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Late Quaternary evolution of the Nysa Klodzka river valley in the Sudetic Foreland, southwestern Poland

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Abstract The late Quaternary Nysa Klodzka river terrace system has developed since the retreat of the Early Saalian (Odranian) ice sheet, which entirely covered the Sudetic Foreland and partly the Sudetes Mts. There are four terraces in the river valley, where the oldest one, the Upper Terrace, developed during and immediately after the ice sheet retreat, other terraces were deposited during the subsequent cold and warm stages, Wartanian, Weichselian and the Holocene. At the initial stage, the present river valley formed at the margin of retreating ice sheet. Later, the valley developed due to several erosion and sedimentation phases. The Nysa Kłodzka river flows through a zone of moderate to distinct tectonic activity, which is confirmed by seismic activity and recent crustal movements in the eastern part of the Sudetic Foreland. The neotectonic movements influenced much the evolution of morphology of this zone throughout the Quaternary and led to the shaping of the valley into its current form. During the late Quaternary, neotectonics could have been strenghten due to post-glacial isostatic rebound. These vertical movements disturbed the terrace system of the Nysa Kłodzka river valley, with the strongest terrace tilt in the Upper Terrace level, but less deflections visible even in the Holocene terrace levels.

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INTRODUCTION

The paper presents the foremountain part of the Nysa Klodzka river valley, from the margin of the Sudetes Mts near Bardo, throughout the hilly Sudetic Foreland, to its lowland part in the Silesian Lowland, where it joins the main river of the region, the Odra river (Fig. 1). The characteristic feature that enables to recognize sediments of the Nysa Klodzka river from sediments of other rivers in the eastern part of the Sudetic Foreland is high content of Sudetic Permian rocks, mainly the porphyry.

The Pliocene to Early Pleistocene development of the river network in this region has been discussed in detail by Przybylski *et al.* (1998). That time, the Nysa Klodzka river and its tributaries flowed generally to the east, forming a widespread alluvial surface in the eastern part of the Sudetic Foreland. In spite of many outcrops with these sediments, the preglacial series is in many regions completely eroded or, in other regions, is not sufficiently identified. The Middle Pleistocene fluvial sediments that may be connected to the Nysa Klodzka river are even more poorly documented, where some gravel pavements are interpreted as traces of fluvial erosion. As well, some gravel series are interpreted as Middle Pleistocene fluvial deposits, basing on their petrographic composition with a mixture of local, Sudetic rocks and resistant Scandinavian components, and their position between tills.

The aim of this paper is to describe the youngest, late Middle Pleistocene, Late Pleistocene and Holocene alluvial sediments of the Nysa Klodzka river, which are well exposed in terraces along the river valley. Besides the terrace geomorphology and sediment description, gravel petrography of clasts larger than 5 mm has been introduced, in order to recognize differences between fluvial horizons of various age. The paper discusses also the main reasons for the formation of the present-day valley, and especially the role of glaciation and neotectonic movements in the valley development. The latter is very important, as geodetic measurements show that the eastern part of the Sudetic Foreland undergoes moderate crustal movement until present-day (Cacoń & Dyjor, 1995). The tectonic activity of the region is also indicated by the relatively numerous earthquakes recorded in this region during historical times (Pagaczewski, 1972).

Former views on the Nysa Klodzka river terraces in the Sudetic Foreland were presented by Walczak (1954, 1970, 1972), Szczepankiewicz (1972), Wroński (1974a) and Badura & Przybylski (1992, 1995a). The adjacent, moun-

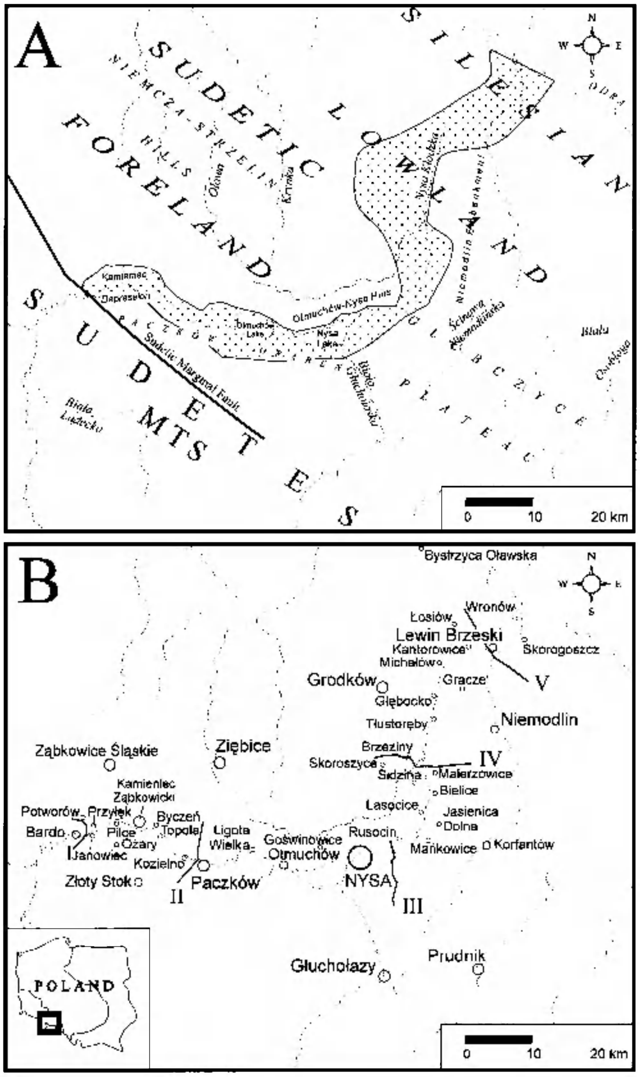

Fig. 1. **A** – Location of the Nysa Kłodzka river valley in the Sudetic Foreland and main morpho-tectonic units of this region; **B** – localities mentioned in the text and location of geological cross-sections (I–V).

tainous part of the river valley was described by Zeuner (1928), Berger (1932), Wilczyński (1991) and, most recently, by Krzyszkowski *et al.* (1998).

TERRACES OF THE NYSA KŁODZKA VALLEY

The terrace system in the Fore-Sudetic part of the Nysa Kłodzka river valley developed after the early Saalian (Odranian) Glaciation and consist of four fluvial levels (Fig. 2, 3, 4). These are, the Upper Terrace, lying 20–32 m above the present river channel; the Middle Terrace, lying 10–17 m above the river channel; and two Lower Terraces, of varying heights above the river channel, from 2 to 8 m in the upper Lower Terrace and from 1.5 to 5 m in the lower Lower Terrace. Moreover, there are some valleyside surfaces lying 35–50 m above the river channel, that may represent, at least in part, fluvial surfaces. The lack of the continuity of the older fluvial terraces significantly complicates their correlation, especially when the height of different terrace levels are close to each other (*e.g.* two Lower Terraces near Paczków) or terrace height changes rapidly in adjacent zones of the valley (*e.g.* Upper Terrace between Nysa and Skoroszyce). Gravel petrography does not help in these correlations, as clast lithology is very similar in all terraces or changes regionally in the individual levels.

HIGH VALLEYSIDE FLUVIAL SURFACES

There are many flat surfaces on both sides of the valley which height varies from 35 to 50 m above the present river channel (Fig. 3, 4). They were not hitherto explained as fluvial in origin and were named the "denudation" surfaces (Walczak, 1954, 1972; Szczepankiewicz, 1972; Wroński, 1974a). Such a flat surface is visible in the region of Ligota Wielka, north of Otmuchów, and other one is south of Nysa (Fig. 3). However, the best devoloped 35–50 m level is between Bardo and Paczków, between the main river valley and the margin of the Sudetes Mts (Fig. 2, 3). This surface is slightly tilted to the north, towards the Nysa Klodzka valley. There are some exposures of the Miocene sandy-clayey deposits and the Pliocene (preglacial) gravels as well as other exposures with Pleistocene gravels. These deposits were accumulated on alluvial fans, formed at the front of raising Sudetes Mts (Krzyszkowski *et al.*, 1998). However, all these deposits were at least once covered by an ice sheet during the Middle Pleistocene and recently the 35–50 m surface has a dicontinuous cover of glacial deposits, mainly a till. In places, glacial deposits are completely eroded, with only an erosional boulder pavement left on the older fluvial deposits. Thus, the 35–50 m high surfaces that are present along the Nysa Klodzka river valley has a complex stratigraphic record, that may contain all fluvial terraces/series older than early Saalian glaciation.

The 35–50 m surface which occurs at the front of the Sudetes Mts was partly active also during the post-glacial times. During the period of the accumulation of gravels of the Upper Terrace, the stepped flattened surfaces of this level became a transit zone, with mainly the erosional processes. Accumulation was limited to the surfaces lying directly at the mountains edge, where local fans covered the till or older fluvial sediments, and to the valleys cut down 20–25 m into the 35–50 m surface (Fig. 2). These deposits are correlative with the Upper Terrace level in the main valley.

UPPER TERRACE

The Upper Terrace occurs throughout the river valley, although in its different parts, this fluvial level has variable extent (Fig. 2). Between Bardo and Kamieniec Ząbkowicki, the terrace is poorly developed on the southern side of valley, forming 25 m high, isolated and narrow benches (Fig. 3 – section I). Also, it is here partially covered by slope deposits and young alluvial fans. In contrast, the Upper Terrace level is here very extensive on the north

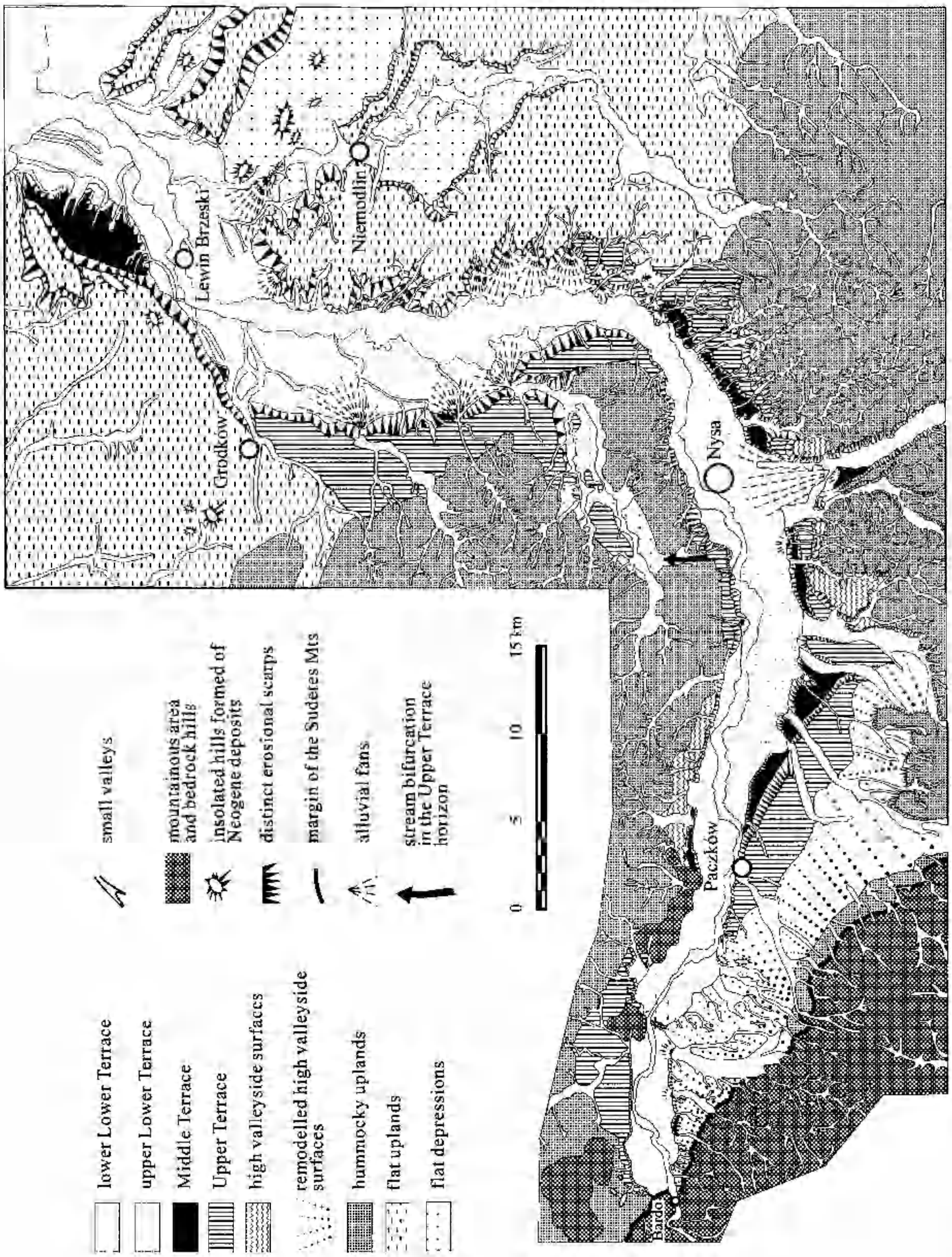

Fig. 2. Geomorphological map of the Nysa Kłodzka river valley and surrounding uplands.

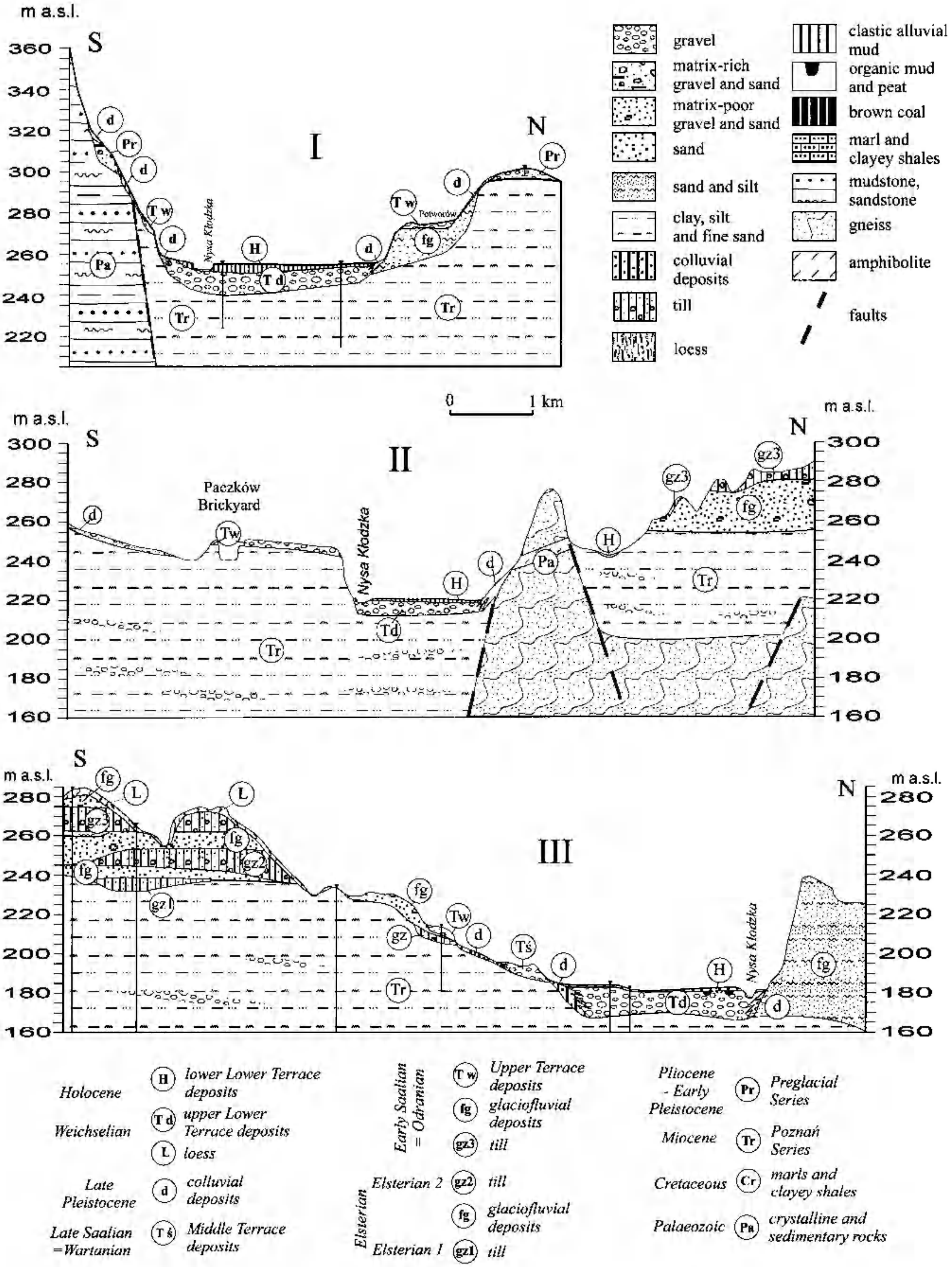

Fig. 3. Geological cross-sections through the Nysa Kłodzka river valley in the Paczków Graben. Location of cross-sections in Fig. 1.

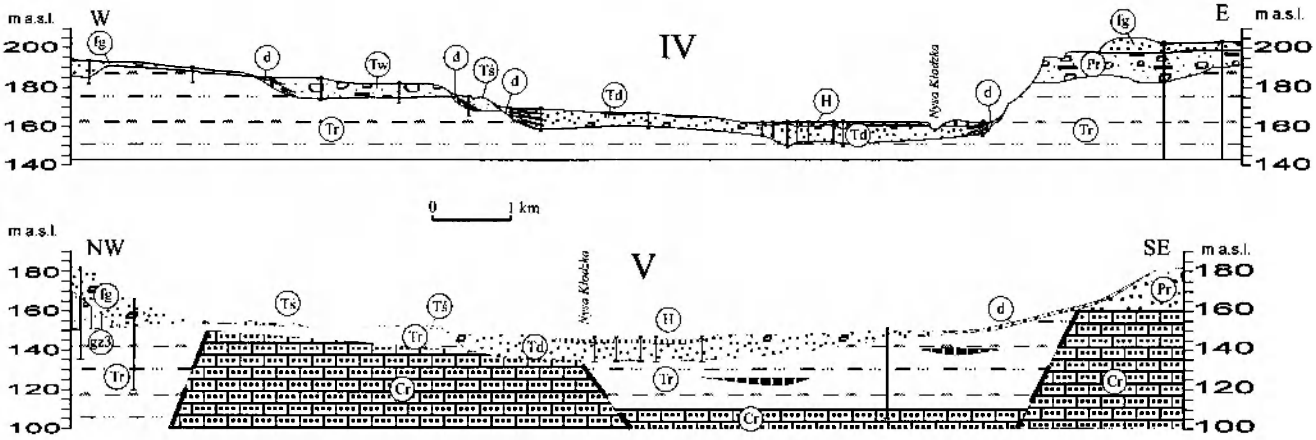

Fig. 4. Geological cross-sections through the Nysa Kłodzka river valley in its lower course. Location of cross-sections is in Fig. 1; Explanations in Fig. 3.

side of the valley. This is up to 3 km wide alluvial surface, which partly shows an evidence of a former valley located north of the crystalline bedrock hills near Kamieniec Ząbkowicki (Behr *et al.*, 1931; Walczak, 1954). The present-day valley is located south of these hills (Fig. 2). The thickness of the Upper Terrace gravels is up to 5 m in this zone, as evidenced in Potworów and Przylęk (Krzyszkowski *et al.*, 1998) and at Byczeń. In the latter case, the Upper Terrace gravels lie directly on the Miocene sandy-clayey deposits.

Between Kamieniec Ząbkowicki and Paczków, the Upper Terrace level is slightly higher (30–32 m above the river channel) and forms an extensive alluvial surface only on the southern side of the valley (Fig. 2, Fig 3 – section II). The section at Paczków brickyard shows that the alluvial gravels are 1–2 m thick and are underlain by Miocene clay. Moreover, gravels are overlain by 0.5 m thick loess-like deposits that contain numerous large clasts (Fig. 5A).

In the Nysa region, the Upper Terrace horizon is present as a row of isolated surfaces cut by the valleys of the tributary streams (Fig. 2, 3). There are no large outcrops of Upper Terrace deposits on the southern bank of the river, although drillings document that the gravels are up to 10 m thick. The Upper Terrace gravels are, however, well exposed in the northern bank (Fig. 2, 3). The base of the terrace is formed here of glaciofluvial and glaciolacustrine deposits, and in part, of a till, which make up Otmuchów–Nysa Hills (Fig. 3 – section III). The alluvial sediments are up to 2 m thick. The Goświnowice section comprises 8–10 m thick glaciolacustrine sequence at the base and 1–2 m thick alluvial gravels on the top. The boundary is erosional and alluvial gravels fill large troughs (Fig. 5B). This section documents also, that the river accumulating the Upper Terrace gravels could have flowed also to the north, to the Cielnica valley, through a local depression in the Otmuchów–Nysa Hills (Fig. 2). The extensive Upper Terrace level is present in the Cielnica river valley as well as in the Nysa Klodzka river valley, and both gravels include porphyry, suggesting the same fluvial system of the Nysa river (Fig. 6). It seems, that the river could bifurcated at the same time during deposition of the Upper Terrace (Fig. 2).

The Upper Terrace occurs practically only on the left side of the valley in the S–N stretching valley fragment between Nysa and Grodków (Fig. 2). At Rusocin and Lasocice, the Upper Terrace gravels lie on the Miocene sandy-clayey deposits and locally on a thin till or glaciofluvial sand. The alluvial gravels are up to 4 m thick. In places, further erosion moved alluvial gravels away, and recently there are only flat erosional surfaces in the terrace level, with till or Miocene clay at surface. Badura & Przybylski (1992) distinguished two Upper Terraces levels in this region, basing on different heights of the terrace levels downvalley. However, it seems now that this is an uniform horizon which changes rapidly its height downvalley, with a knickpoint near Lasocice. Also, north of this knickpoint, the alluvial gravels are much more thick, reaching 10–12 m (Fig. 4 – section IV). The Upper Terrace gravels were formed in this region not only by the Nysa river, but also in part its left-side tributaries, which provided a new material, mainly milk quartz from redeposited Pliocene series (Fig. 6)

The Upper Terrace is not present at surface near Grodków and down the river (Fig. 2, Fig. 4 – section V). However, north of the valley, porphyry-bearing gravels were found in boreholes and outcrops. They are covered by glacial deposits, which locally form large hills. Woldstedt (1932) interpreted these hills as representing ice marginal zone of the retreat phase of the early Saalian glaciation. Walczak (1970, 1972) suggests that these hills represent kames from the time of early Saalian ice sheet retreat. The porphyry-bearing gravels covered by 1–2 m thick till can be also observed in Bystrzyca Oławska, in the Odra river valley zone (Fig. 6). These gravels are up to several metres thick. It seems, that the Nysa Klodzka river could have flowed before the latest ice sheet advance directly to the north, from Grodków to Bystrzyca Oławska.

MIDDLE TERRACE

The Middle Terrace horizon is from 10 to 17 m high above the present river channel and forms only isolated

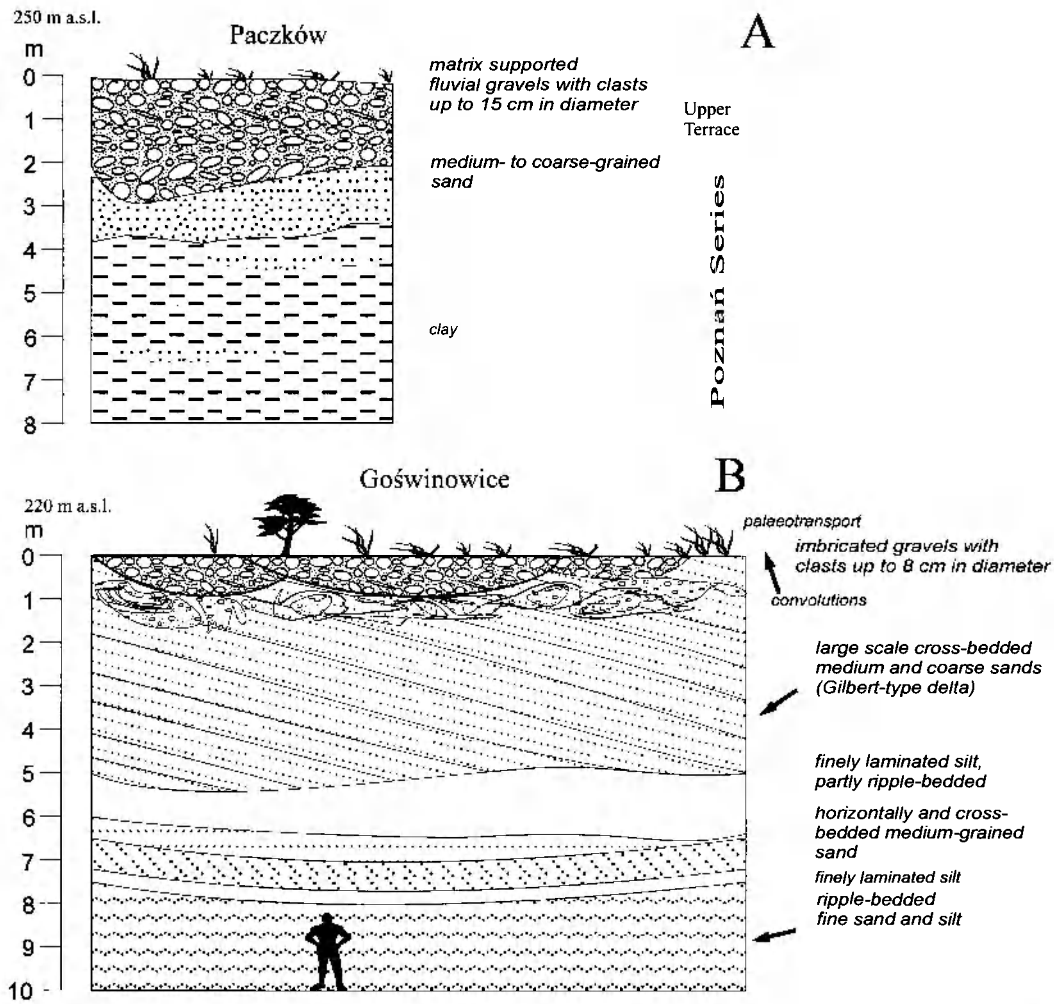

Fig. 5. The Upper Terrace gravels at Paczków (**A**) and at Goświnowice (**B**) gravel pits. Note that the uppermost alluvial gravels at Paczków are matrix-rich and are mixed with slope, loess-like deposit, and alluvial deposits from Goświnowice distinctly differ in size from the underlying glaciodeltaic sediments.

benches on both sides of the valley (Fig. 2). The well preserved, 15 m high, fragments of this horizon are between Bardo and Kamieniec Zabkowicki, although not much is known about their internal structure. Other well preseved Middle Terrace benches are between Paczków and Nysa. The Middle Terrace level in this region is separated from the Upper Terrace level by a distinct edge formed in Miocene deposit. The Middle Terrace deposits are, however, poorly exposed in outcrops. The sediments are described only in 1–2 m deep trenches and occasional boreholes. Coarse-grained gravels with a thickness of around 10 m make up here the Middle Terrace. Petrographic studies shows that the gravel clasts are very like those of the Upper Terrace in the same region (Fig. 6). Only limited remnants of Middle Terrace are preserved on the western side of the S–N stretching fragment of the valley. In contrast, the Middle Terrace level forms an extensive surface on the left side of the valley near Lewin Brzeski, where it reaches 13–15 m above the river channel. Alluvial deposits are, however, poorly preserved, and the surface is mainly erosional. It is separated from the till upland by a distinct edge running from Michałów through Losiów to the Odra river valley.

LOWER TERRACES

Generally there are two Lower Terraces. In many sections, however, it is difficult to separate each from the other as the morphological edge between them is not well developed (Fig. 2, 3, 4). In such places, the boundary between the upper Lower Terrace and lower Lower Terrace levels is placed at the margin of recent channel erosional features.

Upper Lower Terrace

The upper Lower Terrace occupies the external zone of the valley bottom, and is 1–7 km wide and usually 2–5 m high above the river channel. In places, were local fans of the tributary rivers are formed, it may reach height up to 8 m above the river channel (Fig. 2). The base of this terrace is usually cut directly into the Miocene sandy-

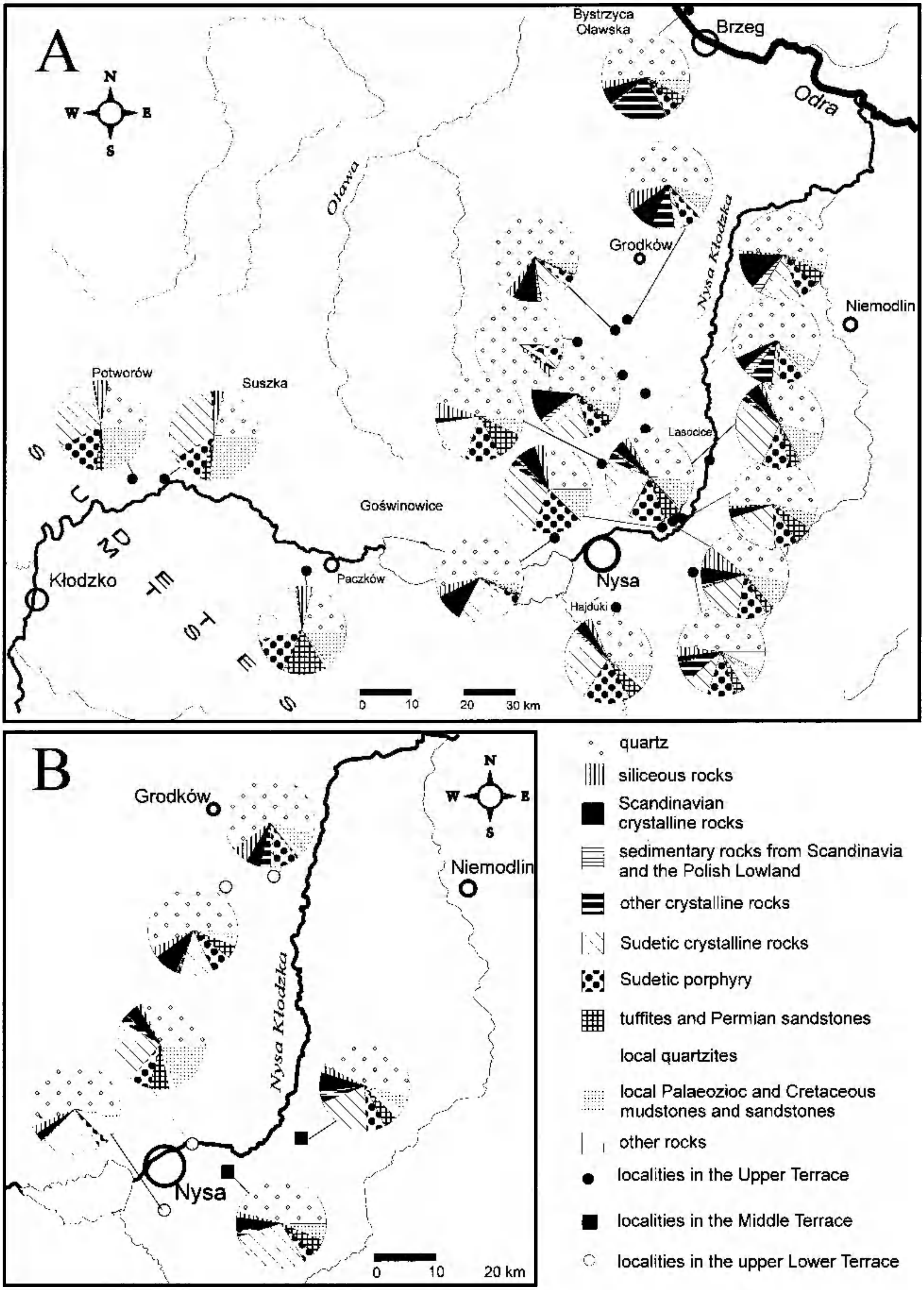

Fig. 6. The petrographic composition of the gravels from the Upper Terrace (**A**) and Middle and upper Lower Terraces (**B**).

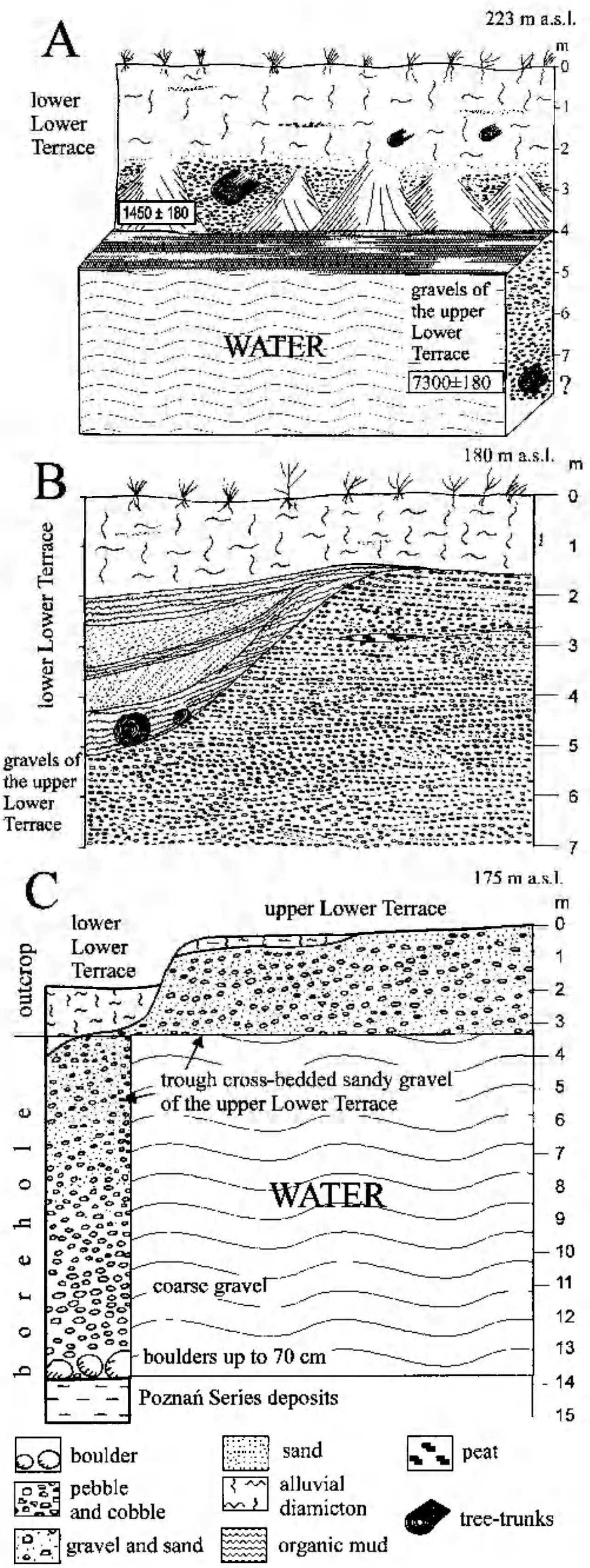

Fig. 7. Examples of sediment sequences of the Lower Terraces: A – at Kozielno, B –at Nysa, C – at Malerzowice. Note different positions of the Holocene tree trunks at Kozielno and Nysa; detailed discussion in the text.

clayey deposits (Fig. 3, 4). Relative erosion, with the Middle Terrace surface as a marker level, reached a depth of 20–30 m. This erosional valley bottom is relatively flat (Fig. 3, 4). However, there are two distinct erosional surfaces in the valley bottom, with 2–5 m height difference, between Otmuchów and Malerzowice (Fig. 3 – section III, Fig. 4 – section IV). They show, most probably, that the floor of the Nysa Kłodzka valley was formed during two separate erosional phases. The thickness of alluvial deposits is 10–15 m. Alluvial suites are represented by a series of gravels and pebble sands. Lenses of fine grained and organic deposits have been noticed occasionally (Fig. 7B). Often, a lag pavement made up of cobbles and boulders is present on the erosional floor of the valley as well as there are common tree trunks in gravelly sediments (Fig. 7A). The maximum observed boulder, 70 cm in diameter, is from Malerzowice (Fig. 7C).

The upper Lower Terrace sequence of section at Nysa is 7–9 m deep and contains poorly sorted, massive to crudely horizontally bedded gravels. There is also a 20 cm thick layer of peat in the uppermost part of gravels (Fig. 7B). Similar gravelly deposits of the upper Lower Terrace have been observed in outcrops at Pilce, Malerzowice and Brzeziny. These sections are 0.5–1.0 km long and 3–4 m high. At Pilce, there are only massive to crudely horizontally bedded gravels, whereas down the valley, the content of sand increases markedly. At Brzeziny, sandy lithofacies dominate and gravels are only up to 20–30% of the sediment sequence. Besides the massive and horizontally bedded gravels, the sections at Malerzowice and Brzeziny contain also cross bedded sand and gravel, including large troughs. These sequences have neither fine-grained (silt, clay) nor organic deposits. The sediment characteristics described above suggests, that the upper Lower Terrace sequence was deposited in a gravel-bearing river. The almost total lack of overbank sediments and size of gravels suggest high energy river, representing, most probably, a braided river system. The gravels of the upper Lower Terrace are markedly smaller at the top alluvial sequences in the whole valley, suggesting decrease in river energy through time. The petrographic composition of gravel clasts of the upper Lower Terrace does not differ from that of gravels of the Upper and Middle Terrace levels (Fig. 6). Also, as in older terraces, the tributaries markedly changed the petrographic composition of the gravels, especially those flowing from the south, *e.g.* the Biała Głucholaska river. The southern rivers formed also large fans with very coarse-grained material, that transist lateraly into the upper Lower Terrace in their valley mouths (Fig. 2). Other tributaries of the Nysa Kłodzka valley deposited slightly finer material, sand and silt.

Lower Lower Terrace

The lower Lower Terrace is from 1.5–2.0 m to 3.5–5.0 m high above the river channel. It occupies either central part of the valley bottom, or occurs at the valley side (Fig. 2). It is 250–300 m wide between Bardo and Kamieniec Ząbkowicki and 1–3 km wide in the remaining part of the valley. However, its width varies downvalley, forming zones with wide terrace (2–3 km) separated by a narrow terrace (*ca* 1 km) zones (Fig. 2). The lower Lower Terrace comprises practically only fine-grained deposits, fine sand, silt, organic sediments and alluvial diamictons (poorly sorted silt with gravel clasts) (Fig. 7B). The thickness of sediments is from 1–2 m in the Paczków region and up to 5 m in the S–N stretching valley fragment.

AGE OF TERRACES

Apart from single analyses of wood using ^{14}C method and dendrochronological analyses carried out from the two lowest fluvial horizons, there is a lack of absolute dating of terrace horizons in the Nysa Klodzka valley. Their relative age can be defined by correlation to glacial deposits and to terrace sequences in the mountainous Nysa Klodzka river and in the Odra river valleys.

The crucial fact in the discussion of the age of the Upper Terrace is, that this fluvial level is covered by glacial deposits north of Grodków. The alluvial surfaces at height 25–32 m were not found in the Odra river valley down from Opole (Badura & Przybylski, 1996), and it seems, that similarly to the lower courses of the Nysa Klodzka, the Upper Terrace gravels are buried under the till cover (Fig. 8). Walczak (1954) suggested that the till covers the entire Upper Terrace of the Nysa Klodzka valley south to mountain margin, with the type section at Paczków brickyard. He argued, that fluvial gravels are overlain there by a till from the early Saalian (Odranian) glaciation. However, it is clear from recent study at Paczków, that there is no till at all, and it seems, that in former study (Walczak, 1954; Walczak, & Rutkowski 1974), the uppermost loess-like slope deposit was misinterpreted. Thus, the Upper Terrace is therefore not covered by glacial deposits until it reaches Grodków.

The Upper Terrace of the Nysa Klodzka valley can be correlated by its height with the so known 'Ocice' Terrace of the Odra river valley near Racibórz. The age of this terrace level was suggested to late Saalian (Wartanian) stage (Szczepankiewicz, 1972; Lewandowski, 1988). This dating is, however, very far from precise, and takes into account only the lack of loess cover at the top of terrace (Lewandowski & Wieland, 1994) and the occurrence of Acheulian artifacts at the base of terrace gravels (Chmielewski, 1975). Lewandowski & Wieland (1994) suggested that the artifacts are rather of Middle Palaeolithic age than of Early Palaeolithic. If so, the 'Ocice' Terrace could have been formed also during the Weichselian.

The Upper Terraces of the moutainous region are usually interpreted as formed after the early Saalian glaciation, and in some valleys, gravels of this terrace lie on the till (Krzyszkowski *et al.*, 1998; Krzyszkowski & Biernat, 1998). The late Saalian (Wartanian) age is usually suggested for this terrace level. However, data from the Sudetic Foreland and the Silesian Lowland suggest that the Upper Terrace could have been formed directly after glaciation, most probably during the general retreat of the ice sheet of the early Saalian (Odranian) glaciation. In this case, the glacial sediments overlying the Upper Terrace gravels north of Grodków may come from local re-advance during the general ice sheet retreat. However, the age of the glacial series north of Grodków is controversial, as lately these deposits were interpreted as belonging to the main, early Saalian advance (Czerwonka & Krzyszkowski, 1992; Badura *et al.*, 1998).

The Middle Terrace may represent a fluvial level from the next cold stage following the early Saalian (Odranian) glaciation, the late Saalian (Wartanian) (Fig. 8). The ice sheet of the latter glaciation was further north, and the Odra river valley collected water from the ice sheet (via proglacial sandurs) and from southern rivers, such as Nysa Klodzka. Jersak *et al.* (1992) found that the Middle Terraces of southern Poland, including the upper reaches of the Odra river valley, are of Weichselian age. The heights of these terraces are, however, highly variable ranging from a few metres to 12–18 m. The heights of the Upper Terraces in the same regions are very similar and often older fluvial deposits can be found at the base of Weichselian sequences. Thus, the terrace heights probably cannot be used for relative dating of terraces. In the case of Nysa Klodzka, the Middle Terrace and the upper Lower Terrace are both in the height range for the Weichselian

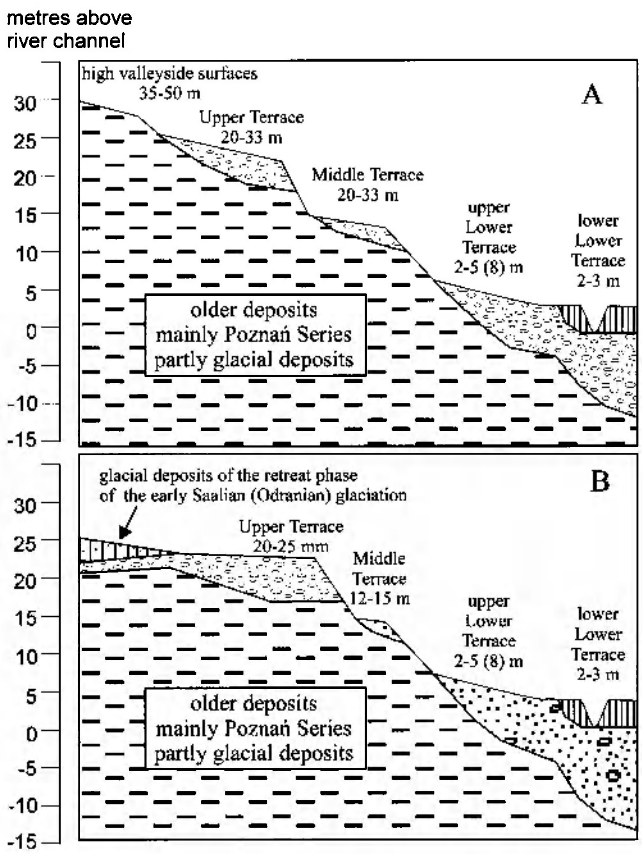

Fig. 8. Terrace successions in the Nysa Kłodzka river valley: **A** – Paczków Graben area, **B** – lower course of the valley near Grodków. Detailed discussion on terrace ages is in the text.

fluvial deposits described by Jersak *et al.* (1992). It seems, that correlation of terraces and fluvial events between the upper reaches of the Odra river drainage basin (Jersak *et al.*, 1992) and the Nysa Kłodzka river is not plausible. The last one represents the fore-mountain, gravel-bearing river crossing the bedrock hills of generally uplifted tectonic zone. In turn, the upper reaches of the Odra river and its tributaries are located in the tectonic basin with subsidence and sediments are fine-grained and come from redeposition of glacial deposits. This may explain differences between these two regions, and thus terrace stratigraphy by Lewandowski (1988) and Jersak *et al.* (1992) has only limited value in the Sudetic Foreland. In the mountainous area, Krzyszkowski *et al.* (1998) described two Middle Terraces with possible Weichselian age. It can be that the Middle Terrace of the Sudetic Foreland represents an age equivalent level to one of them, although there are no data to confirm unambiguously this correlation.

The present-day Nysa Kłodzka valley bottom was most probably eroded during Eemian Interglacial, a period when the climatic conditions favoured the development of meanders and strong lateral erosion. The upper Lower Terrace deposits could have been deposited during the following cold stage – during the Weichselian. The dominant gravelly sedimentation in this fluvial horizon and a lack of clear palaeomeanders, as documented in the gravel pits at Pilce, Malerzowice and Brzeziny, suggests a braided river, similarly to Upper and Middle Terraces, and probably periglacial climatic conditions during accumulation (Fig. 8). This terrace level well corresponds to the level of the Weichselian terrace in the Odra river valley between Opole and Wroclaw (Szczepankiewicz, 1968, 1972). However, the other interpretation is also possible. Small oxbows can be buried under the gravelly series, which have not been hitherto found. Moreover, at Nysa, the gravel series exposed down to a depth of 7–9 m contains thin peat layer in its upper part (Fig. 7B), and, at Kozielno, upper Lower Terrace gravels contain several tree trunks (Fig. 7). Wroński (1974b) claims that the trunks are present down to the depth of 10 m, *i. e.* practically to the base fluvial gravel. The absolute age of the wood taken from a depth of 7 m is 7300 ± 180 yrs BP (Pazdur 1973; *vide* Wroński, 1974b). This suggest the trunk accumulation during the Holocene climatic optimum. However, position of this trunk is ambiguous, as it was not found *in situ*, but dug out from the bottom of the water pond (Fig. 7A). The age of other trunk, taken from the upper part of gravels of the same profile, has been established to 1450 ± 180 yrs BP (Pazdur, 1973; *vide* Wroński, 1974b). The tree trunks from Kozielno were also examined using the dendrochronological method. Krąpiec (1992) has stated, that the trunks have 300–350 growth rings and that are two generations of trees at the site, which were felled two hundred years apart. The youngest tree trunks were dated dendrochronologically to 1285 ± 90 yrs BP (Krąpiec, 1992). Similarly to Kozielno, wood fragment were found down to the base of upper Lower Terrace gravels near Gracze. However, this wood was not investigated in detail, and it also may represent redeposited Miocene plant remains, as outcrops of the Miocene lignite occurs in adjacent region. Thus, the evidence at Kozielno is rather unusual. If the deepest tree trunk at Kozielno is *in situ*, it means that the upper Lower Terrace gravels were deposited almost only during the last few thousand years. However, in the majority of rivers of southern and central Poland, the Holocene is characterised by erosion in channels, with accumulation of fine grained sediments restricted only to floodplains. Hence, the Nysa Kłodzka must have represented an exceptional river, carrying coarse-grained material far away from the mountain area also during the Holocene. In other case, when the lowest tree trunks at Kozielno is not *in situ*, only the uppermost part of the upper Lower Terrace gravels at Kozielno is of Holocene age. This stratigraphy may be explained due to activity of the Holocene floods and superposition of young gravels and tree trunks on top of the older (Weichselian) terrace (Fig. 8). Such floods, covering the entire bottom of the valley and leaving tree trunks troughout the valley, were observed several times during last 200 years, with the latest in 1997. This interpretation is also in a good agreement with the fining of gravel sizes in the uppermost parts of the upper Lower Terrace sequences.

The lower Lower Terrace is of Holocene age. Numerous hazel seeds that were found in organic muds of this terrace, *i.e.* at Nysa, indicate a relatively warm period during accumulation, probably climatic optimum of the Holocene and later (Fig. 8). A distinct division of meanders into generations, which enable to distinguish a sequence of Lateglacial and Holocene terraces, is not present in the Nysa Kłodzka river valley, in contrast to other valleys in southern and central Poland (Szumański, 1983, 1985; Starkel 1988).

THE ROLE OF GLACIATION IN THE DEVELOPMENT OF THE NYSA KLODZKA VALLEY

Since the work of Behr & Mühlen (1933) there is a discussion on position of the Nysa Kłodzka valley prior and during the Saalian glaciation. These authors claimed the Saalian ice sheet stopped at its maximum extent along the Otmuchów Nysa Hills (Fig. 1), and thus the Nysa Kłodzka valley developed eastward, at the margin of an ice sheet (Fig. 9). Walczak (1954) claimed that the original Nysa valley functioned during an ice sheet advance, and later the ice sheet stopped fluvial activity reaching the Sudetes Mts, and finally, during the ice sheet retreat, the valley developed as ice marginal "pradolina" valley as described Behr & Mühlen (1933).

However, the Nysa Kłodzka valley was thought to have also functioned during the Pliocene and Early to Mid-

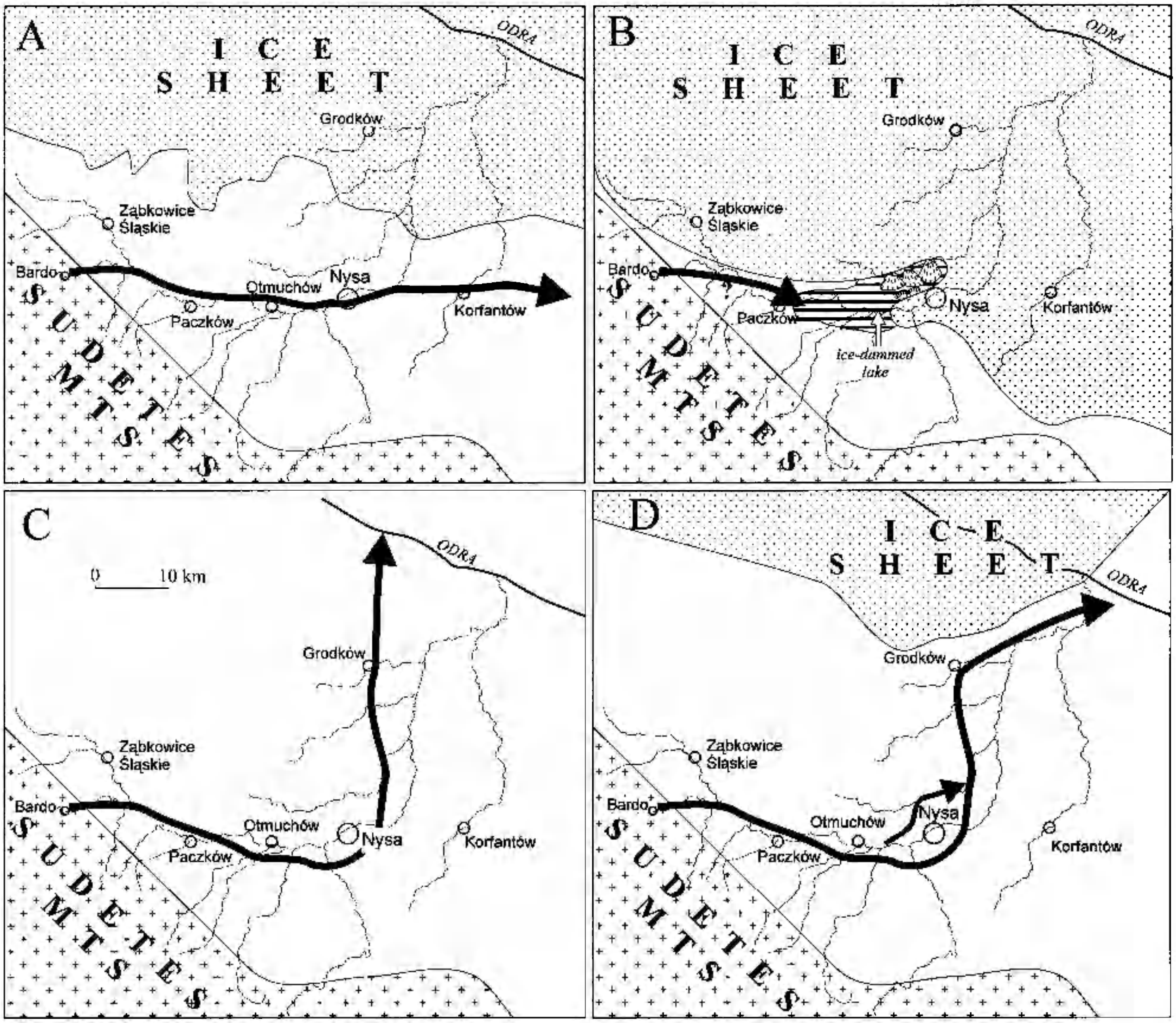

Fig. 9. Hydrographic changes in the Sudetic Foreland and formation of the Nysa Kłodzka valley: Early Saalian (Odranian) ice-sheet advance (**A**), continued ice sheet advance and formation of proglacial lakes as documented at Goświnowice delta (**B**), ice sheet retreat and river piracy to the north (**C**), and possible local ice sheet re-advance and blocking outflow to the north (**D**).

dle Pleistocene. During at least a part of this period, the Nysa Kłodzka river flowed to the east, as documented in preglacial series (Przybylski *et al.*, 1998), and due not to glacial action but to the uplift of the Niemcza–Strzelin Hills block and the forcing of the river in the direction of the Paczków graben (Fig. 1). This fluvial route was probably active many times until the Saalian Glaciation. Thus, the original, pre-Saalian valley, which is generally parallel to the ice shet margin, became a very good route for meltwaters during the ice sheet activity (Fig. 9A, B). After the retreat of the early-Saalian ice sheet, the Nysa Kłodzka river system continued to flow from Bardo along the line of the Paczków Graben but later was to change from easterly flow to northerly flow (Fig. 9C), forming the Upper Terrace horizon.

The rapid change of direction of the lower course of the Nysa Kłodzka valley east of Grodków may be of glacial origin (Fig. 9D). This change could have come into existence during local re-advance of an ice sheet, and shifting the Nysa Kłodzka river to the east.

THE ROLE OF NEOTECTONICS IN FORMATION OF RECENT NYSA KLODZKA VALLEY

GENERAL FEATURES OF THE LANDSCAPE

A characteristic feature of the eastern part of the Sudetic Foreland is the occurrence of several morphological zones, that are parallel to each other and to the major tectonic lines in the region, the Sudetic Marginal Fault and the Middle Odra Fault. This is especially well visible in the densed contour map (Fig. 10). A distinct edge, dividing the margin of the Strzelin Hills and Głubczyce Pateau from the Silesian Lowland, is probably related to another fault zone parallel to the Sudetic Marginal Fault. It is highly possible, that the eastern part of the Sudetic Foreland was uplifted along this fault line, and thus more intensively eroded than the high ground to the north-east of this morphological border. The latest uplift must have taken place also after the retreat of the last ice sheet in the area, therefore after the early Saalian glaciation. This is because the strong erosional processes brought about almost total erasure of the features of the glacial sediments and forms, leaving only fluvial (valleys) and tectonic (scarps) landscape in the marginal zone of the Strzelin Hills and Głubczyce Plateau. Also, there is a distinct deflection of several rivers along fault lines, among them the Nysa Kłodzka river, which strenghten the neotectonic interpretation of the lanscape (Fig. 10). Within the general morphological zones, there is a series of small units which indicate a clear link with the tectonic movements. Among them, there are romboid-shaped depressions and elevations, such as the Niemodlin Embankment and others (Fig. 10). The depressions follow the tectonic grabens in the bedrock, and some of them contain volcanic neks (*e.g.* at Gracze) (Badura & Przybylski, 1995b). Hence, the change of the course of the

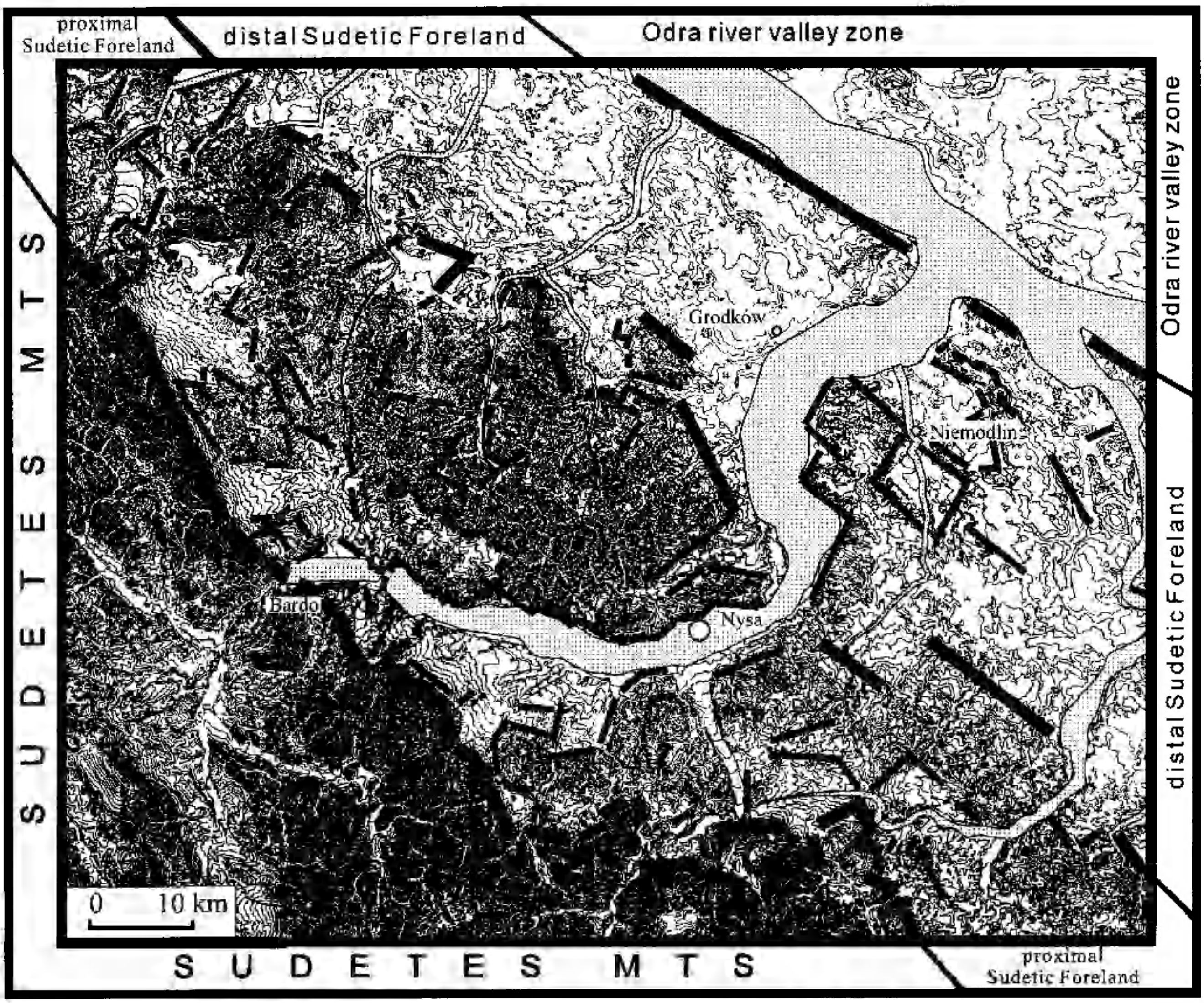

Fig. 10. Main morpho-tectonic zones of the eastern part of the Sudetic Foreland and interpretation of tectonic lines based on densed contour map: bold lines – main fault lines documented geologically, thin lines – possible faults with only morphological evidence (morpholineaments). Note distinct valley deflections along different fault lines and romboid depressions between Niemodlin, Nysa and Grodków.

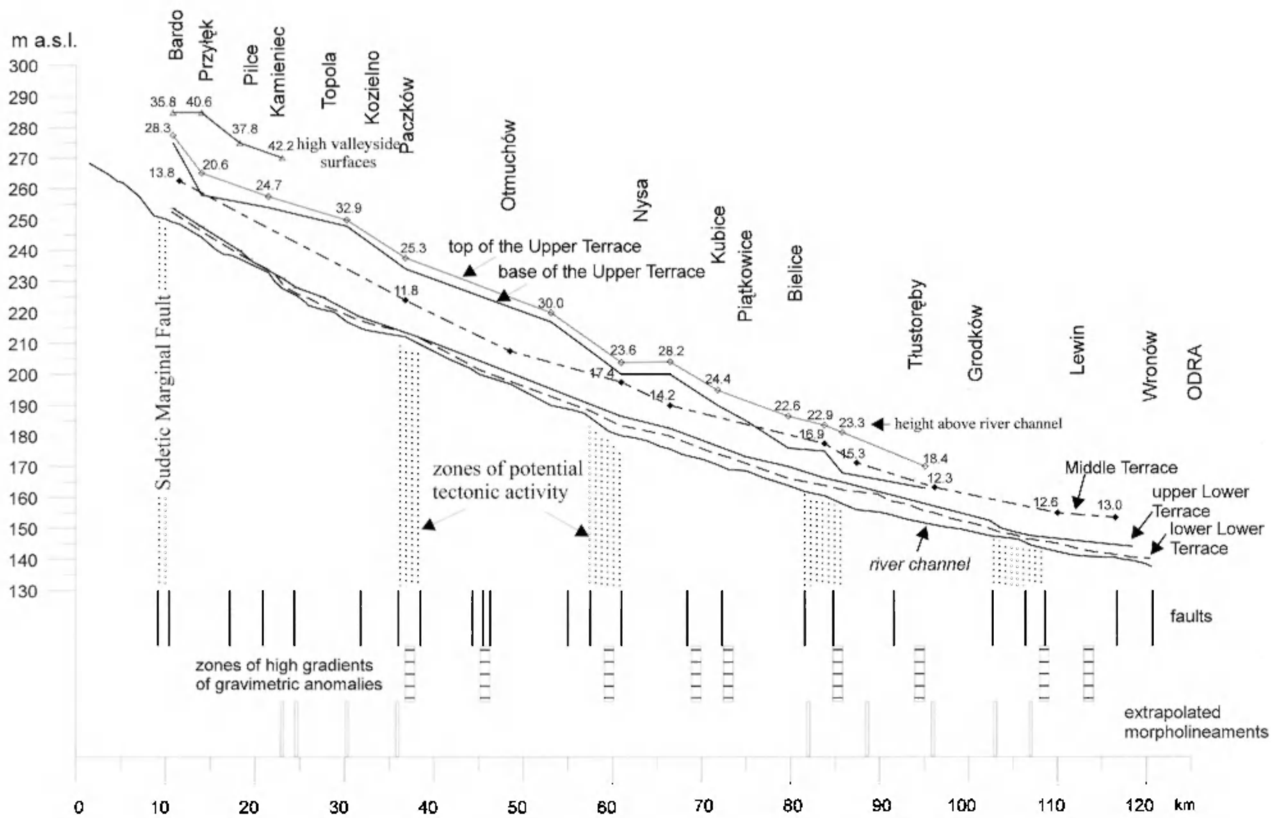

Fig. 11. Longitudinal profiles of the channel and terraces of the Nysa Kłodzka river. Note changes in sediment thickness as documented by position of the base and top of Upper Terrace gravels; and the occurrence of knickpoints in the terrace longitudinal profiles, which are located approximately in the fault zones.

Nysa Kłodzka valley to the north, between Nysa and Skoroszyce, is due to river piracy caused by headvalley erosion in the romboid-shaped depressions. The next change of the valley course to the east near Grodków is not necessarily only of glacial origin, but tectonic movements could influenced this process, too. The changes of direction of the Nysa Kłodzka river was probably caused due to post-glacial tectonic activity in the Niemodlin Embankment and adjacent depressions, with several probably located in the present-day valley (Fig. 10).

TERRACE TILTING

The height of terraces of the Nysa Kłodzka river distinctly vary along the valley (Fig. 11). Position of main knickpoints of individual terraces well coincides with some tectonic lines cutting the Nysa Klodzka valley and gravimetry anomalies. Most probably, the activity of a part these tectonic zones caused deformation of the terraces during the late Quaternary. Particular activity, leading to the deformation of the all terraces, is along the faults near Nysa and Tłustoręby (Fig. 11). Less deformation is near Paczków and between Grodków and Lewin Brzeski. The deformation could be a result of Quternary movements of individual blocks. The tilt of the Upper Terrace level is up to 5–8 m. Subsequent increase in thickness of alluvial cover suggests that the tectonic movements took place during the terrace formation. The only weak deformation of the younger terrace horizons indicates that the intensity of neotectonic movements reduced gradually from the time of the early Saalian, which well coincides with the glacio-isostatic origin of the tectonic uplift. However, even the youngest terrace exhibits clear deformation, especially in the region of Lewin Brzeski, where the valley crosses romboid depressions (Fig. 11). Also, the successive changes of width of the valleys at the time of formation of Lower Terraces are probably of tectonic origin. These facts suggest minor tectonic activity until recent.

CHANGES OF THICKNESS OF THE FLUVIAL SERIES

The alluvial gravels of the Nysa Kłodzka valley are relatively easy to differentiate from the basement deposits, as the valley floor is mainly made up of the Miocene clay, silt and fine-grained sands and partly of till or glaciofluvial sand. This is especially valid for the Lower Terraces, where only Miocene deposits were found in the basement. Thus, the changes of thickness of the alluvial sequence may be eventually related to neotectonic movements. These changes are well visible in the Upper Terrace level, where sediment thickness increases much directly at the mountain margin (Bardo region) and north of Nysa (Fig. 11)

The thickness of the upper Lower Terrace alluvial series varies from 10 m to 25 m. One of the best documented valley fragment is near Nysa (Fig. 12), based on over 2000

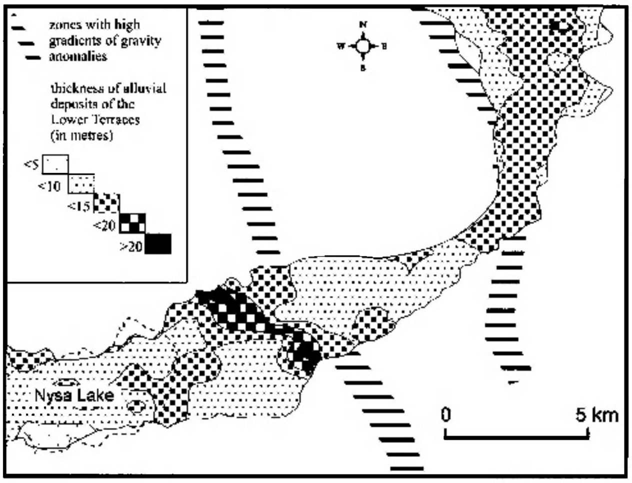

Fig. 12. The thickness of alluvial deposits of the Lower Terraces near the town of Nysa. Note that the local increase of alluvial sediment thickness coincides well with the possible fault zone interpreted from the map of the gravimetric anomalies.

drill holes, shows that the gravel-sand series has almost uniform thickness of 14–15 m, except one zone with gravel sediments of thickness up to 25 m, running perpendicular to the valley. It is possible to interpret this zone as a trace of an earlier deep through filled in with the older sediments, but it must be strenghten that this zone runs along a tectonic line in the basement (Fig. 10).

CONCLUSIONS

1. There are four terraces in the Fore-Sudetic part of the Nysa Kłodzka valley, which were formed probably during the retreat phase of the early Saalian (Odranian) glaciation (Upper Terrace), the late Saalian (Wartanian) (Middle Terrace), the Weichselian (upper Lower Terrace) and the Holocene (lower Lower Terrace).

2. The rapid changes of valley course could have been created due to tectonic activity in the region and one of them, between Grodków and Lewin Brzeski, also due to blocking of the outflow during local re-advance of an ice sheet.

3. Terrace height and thickness of alluvial sediment changes along the valley, and are especially distinct in the fault zones cutting the valley. The Upper Terrace level shows displacements of about 8–10 m, and younger terraces only 2–3 m. This suggests active tectonic processes during formation of late Quaternary terraces.

4. The postglacial tectonic activity can be assumed also for regions beyond the Nysa Kłodzka valley, where tectonic uplift led to more intensive erosion and a total removal of glacial deposits and forms.

5. Postglacial tectonic movements was, most probably, created by glacio-isostatic rebound after the early Saalian (Odranian) glaciation, though tectonic activity continued until Recent, as documented in the youngest terrace levels.

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