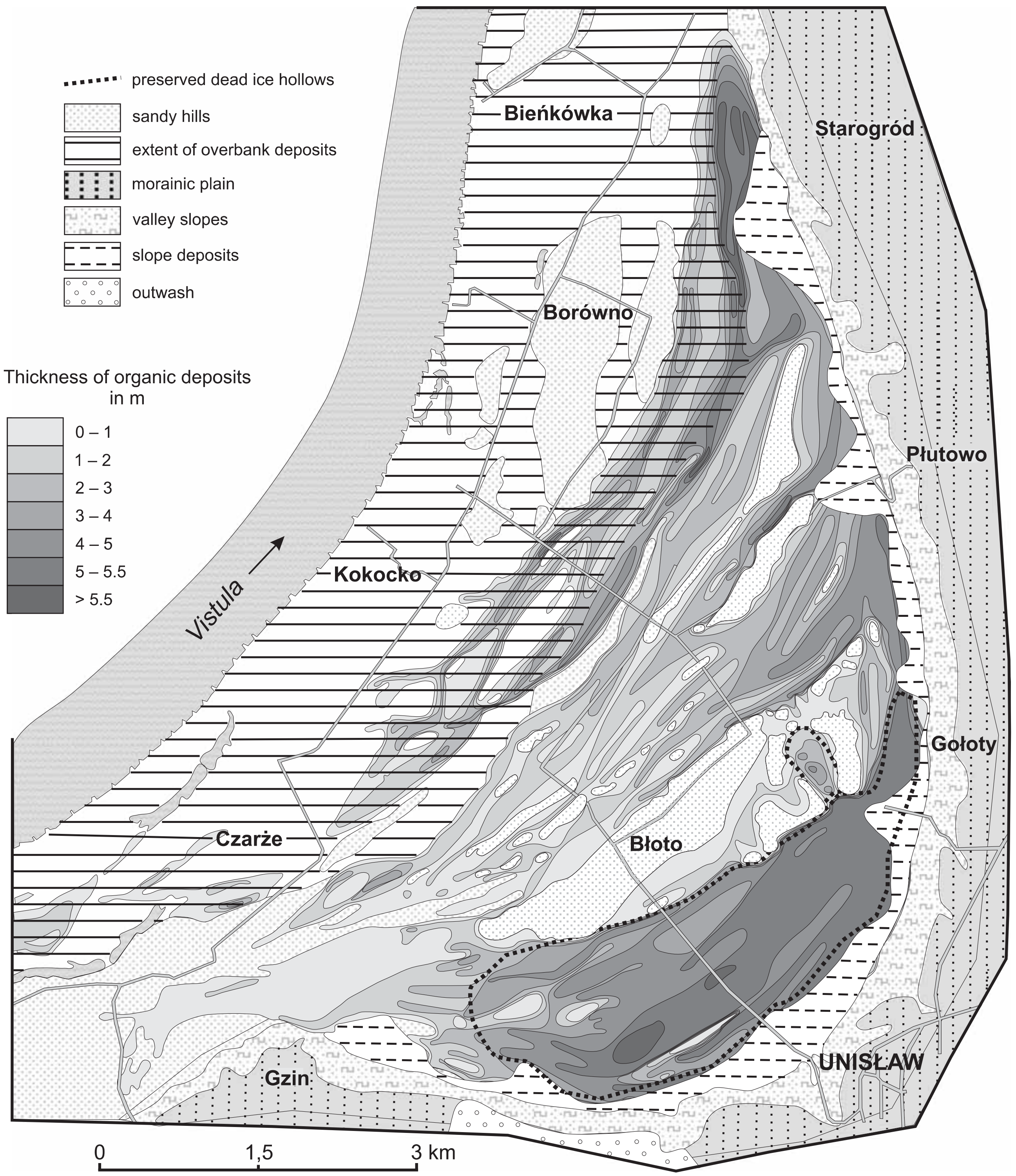

Fig. 6. Organic and carbonate deposits thickness in the south-eastern part of the Unisław Basin

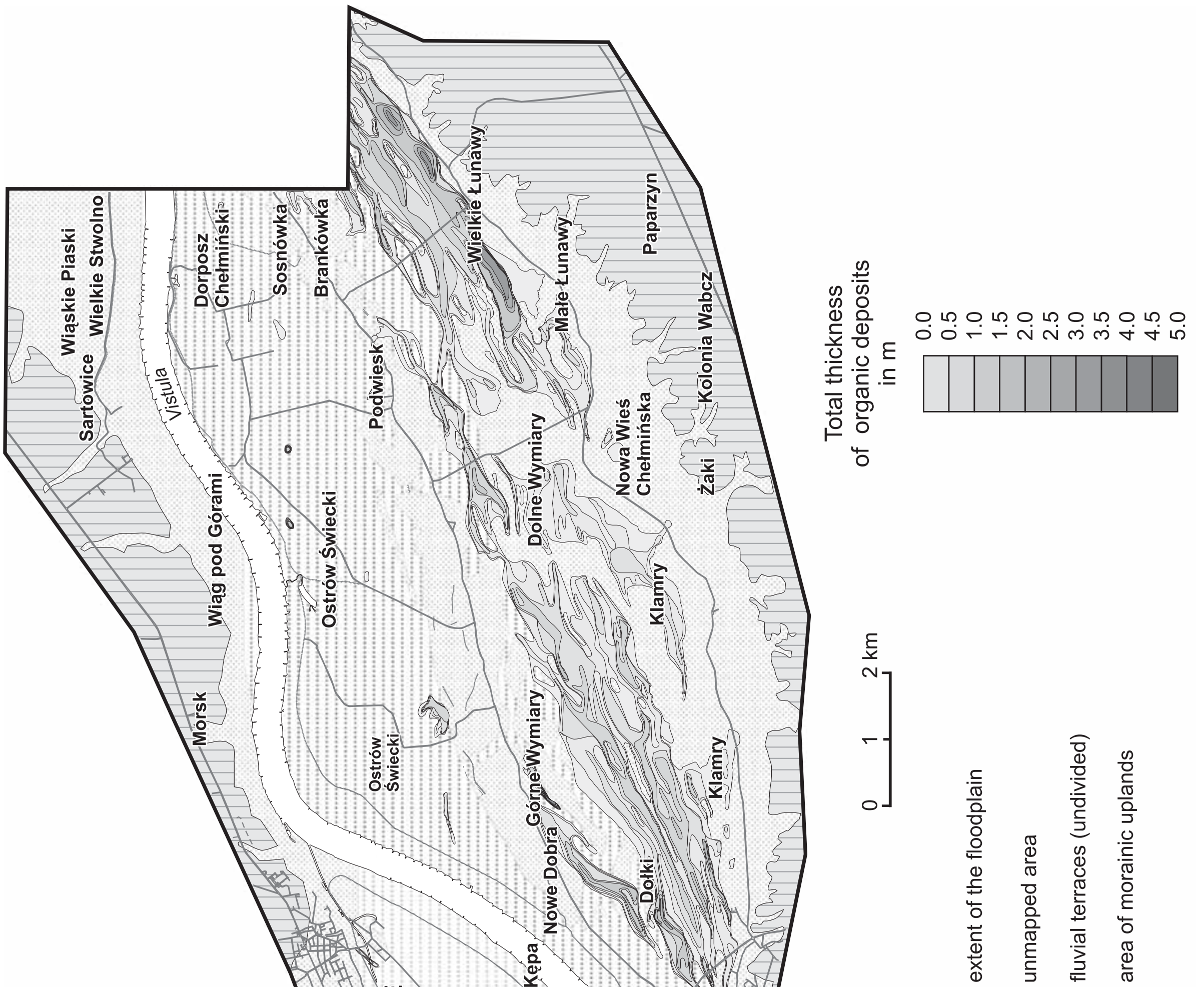

Fig. 7. Organic deposits thickness in the Świecie Basin

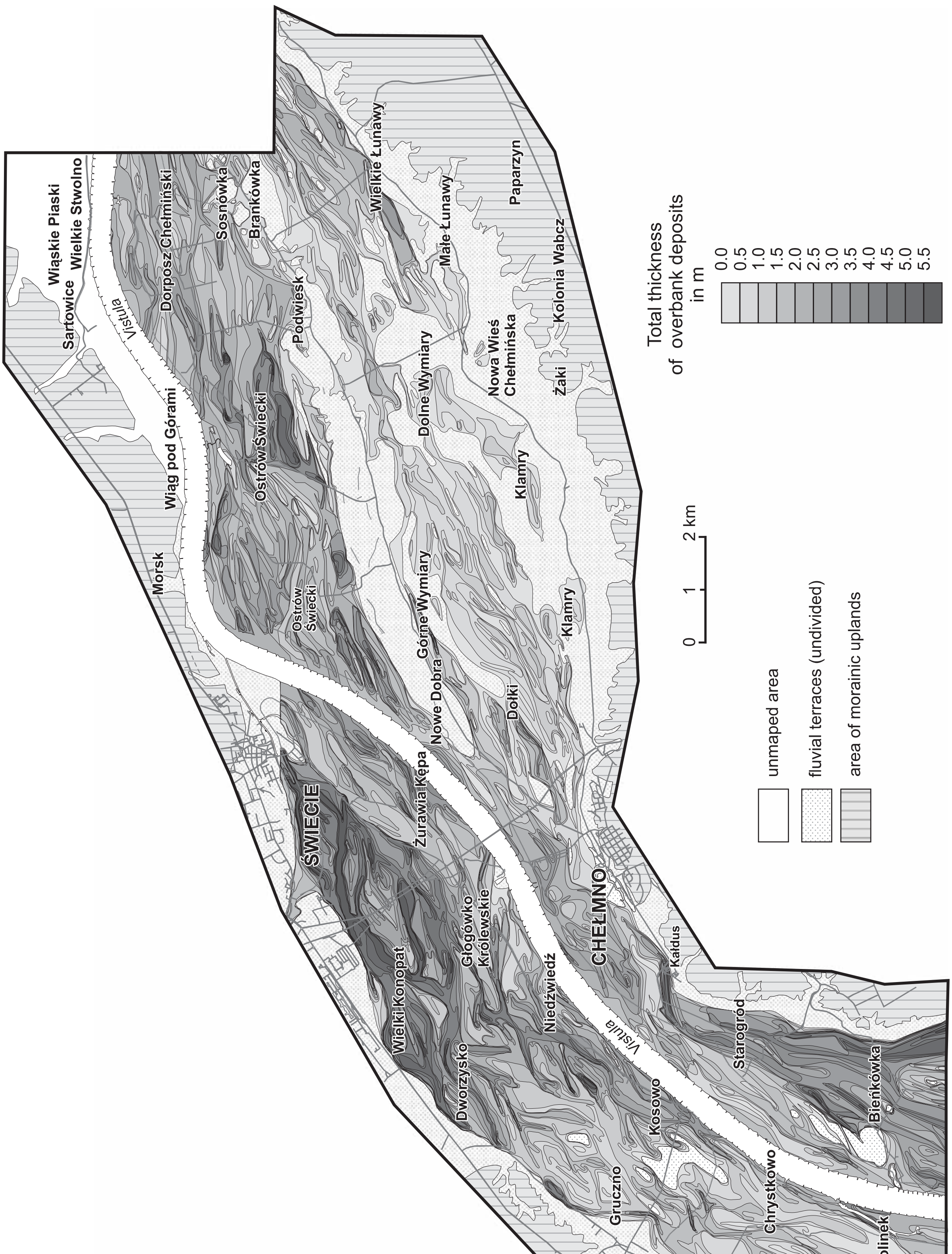

Fig. 8. Overbank deposits (flood, blue clays and organic ones) thickness in the Świecie Basin

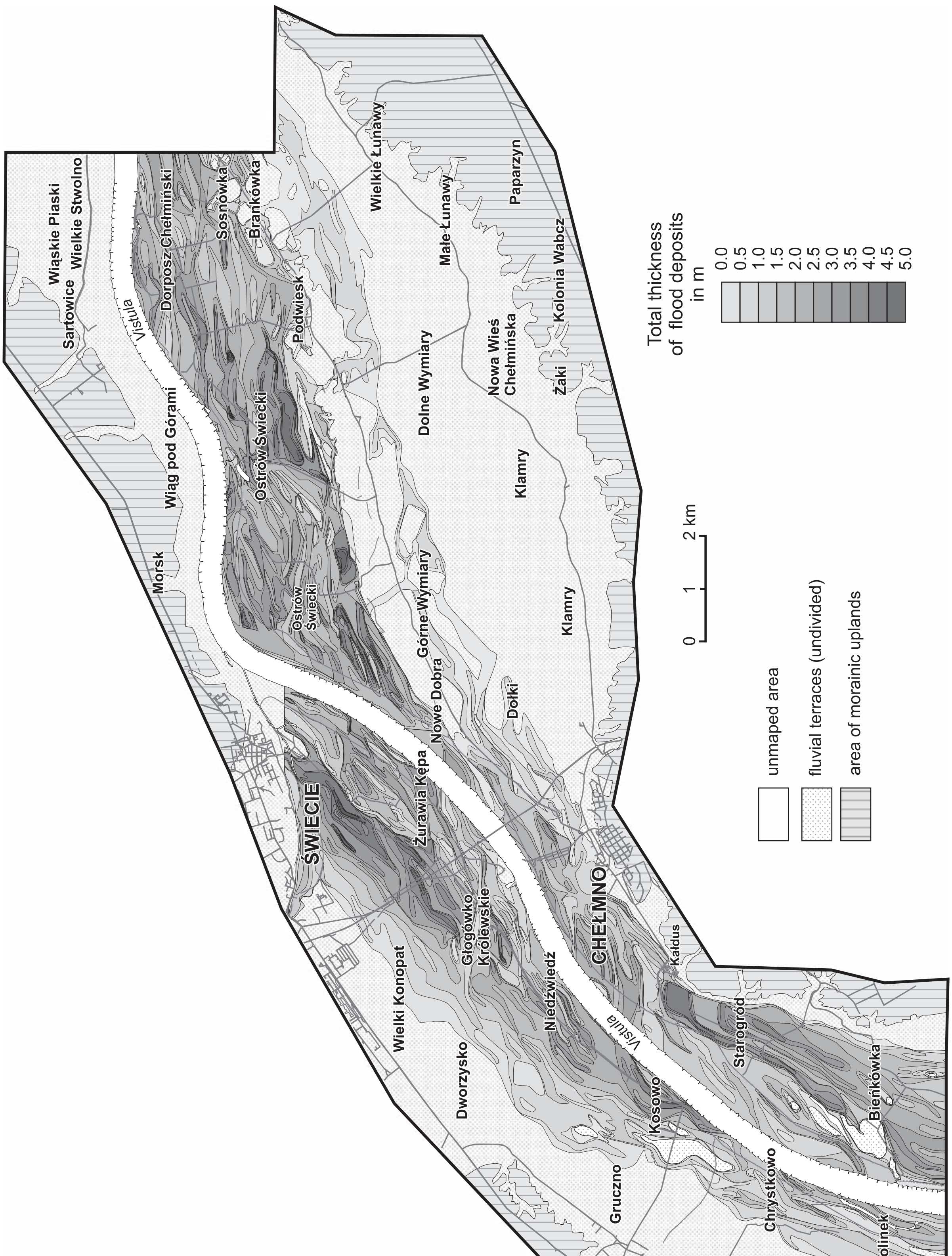

Fig. 9. Flood deposits thickness in the vicinity of Chełmno and Świecie

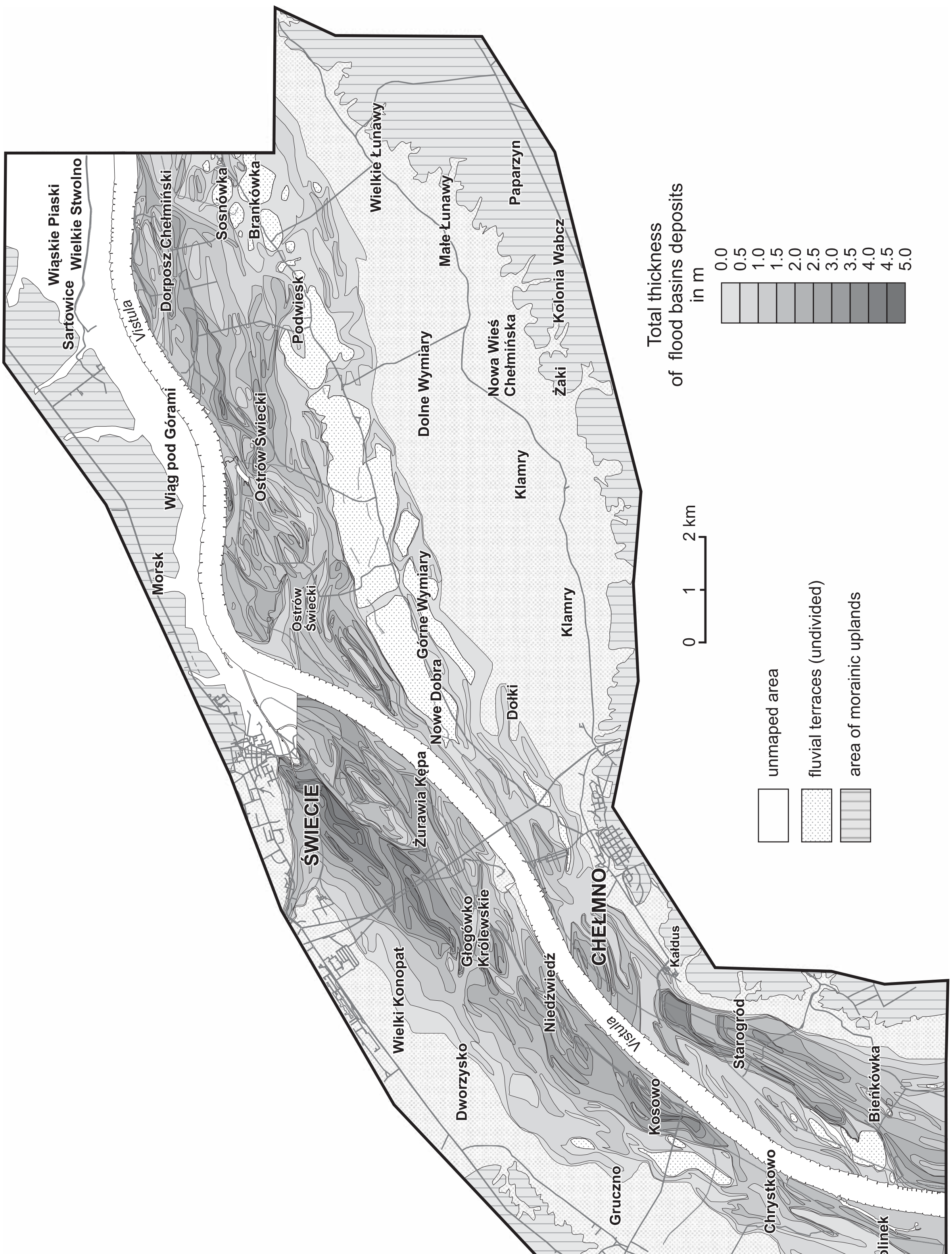

Fig. 10. Flood basin deposits thickness in the vicinity of Chełmno and Świecie

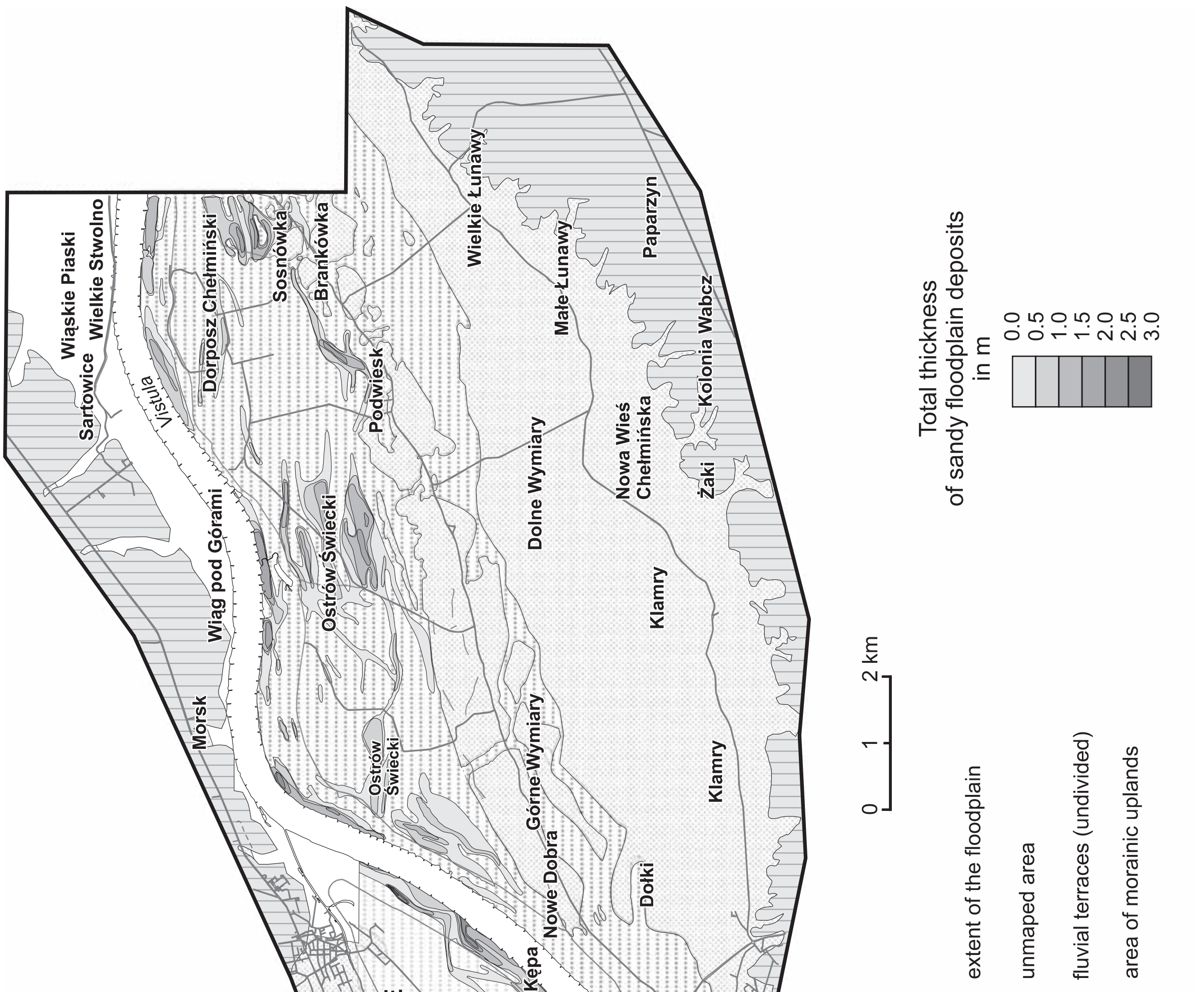

Fig. 11. Extent and thickness of sandy flood deposits (natural levees, sandy shadows, micro-deltas and sandy ribbons) in the Świecie Basin

33%, with other sediments (iron compounds, plant detritus) about 1%. There is a long hiatus between the deposition of the underlying sands associated with channel deposition in a braided Late Glacial river and the vertical accretion sediments of the floodplain.

At the beginning, the so-called 'blue' clays were deposited. The sedimentation mode of those deposits fairly resembled a lacustrine one, because of their unimodal granulometry, unusual for typical flood deposits.

At least ca 2.4 ka BP (after investigations of Noryśkiewicz, 2004), a deposition has been transformed and it resulted in typical fine-grained polymodal sediments. The flood-basin sediments had the largest share among them (Fig. 10).

Basing on structural and textural properties, these sediments can be subdivided into two types, typical and transformed ones. Typical sediments are composed of silts without any significant sand admixture and with sand intercalations. Sediments of classical basins originate in distal parts of the floodplain, where long-existing pools occurred, having specific conditions favouring slow deposition from suspension. Their primary sedimentary features are lost, due to processes leading to development of the basins enriched in a sandy fraction. The most significant process (apart from many others) is vertilisation. Very dry conditions through the whole fine flood sediments cover favoured development of deep crevasses. These openings are commonly filled with aeolian sediments and with redeposited, easily erodible sands after thunderstorms or sudden local rain floods. Such genetic sediment class is polymodal.

The second largest group of flood sediments consists of broad genetic class of sandy ones (Fig. 11) that build natural levees, micro-deltas, sandy ribbons and shadows. Levees based on sedimentary structures can be subdivided into initial and developed ones. Initial levees have a set, composed of a sandy layer from the ascending phase of flooding and a silty one from the descending phase. In the developed levees there is a lack of the second member of the set. Initial levees are polymodal.

The most important features in this group are sandy ribbons (crevasse splays situated parallel to the river channel). They occupy proximal and middle reaches of the floodplain. They are large. reaching a length of 1.5 km and a width of 500–600 m, and indicate a great morphological variety. Sandy deposits occur rarely further than 2 km apart from the channel and form a dendritic pattern linked with the crevasses pattern. Crevasses, apart from concave banks of the river, are the preferred sites for deposition of sands. An increased amount of them, along with increased amount of crevasses in several reaches of the valley, indicates particular probability for the occurrence of winter ice jams. Every change of the channel course, more than 10 degrees, intensifies sand deposition and development of sandy ribbons. A great intensification of ribbons formation must have probably happened during the Little Ice Age, due to the climatically influenced number of ice-jam floods in winter and spring.

CONCLUSIONS

A development of the Lower Vistula River valley was strongly influenced by the older geological setting. The present valley in the basin areas resembles in many places the valley depressions, which had come into being before the Vistulian main stadial (Makowska, 1979) and its modern shape is a result of glacial, glaciofluvial, melt-out and fluvial relief imposition (e.g. Drozdowski, 1982; Błaszkiewicz, 1998; Kordowski, 2001). After a retreat of the last ice sheet, there were large dead-ice blocks, which had left many kettle holes, ice-crevasse fillings, debris flow sediments and kame terraces. Their melting had a huge impact upon the development of the terraces. Due to their existence in the valley, two separate hydrological systems may have existed temporarily, locally governed by melting-out of the dead-ice and regional governed by melting-out or a retreating glacier. The Late Glacial Vistula had a braided channel pattern that is proved by investigations of topography beneath the present-day floodplain sedimentary cover. The analysis of sedimentological properties of the floodplain sediments indicates that the Vistula channel was fairly stable during its development. There is a relatively small amount of proved avulsions. Changes of the river course as well as deposition of large sandy ribbons were caused by increased frequency of floods due to winter ice jams. The analysis of biogenic sediments leads to the conclusion that they are overwhelmingly limnic. A development of the floodplain was also associated with shallow and vast lakes development. These features allow assuming that development of the initial stage of an anastomosing-like fluvial pattern in the present Vistula floodplain was recently interrupted by the human impact (river regulation).

In the case of the lower Vistula region the anastomosing has been most probably caused by presence of many valley basins occurring over former valleys established prior to the last glaciation (Vistulian Main Stadial) and gaps between them, where no valley occurred. They have played to some point, a similar role to mountain foredeeps, favouring development of typical anastomosis (i.e. Smith, Smith, 1980; Rust, 1981; Miall, 1996; Makaske, 1998; Makaske *et al.*, 2002; Wang *et al.*, 2002).

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