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Late Cainozoic evolution of the Nysa Kłodzka river system between Kłodzko and Kamieniec Ząbkowicki, Sudetes Mts, southwestern Poland

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Abstract The Nysa Kłodzka river drainge basin in the Sudetes Mts, SW Poland, preserves a complex late Cainozoic sequence that includes eight fluvial series/terraces and deposits from two glacial episodes as well as locally volcanic rocks, slope covers and loess. Sedimentation took place during the late Pliocene and since early Middle Pleistocene (Cromerian), with a long erosion phase (hiatus) during the Early Pleistocene. Fluvial series occur in the late Pliocene, Cromerian, Holsteinian, late Saalian/Eemian, Weichselian and the Holocene. Glacial deposits are represented in the early Elsterian and early Saalian stages. The main tectonic uplift and strong erosion was during the Early Pleistocene, with displacement about 60–70 m. Tectonic uplift was documented also for the post-Elsterian and the post-early Saalian time, and these uplift phases are most probably due to glacio-isostatic rebound. The Quaternary terrace sequence has been formed due to base level changes, epigenetic erosion after glaciations and neotectonic movements. The Cromerian fluvial deposits/terraces do not reveal any tectonic influence. However, all other Quaternary terraces indicate clear divergence, and the post-early Saalian terraces also offset by fault scarps. The total Late Pleistocene displacement along the fault scarps is about 25 m. The fluvial pattern is stable, once formed during the Pliocene, it continued in the same place until recently, with only minor changes along the uplifted block surrounding the Bardo gorge which infers the antecedent origin of the Bardo gorge. During the post-glacial times, epigenetic incisions have only slightly modified the valley.

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INTRODUCTION

Cainozoic deposits and fluvial terraces of the Nysa Klodzka (Glatzer Neisse) river valley have been investigated since the late 19th century (Dathe, 1895, 1900; Leppla, 1900) and this valley represents one of the most attractive research areas in SW Poland (Krzyszkowski *et al.*, 1995). The valley is located within three different geomorphological and geological zones: the Klodzko Basin and the Bardo Mts range (Bardo gorge) in the Sudetes and the Paczków Graben in the Sudetic Foreland (Fig. 1). It is only one of the valleys in the Sudetes Mountains which contain the Pliocene fluvial series (Dathe, 1895; Berger, 1932; Walczak, 1952, 1968, 1975; Jahn *et al.*, 1984); it also possesses the highest number of the Middle and Upper Pleistocene terraces (Finckh, 1925, 1929; Zeuner, 1928; Berger, 1932; Walczak, 1954; Wilczyński, 1991; Oberc *et al.*, 1996; Krzyszkowski *et al.*, 1995) and glacial deposits of at least two Scandinavian ice advances, not only till and glaciofluvial deposits, but also varved clays (Dathe, 1895, 1900; Leppla, 1900, 1906; Friedrich, 1904, 1906; Zeuner, 1928; Berger, 1932; Walczak, 1968, 1975; Jahn, 1985; Chmal *et al.*, 1993) (Table 1). This unusually rich stratigraphic evidence makes possible quite detailed palaeogeographic reconstruction of the Sudetes and its foreland since the Pliocene and facilitates correlation of some geological events with neotectonic movements, climatic changes and Scandinavian glaciations. This area is also crucial to discussions about the number of Scandinavian glaciations in the Sudetes Mts (Zeuner, 1928; Berger, 1932; Walczak, 1952, 1954, 1968, 1975; Jahn *et al.*, 1984; Jahn, 1985; Wilczyński, 1991; Chmal *et al.*, 1993).

A detailed terrace survey has been provided from the Nysa Klodzka river valley by Zeuner (1928), Finckh (1929), Berger (1932), Fischer and Meister (1934), Walczak (1954) and Wilczyński (1991). Results of recent studies have already been partially published by Krzyszkowski *et al.* (1995), Oberc *et al.* (1996) and Przybylski (1997). This paper presents all data from recent study, collected during 1993–1997, and provides a new stratigraphic synthesis.

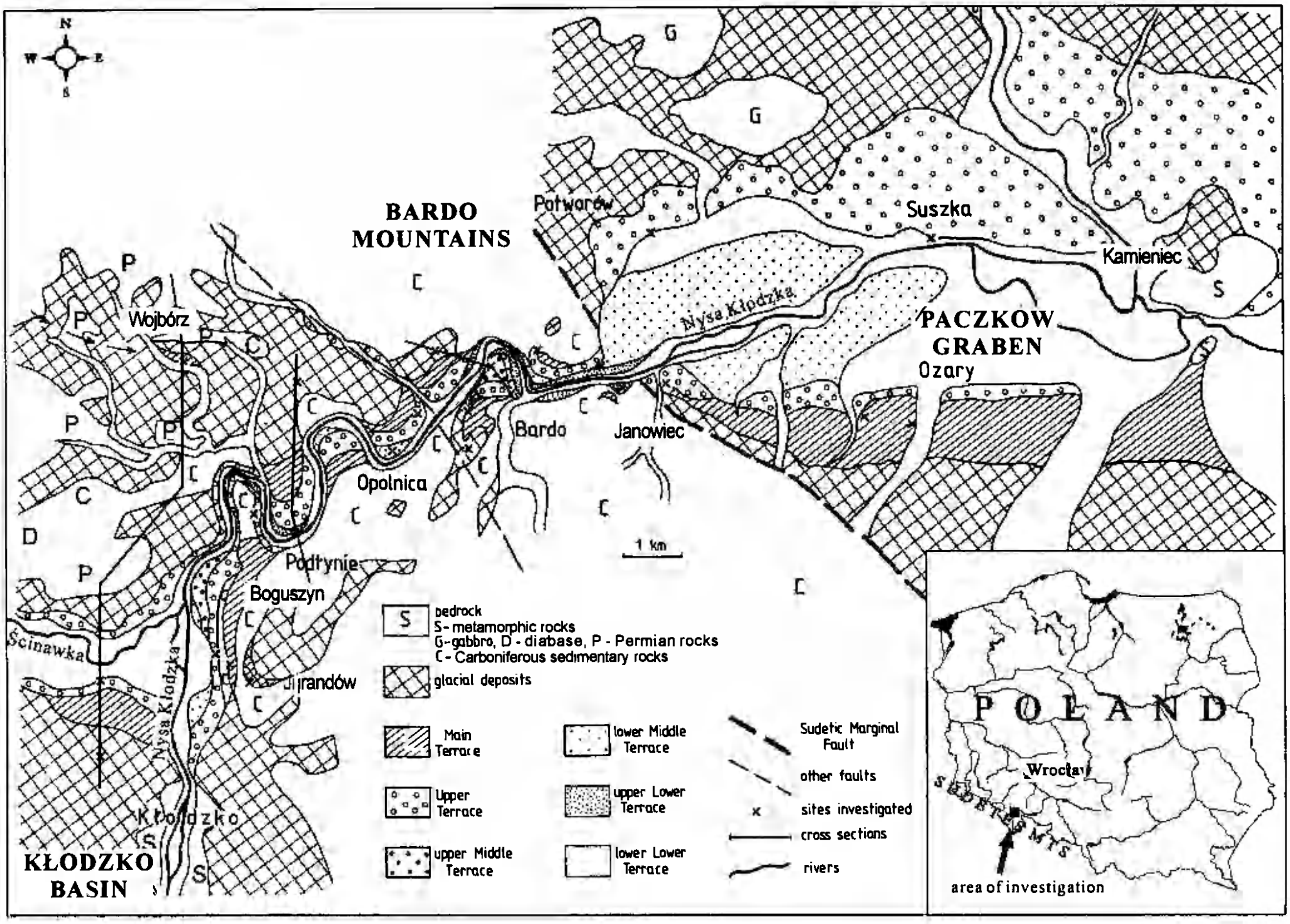

Fig. 1. Fluvial terraces and glacial deposits along the Nysa Kłodzka river valley between Kłodzko and Kamieniec Ząbkowicki. Cross sections are in fig. 10 (Bardo and Podtynie) and fig. 16 (Kłodzko–Wojbórz).

Table 1

Fluvial and glacial morphology/deposits in the Nysa Kłodzka river valley compared to other river valleys in the Sudetes Mts (after Krzyszkowski *et al.*, 1995)

morphology/deposits	other Sudetic river valleys	Nysa Klodzka river valley– -Kłodzko Basin	Nysa Klodzka river valley – Bardo Gorge	Nysa Klodzka river valley – Sudetic Foreland
Poznań Series (Miocene)	–	–	–	+
Pliocene gravels	–	+	+?	+
number of terraces older than the early Saalian glaciation	1	1–2	1–2?	2
till and glaciofluvial deposits	+	+	+	+
glaciolacustrine deposits, including varved clay	+	+	+	+
number of terraces younger than the Early Saalian glaciation	3–4	3–4	5	3–4
terrace divergence and fault scarps	+	–	+	–

Table 2

Terrace heights and stratigraphy in the Bardo gorge according to different authors

Zeuner (1928)		Berger (1932)	Wilczyński (1991)	Krzyszkowski *et al., this paper*	
Ławica	Bardo	Ławica	different areas	Boguszyn	Bardo
recent alluvial plain (?)		recent alluvial plain (?)	recent alluvial plain (?)	1–2 m	2–3 m
4–5 m	6 m	2–3 m	7–9 m	2–3 m	6–8 m
8–9 m (loess)	11–12 m (loess)	6–7 m (loess)			
12–13 m	16 m (Saale?)	10–11 m	11–13 m	10–12 m (loess)	16 m (loess)
16 m	24 m (Saale?)	12–14 m	16–17 m	15–16 m	25 m
			21–22 m		
24–25 m	35 m (Saale?)	22–23 m	25–30 m	20–25 m	30–35 m
glacial deposits (Elster) + Janowiec Gravels		glacial deposits (Saale)			glacial deposits (Saalian)
38 m	55 m	36 m	35–40 m	30–35 m	55 m
glacial depoits (the Oldest Glaciation)		glacial deposits (Elster)			glacial deposits (Elsterian)
			70 m glacial deposits (Saale)	70 m (fluvial gravels below glacial deposits ?) + Janowiec Gravels	70 m
		Janowiec Gravels			
preglacial gravels		preglacial gravels			95 m ? (=preglacial gravels ?)

Our conclusions differ from the older ones mainly in terms of the heights of the younger terraces and the proposed ages of geological events (Table 2). The former differences may be the result of base level changes, in turn the consequence of modern hydrotechnical development along the valley.

TERRACES OF THE NYSA KŁODZKA RIVER

There are seven terraces in the Nysa Klodzka river valley of which five are undoubtedly fluvial. The two highest flat levels are formed on thick glacial, slope or loess deposits (Fig. 1). However, fluvial gravels have been observed below glacial deposits and loess at least at some sites. Terraces have been mapped in the field; the heights of terrace surfaces have been measured by altimeter and then compared with heights indicated on 1:25,000 and 1:10,000 scale topographic maps. Measurements have been done in several cross-sections along the valley: Klodzko-Scinawica, Boguszyn, Ławica, Podtynie, Morzyszów, Opolnica (two sections), Bardo (three sections), Janowiec-Potworów, Ożary-Suszka and Kamieniec Ząbkowicki (Fig. 1). The heights of the top surfaces of fluvial gravels were measured along the same profiles, where it was possible.

LOWER TERRACES

Lower Lower Terrace. This is the lowest terrace, which represents the recent floodplain. It is 1–2 m high except the zone near the Sudetic Marginal Fault where it is 2–3 m high. The terrace is usually 300–500 m wide in the Klodzko Basin, with a maximum width of about 1 km at Boguszyn, and widths of 150–200 m in the Bardo gorge and 0.5–2.0 km in the Sudetic Foreland (Fig. 1). It represents a cut and fill terrace composed of a few metres of gravels with 1–3 m of silty-sandy deposits on top. This terrace has not been investigated in detail.

Upper Lower Terrace. This terrace occurs only in the Bardo gorge, between Ławica and Bardo, and forms the 50 m wide shelves on both sides of the valley (Fig. 1). The height of the terrace varies from 2–3 m (Ławica) to 6–8 m (Bardo). Zeuner (1928) calculated the height of this terrace

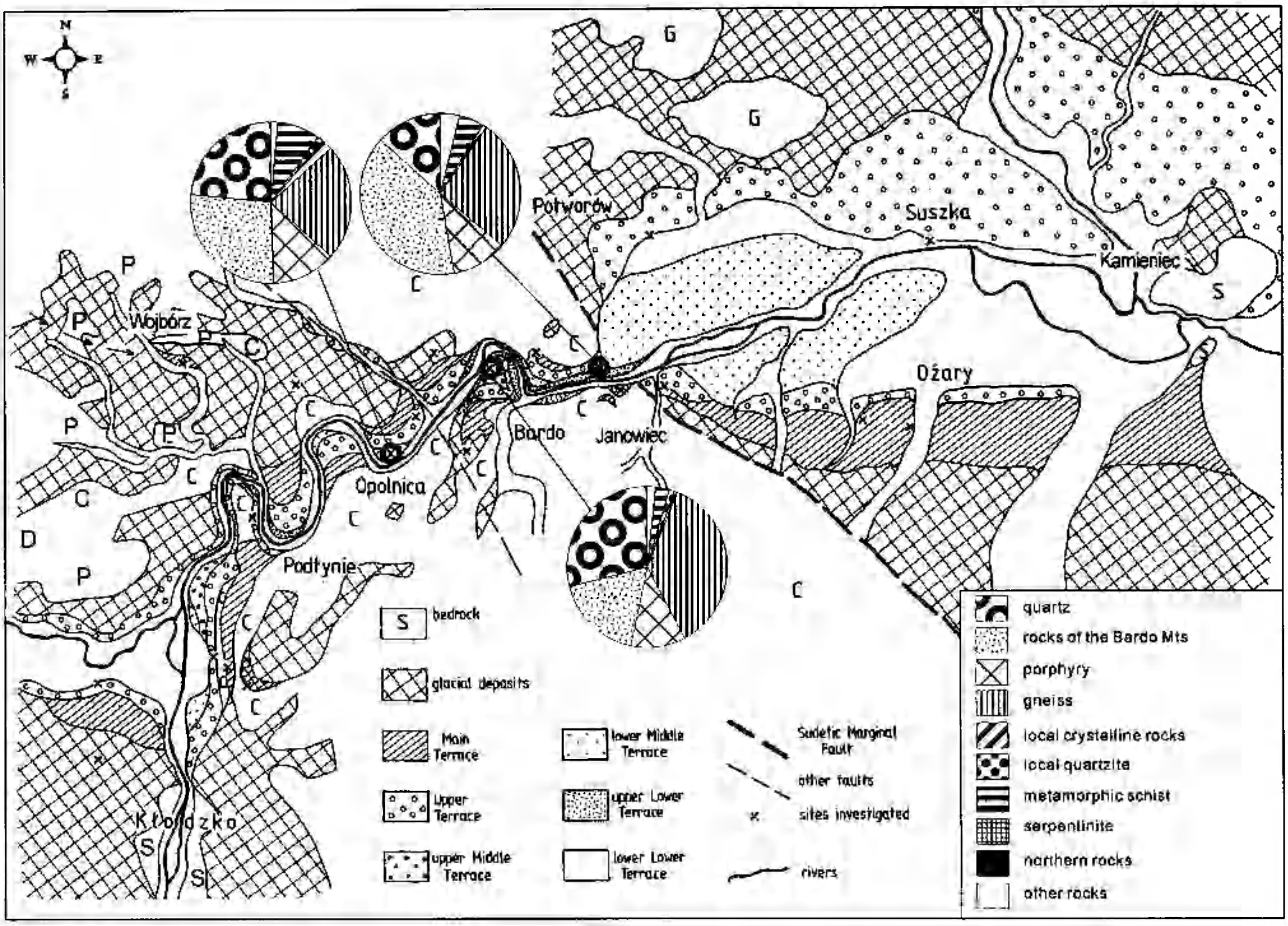

Fig. 2. Location of sites investigated and petrographic composition of the fluvial gravels of the Middle Terraces.

as 4–5 m at Ławica and 6 m at Bardo, but Berger (1932) and Wilczyński (1991) described heights similar to those presented in this paper (Table 2). The upper Lower Terrace represents a cut and fill terrace composed of a few metres of gravels with 0.5–1.5 m of silty-sandy deposits on top. This terrace has not been investigated in detail.

MIDDLE TERRACES

Lower Middle Terrace. This terrace level occurs discontinuously along the entire valley. Usually, the terrace patches are 50–200 m wide in the mountainous zone (Boguszyn, Ławica, Opolnica, Bardo) and it forms an extensive plain up to 2.5 km wide in the mountain foreland, presumably of an alluvial fan. Further downstream, near Kamieniec Ząbkowicki, width of the terrace is again limited (Fig. 1). The terrace height varies from 10–12 m at Ławica to 12–14 m at Podtynie and Opolnica and 16 m near the Sudetic Marginal Fault at Bardo. Zeuner (1928) and Berger (1932) described two terraces within this height range, respectively with terrace heights 8–12 m and 12–16 m (Zeuner, 1928) or 6–7 m and 10–11 m (Berger, 1932), both covered by loess. The first terrace with loess cover in our study is the 10–16 m terrace, and thus we correlate both terraces described by Zeuner (1928) and Berger (1932) with our lower Middle Terrace. Wilczyński (1991) also found only one terrace within this height interval.

The height of the lower Middle Terrace near the Sudetic Marginal Fault scarp is 16 m. It changes to only 6 m within a distance of about 200–300 m inside the mountain foreland, forming a narrow zone with an increased terrace gradient. The lower Middle Terrace in the mountainous area represents the rock terrace, with at least 1 m of fluvial gravels and 1–2 m of loess on top. Fluvial gravels have been investigated at Bardo and Opolnica (Fig. 2). These are massive to crudely bedded gravels with clast diameter up to 15 cm. Petrographic composition of gravels indicates source areas in the entire Kłodzko Basin (gneiss, schists, porphyry, quartz) and in the Bardo Mts (Carboniferous sedimentary rocks). Unambiguous northern material, from Scandinavia and the Polish Lowland, does not occur (Fig. 2; Table 3). The loess cover consists of both a fine aeolian component and clasts up to 10 cm in diameter, suggesting slope reworking.

Upper Middle Terrace. This terrace level occurs only in the Bardo gorge (Fig. 1). It forms shelves on the right side of the valley which are 300–400 m wide and about 0.5–1.0 km long. It is 15 m high at Boguszyn and 21–25 m high at Bardo. Former investigations indicated a similar height for this terrace (Table 2), which represents a rock terrace, with only 1 m of fluvial gravels and 4–8 m of loess cover on top (Fig. 3A). Fluvial gravels are massive to crudely bedded, with a maximum clast diameter of 15 cm. Large clasts are

Table 3

Petrographic composition of fluvial gravels in the fraction 5–10 mm of the Quaternary terraces between Klodzko and Kamieniec Ząbkowicki

Stratigraphy	Site	sample no.	quartz	lydite	siliceous rocks	grey Carboniferous sandstones	Carboniferous mudstones	white Cretaceous sandstones	Permian rocks, including porphyry	grey gneiss	red gneiss	local granitoid (light grey)	feldspar	dark crystalline rocks	local quartzite	metamorphic schists	serpentinite	Scandinavian granitoid (red)	Scandinavian quartzite (red)	flint from the Polish Lowland	concretions	undetermined
lower Middle Terrace	Opolnica	z/203	22.7	0.5	0.5	7.2	20.0	1.0	12.8	18.6	4.8	–	0.7	1.4	1.0	8.7	–	–	–	–	–	–
upper Middle Terrace	Bardo	z/216	27.8	1.1	1.3	8.1	9.6	0.4	11.3	32.2	3.8	–	0.4	0.3	1.0	2.8	–	–	–	–	–	–
Upper Terrace	Boguszyn	z/202	2.8	0.4	–	20.2	74.3	–	0.4	1.4	–	–	0.2	0.2	–	–	–	0.2	–	–	–	–
	Podtynie	z/210	27.4	0.5	1.3	5.8	8.3	0.5	21.4	26.9	2.3	–	1.5	1.0		3.3	–	–	–	–	–	–
	Podtynie	z/211	36.2	1.1	0.9	2.8	6.3	0.6	13.4	26.2	3.1	–	1.1	1.7	1.4	5.1	–	–	–	–	–	–
	Opolnica	z/207	1.4	1.2	0.6	21.9	71.8	–	0.3	2.3	–	–	–	–	–	0.6	–	–	–	–	–	–
	Opolnica	z/208	2.6	–	0.8	32.1	56.4	–	1.3	3.8	–	–	–	0.3	–	2.8	–	–	–	–	–	–
	Bardo	z/234	13.2	0.2	3.3	16.1	23.4	–	11.0	17.5	9.0	–	–	0.6	–	5.1	–	–	–	–	0.6	–
	Janowiec	z/220	–	0.3	0.3	19.0	77.3	–	–	–	0.6	2.3	–	0.3	–	–	–	–	–	–	–	–
	Janowiec	z/221	0.3	–	0.9	21.6	74.8	–	–	1.2	0.9	–	–	–	–	–	–	–	–	–	0.3	–
	Potworów	z/346	22.1	0.2	5.2	7.8	13.2	1.7	16.7	21.0	6.7	–	1.5	–	0.7	1.7	–	0.7	–	–	–	0.7
	Potworów	z/347	20.7	0.9	2.1	8.5	20.9	1.2	13.2	22.8	2.8	–	0.7	1.2	1.2	3.3	–	–	–	0.5	–	–
	Suszka	z/345	22.6	1.2	1.9	11.8	11.5	2.8	15.1	26.6	–	3.1	0.7	0.9	0.5	0.9	–	–	–	–	–	0.5
Main Terrace	Boguszyn	z/201	56.3	1.6	1.8	5.9	8.2	0.4	9.3	7.9	1.6	–	1.2	–	1.7	3.3	–	–	–	–	0.1	0.7
	Wojbórz	z/212	29.2	0.7	3.6	5.0	15.3	1.4	23.5	4.6	1.2	–	–	0.9	1.4	13.0	–	–	–	–	–	–
	Bardo	z/204	29.6	2.8	1.3	15.5	12.9	0.9	13.9	18.1	2.6	–	0.4	1.1	0.7	–	–	0.2	–	–	–	–
	Bardo	z/219	17.5	0.9	0.7	7.1	22.5	0.5	18.7	22.9	3.3	–	0.7	0.2	0.9	3.3	–	–	–	–	0.5	0.2
	Ozary	z/200	3.5	–	–	8.8	37.8	–	0.5	43.7	5.0	–	–	0.3	0.3	–	–	–	–	–	–	–
Glacio-fluvial Terrace (fluvial gravels)	Janowiec	z/231	19.2	0.3	2.5	8.2	9.3	3.1	24.2	15.8	10.7	–	1.7	0.3	3.1	1.7	–	–	–	–	–	–
	Janowiec	z/232	13.6	–	1.4	30.2	16.4	3.7	9.1	8.7	10.5	1.6	0.7	0.9	0.7	1.9	–	–	–	–	0.5	–
	Janowiec	z/233	14.8	–	0.4	22.2	18.3	0.8	16.0	19.3	–	0.6	–	0.2	0.6	0.8	–	5.3	–	–	–	0.4
Glacio-fluvial Terrace (glacial depo-sits)	Podtynie	z/213	23.3	0.7	2.8	11.7	22.1	2.3	12.8	12.8	0.5	–	0.9	–	1.6	0.7	1.9	4.4	–	1.4	–	–
	Opolnica	z/342	36.5	0.2	4.9	8.9	9.6	1.1	17.3	12.4	4.0	–	0.9	–	1.7	–	0.9	1.1	–	–	–	0.4
	Opolnica	z/343	34.1	1.8	2.6	7.9	18.1	0.2	12.1	14.1	2.0	–	0.6	0.8	0.6	3.6	0.4	–	–	0.2	0.4	0.4
	Opolnica	z/344	33.2	1.0	2.8	11.5	18.6	0.4	11.0	12.6	2.5	–	–	0.8	1.7	2.5	0.4	0.2	0.1	–	0.4	0.4
	Bardo	z/218	30.2	0.6	2.6	9.6	11.1	1.1	5.4	16.9	0.9	–	–	3.2	3.2	5.4	7.5	0.9	0.2	0.4	0.9	–
	Bardo	z/217	18.8	0.6	2.1	12.4	15.2	0.9	14.3	13.1	3.4	–	–	8.1	1.3	4.9	3.0	–	–	0.2	0.2	1.3

imbricated, indicating local palaeotransport from NW. The loessic cover contains single clasts with a diameter up to 5 cm and is interbedded locally with sandy laminae, both indicating slope reworking. The petrographic composition of the fluvial gravels is similar to that of the lower Middle Terrace (Fig. 2; Table 3).

UPPER TERRACE

This is the most widespread terrace among the older fluvial levels. It forms a continuous, 50–500 m wide alluvial surface on both sides of the valley in the mountainous area and shelves up to 3 km wide in the mountain foreland

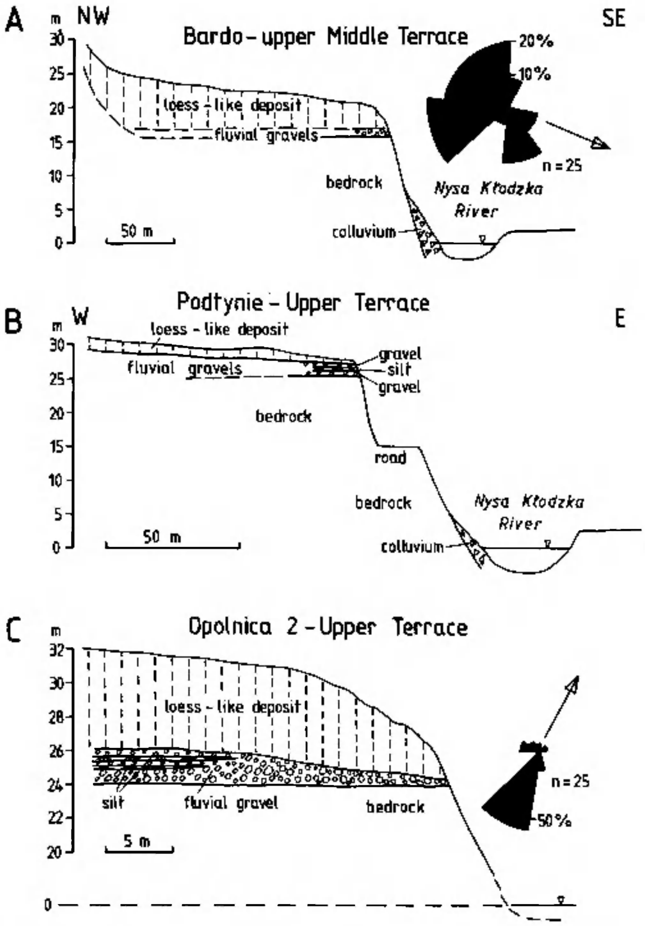

Fig. 3. Rock terraces in the Bardo gorge: **A** – upper Middle Terrace near Bardo, **B** – Upper Terrace near Podtynie, **C** – Upper Terrace near Opolnica.

area (Fig. 1). The latter probably represent remnants of a former alluvial fan (Fig. 1). The Upper Terrace represents a rock terrace (Fig. 3B and C), where the terrace base in the mountain foreland is formed of glacial or older fluvial deposits (Fig. 4). The terrace is 20–25 m high in the Kłodzko Basin, at Boguszyn, 25–30 m at Podtynie and Opolnica and 35 m near the Sudetic Marginal Fault at Bardo. It is only 25 m high in the Sudetic Foreland (Fig. 3). It seems, that like the lower Middle Terrace, the Upper Terrace forms narrow zones, between Bardo and Potworów and near Janowiec, with an increased terrace gradient and a 10 m drop of the terrace height. Former investigations indicated similar heights of the Upper Terrace, and the 21–22 m terrace at Morzyszów described by Wilczyński most probably belongs to the Upper Terrace level, too.

The Upper Terrace deposits have been studied in several exposures (Kłodzko, Podtynie, Opolnica, Janowiec, Potworów, Suszka) and additionally in 1 m deep trenches (Boguszyn, Bardo). The fluvial gravels are 1–3 m thick in the mountainous region (Podtynie, Opolnica) (Fig. 3). These are massive to horizontally bedded gravels, often with sandy or silty layers in their upper part. The maximum size of clasts is 15 cm. Local palaeotransport at Opolnica is from the SW (Fig. 3). Fluvial gravels are usually overlain by 1–2 m thick loess cover, but sometimes coarse-grained colluvium may occur (Bardo). The Upper Terrace gravels of the mountain foreland are from 3 m (Potworów) to 5–6 m (Suszka) thick. At Potworów, these are massive to horizontally and cross bedded gravels. The base of these gravels is erosional, marked by troughs and a boulder lag. The maximum size of clasts here is up to 0.5 m, including the strongly weathered ones. Local palaeotransport in the fluvial gravels is from the NW, whereas this from glaciofluvial deposits below is from the NE (Fig. 4).

Petrographically, the Upper Terrace contains three types of gravels (Fig. 5; Table 3). The first type comprises almost exclusively local Carboniferous rocks, very often angular. This type of gravel occurs always at the mouths of small tributary valleys (Boguszyn, Opolnica, Janowiec), being most probably connected with local sedimentation (Fig. 6). The second type is porphyry-dominated, indicating the source area in the NW part of the Kłodzko Basin (the Ścinawka river valley; Fig. 1). In turn, the third type of gravel indicates mixed petrographic composition, collecting material from the entire Kłodzko Basin and local sources. The latter type is identical with gravel assemblages of the younger terraces. Occasionally, some Scandinavian material occurs within the Upper Terrace gravels, and varies from 0.2% to 5.3% (*e.g.* red granitoids at Boguszyn, Bardo and Potworów and Mesozoic flint at Potworów) (Table 3).

MAIN TERRACE (YOUNGER PRE-GLACIAL TERRACE)

These are 0.5–1.0 km wide surfaces in the Kłodzko Basin and the Sudetic Foreland, and 100–300 m wide surfaces in the Bardo gorge. This level is less continuous than the Upper Terrace (Fig. 1) and it occurs at heights from 25–30 m near Boguszyn, to 30–35 m at Podtynie, Morzyszów and Opolnica and 55 m near the Sudetic Marginal Fault at Bardo. Its height at the Sudetic Foreland is 30–40 m. Similar heights have been reported during former investigations (Table 2). This fluvial level represents the rock terrace, either with bedrock (mountainous area) or older Cainozoic deposits (mountain foreland) at the base.

The characteristic feature of the Main Terrace is that the fluvial gravels are overlain not only by loess (Boguszyn, Ławica, Opolnica), but also by glaciofluvial deposits (Podtynie, Opolnica, Bardo) and diamictons (Boguszyn, Morzyszów, Opolnica, Bardo, Janowiec–Ożary and Wojbórz). The latter have been interpreted by Finckh (1929) as glacial till, although Oberc *et al.* (1996) reported only fine-grained slope colluvium. Fluvial gravels of the Main Terrace have been studied in the Bardo gorge only in three small trenches (Fig. 6); none have reached the terrace base. The thickness of fluvial gravels in the Bardo gorge is at least 1 m. Beyond the gorge, gravels are from 1–2 m (Ożary) to at least 7 m (Kłodzko) thick. Gravels are massive or horizontally and cross bedded. Massive sets indicate strong imbrication. Maximum clast diameter is up to 10–15 cm. Fluvial deposits are overlain by glacial deposits, till and glaciofluvial sand, as well as by slope covers, altogether about 10 m thick.

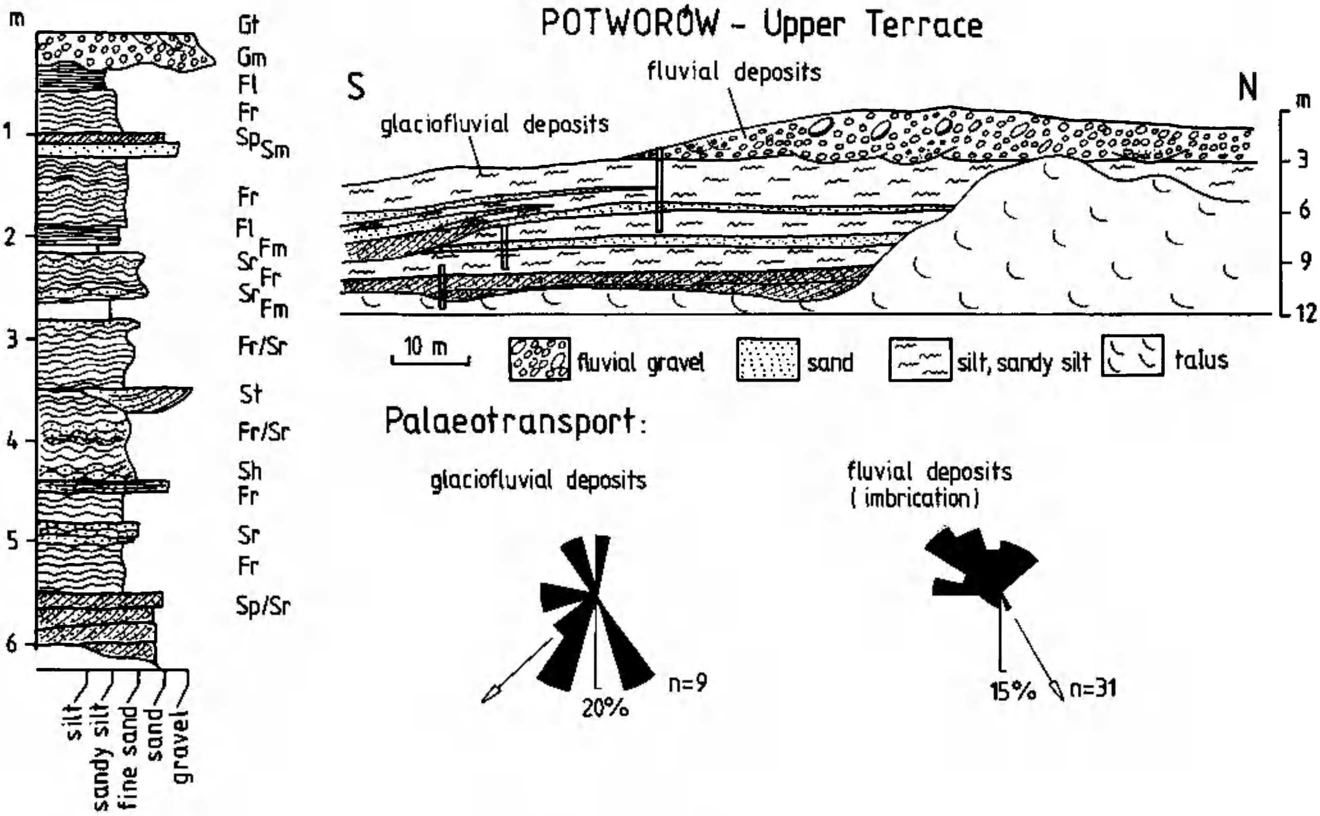

Fig. 4. Sediments of the Upper Terrace near Potworów in the Paczków Graben, Sudetic Foreland.

There are five petrographical types of fluvial gravels within the Main Terrace (Fig. 6; Table 3): 1. Quartz-dominated gravels at Boguszyn, 2. Gneiss-dominated gravels at Klodzko ("Grey Gravels"), 3. Porphyry-dominated gravels at Wojbórz, 4. "Mixed" gravels in several sites along the Bardo gorge, and 5. Local gravels with only Carboniferous rocks at Ożary in the Sudetic Foreland (local source) (Fig. 1, 6). In all types of gravels, there is occasionally a small admixture of Scandinavian material (0.2%–3.8%, exceptionally up to 14% at Ożary).

GLACIOFLUVIAL TERRACE (OLDER PRE-GLACIAL TERRACE)

This level occurs only in the Bardo gorge. The glaciofluvial sediments occurs in the Bardo gorge at different levels. Some of them overlie the Main Terrace (at heigth *ca* 40 m), other, more common deposits, lie directly on the bedrock shelves being 70–75 m above the valley floor. These shelves are 100–300 m wide on the right side of the valley, whereas the left side of the valley is occupied by 0.5–1.5 km wide zone with glacial deposits (Wojbórz–Opolnica area; Fig. 1). The complete sequence of the 70–75 m terrace has been observed only at one site – Jurandów (Wilczyński, 1991) (Fig. 7). This site comprises lower, local gravels of fluvial origin (1–2 m thick), varved clay (0.3 m), till (2–3 m), the upper, glaciofluvial gravels (2 m) and loess (5 m). The till is supposed to represent the oldest till in the region, *i.e.* representing the early Elsterian ice advance (Badura *et al.*, 1998). However, this cannot be proved as Wilczyński (1991) did not present petrographical data from the till and older gravel. Recently the section has not available for investigations. In other sites only glaciofluvial sediments have been observed (Fig. 9). At Podtynie, glacial deposits are represented by sands and gravels with dominant large-scale planar cross bedding, and occasionally with horizontal or low-angle bedding (Fig. 8A). This sequence suggests a Gilbert-type delta, probably connected with the local ice-dammed lake. At Opolnica, massive and horizontally bedded gravels and partly sand and gravel dominate (Fig. 8B). The maximum thickness of glacial deposits is about 10 m at Opolnica (Fig. 8B). Other sites probably indicate similar thickness of glacial deposits, except the Podtynie–Wojbórz area (Fig. 1), where they may reach up to 30 m.

The glaciofluvial deposits differ markedly from fluvial gravels, as they comprise, beside the "mixed" gravels, also more frequent northern rocks and the serpentinites (Fig. 9; Table 3). The latter come from the Sudetic Foreland, and are common components in the tills of this region (*e.g.* at Janowiec, Badura *et al.* 1992, 1998). Moreover, there are two types of glaciofluvial deposits in the Bardo gorge, one containing 0.4–3.0% of serpentinite and the other, with more frequent serpentinite (up to 7.5%), which directly follow the serpentinite content in the late Elsterian and/or early Saalian tills and the early Elsterian till, respectively (Badura *et al.*, 1992, 1998).

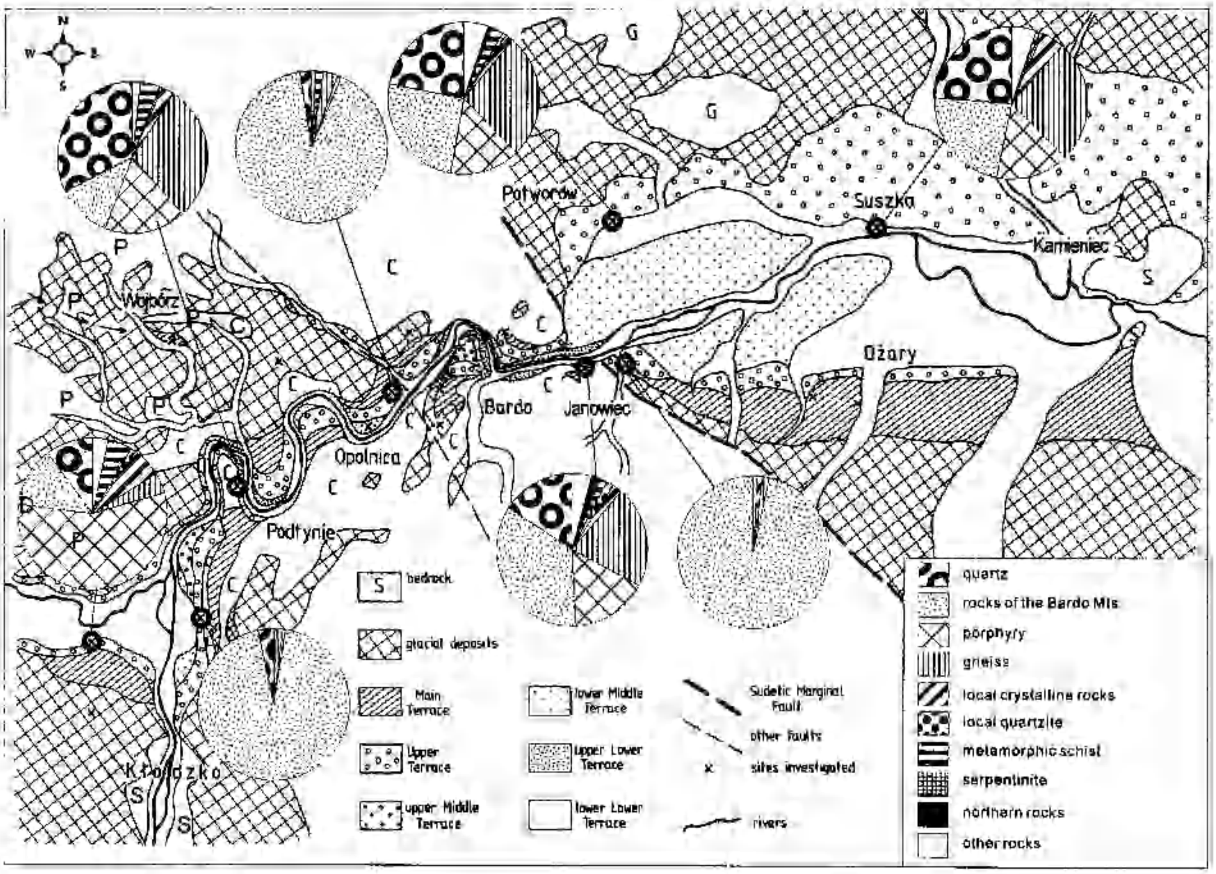

Fig. 5. Location of sites investigated and petrographic composition of the Upper Terrace fluvial gravels.

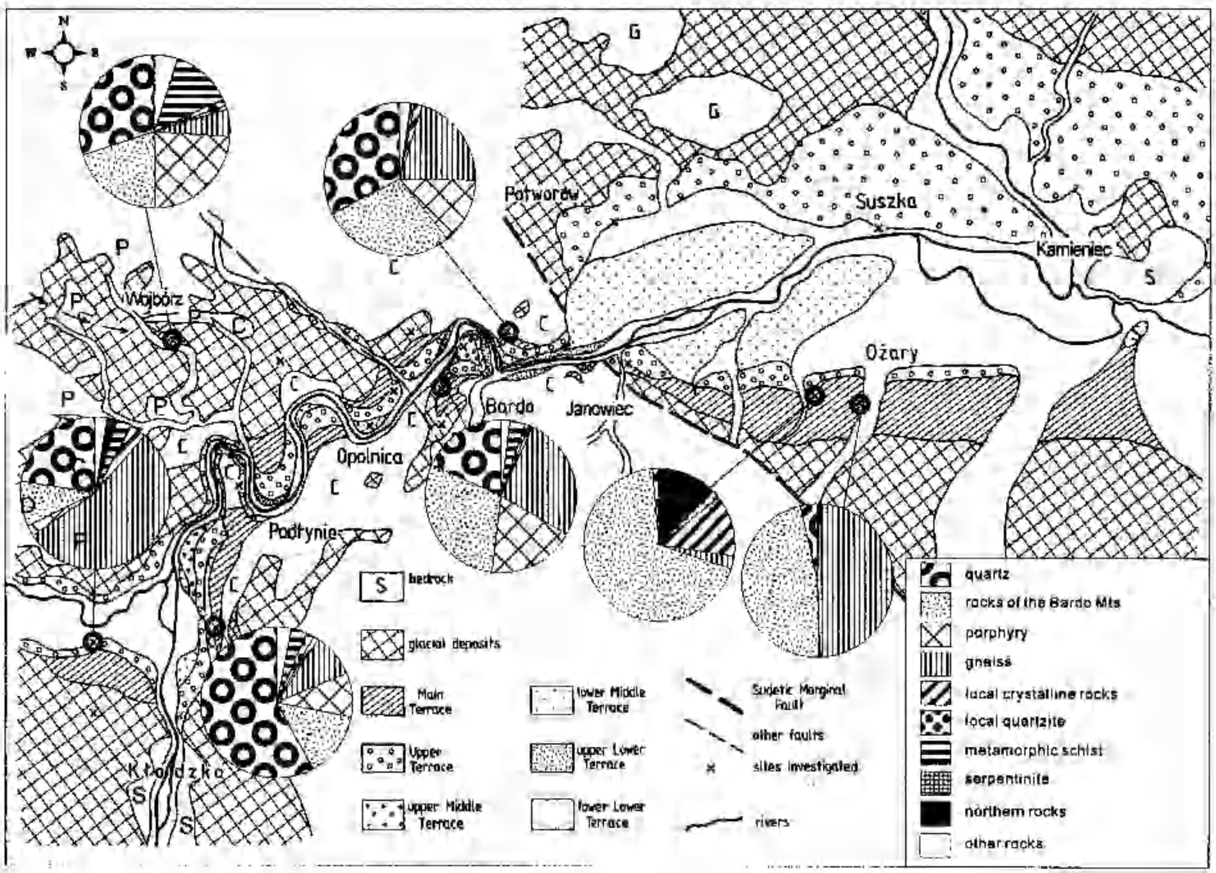

Fig. 6. Location of sites investigated and petrographic composition of the Main Terrace fluvial gravels.

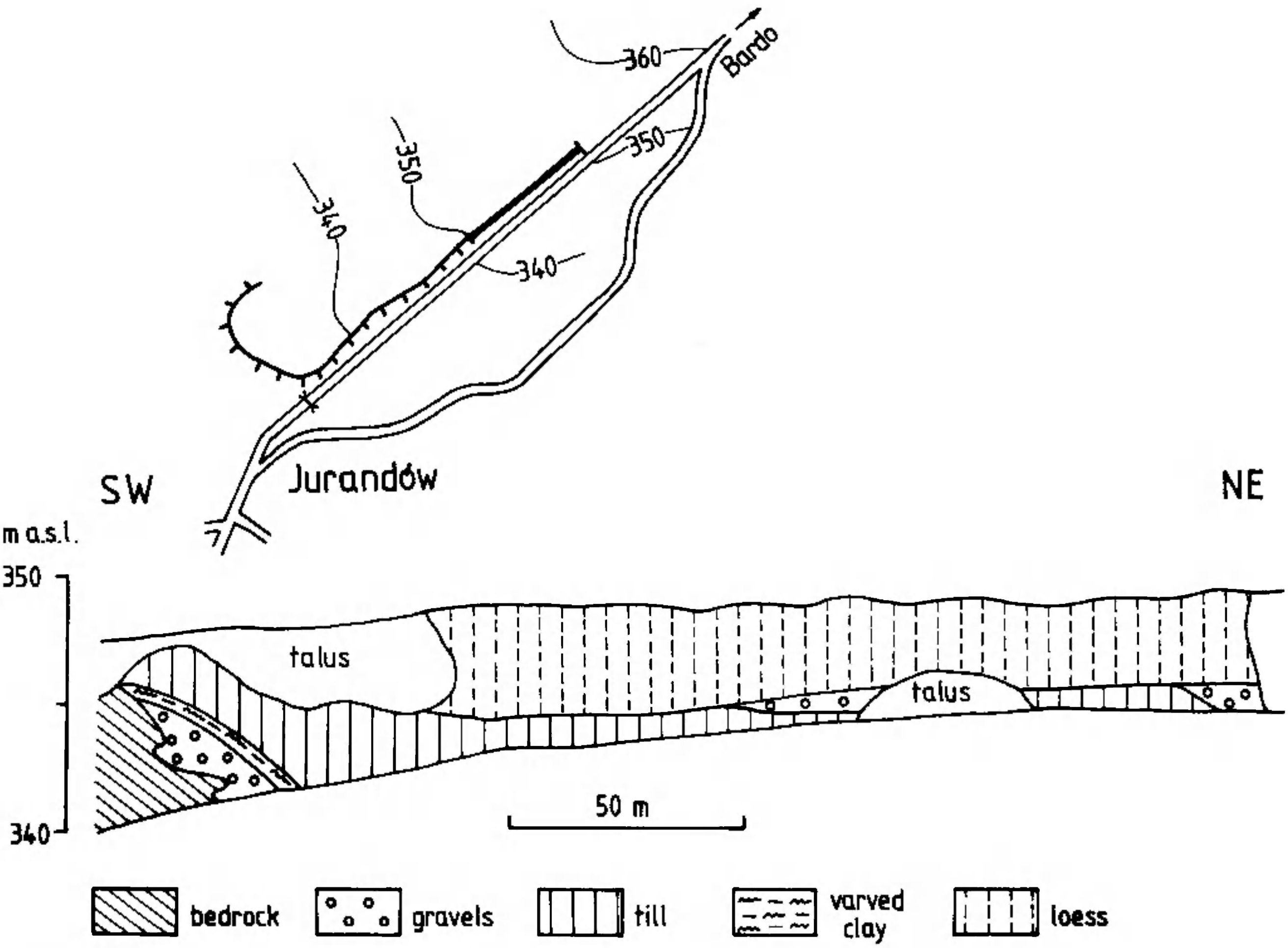

Fig. 7. Sediment succession of the Glaciofluvial Terrace (+70 m) at Jurandów (after Wilczyński, 1991).

GENERAL FEATURES OF THE TERRACE SYSTEM AND ITS DEFORMATION

The terrace distribution along the Bardo gorge is often asymmetric, *i.e.* terraces occur only on one side of the valley, the other side being the steep bedrock slope (Fig. 10B). However, between Opolnica and Bardo, the terrace system is paired, with terraces of equivalent heights on both sides of the valley (Fig. 10A). Hence, the lack of terraces is probably due to further erosion.

Almost all terraces in the mountainous region indicate divergence (Fig. 11). This fact was first documented by Zeuner (1928). The height difference of the terrace levels between Kłodzko and Bardo vary from a few metres (lower and middle terraces) to 15 m (Upper Terrace) and 30 m (Main Terrace). Moreover, all the terraces in the Sudetic Foreland occur at much lower heights above the valley floor than their equivalents in the mountains (Fig. 11). This drop in terrace heights and steep terrace gradients that occur along the Sudetic Marginal Fault are interpreted as degraded fault scarps (Krzyszkowski *et al.*, 1995). Such scarps have been observed in the lower Middle Terrace and the Upper Terrace (Fig. 12), and have possibly formed in the Main Terrace, although this is not documented, yet. The Glaciofluvial Terrace does not indicate downstream divergence, and the slope gradient measured along the rock base is similar to modern river.

The terrace divergence and fault scarps undoubtedly document phases of neotectonic uplift in the Sudeten Mountains. The height difference of the Main Terrace level across the Sudetic Marginal Fault is 15–25 m. This value includes a resultant displacement amplitude during all uplift phases younger than the Main Terrace horizon. It seems, that three phases of the tectonic uplift occurred along the Sudetic Marginal Fault during this period. The amplitude of throw during the first uplift phase, that occurred directly after formation of the Main Terrace was 5–10 m. As the height of fault scarps of the lower Middle Terrace and the Upper Terrace is similar (*ca* 10 m), they must have formed during the same, second uplift phase, which postdate the formation of lower Middle Terrace. The amplitude of throw during this event was most probably about 8–10 m. The latest uplift stage has about 2–5 m throw amplitude, as indicated from the youngest terrace evidence (Fig. 11).

The total uplift along the Sudetic Marginal Fault measured along the terrace profiles is about 15–25 m. The described uplift phases, most probably, took place after the first glaciation of the region (5–10 m; displacement of the Main Terrace only) and after the latest glaciation (10–15

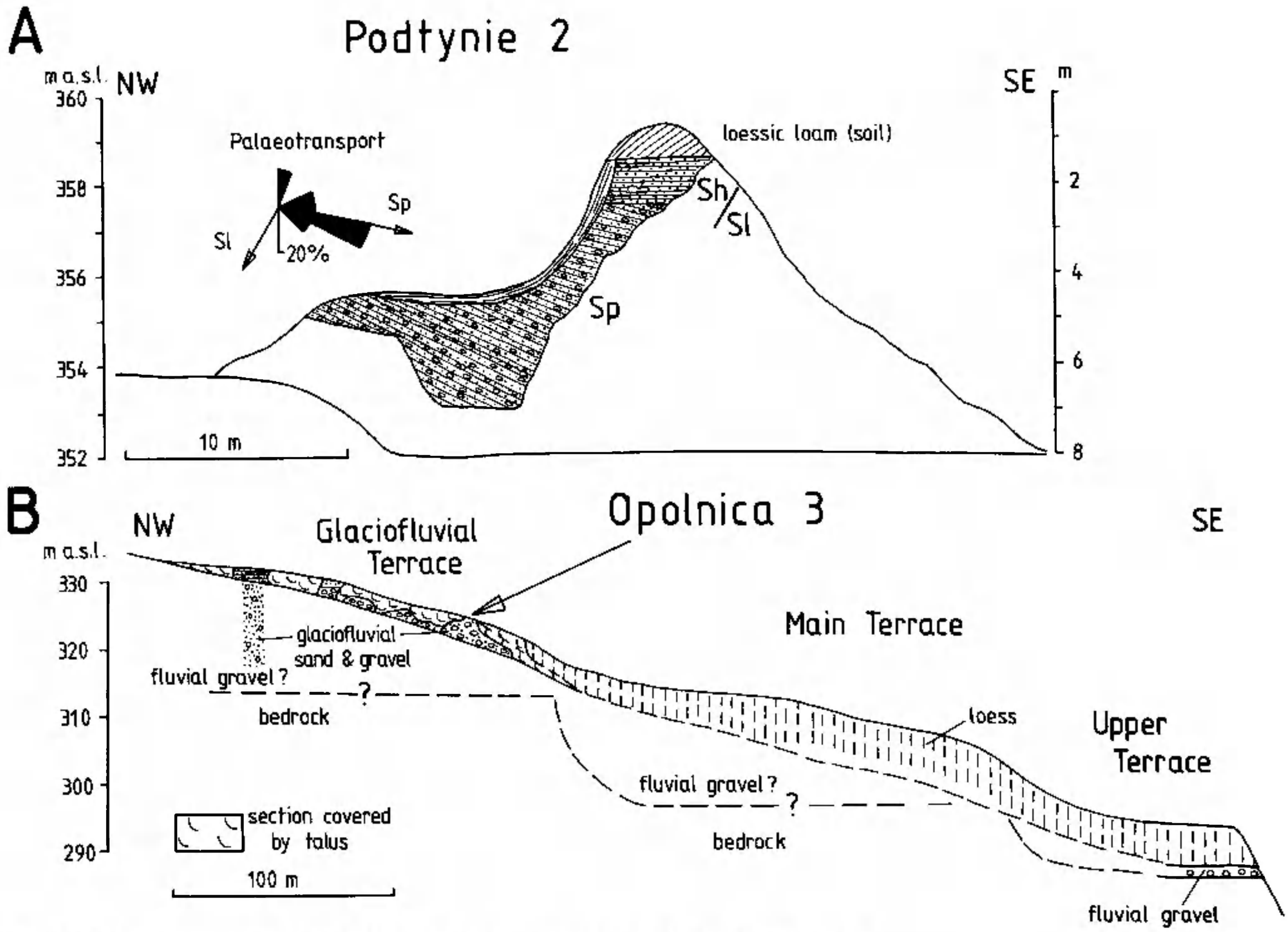

Fig. 8. Sediment succession of the Glaciofluvial Terrace at Podtynie (A) and Opolnica (B).

m). The last one continued until recent times. Futhermore, it seems, that the fluvial deposits lying at the base of Glaciofluvial Terrace, which were formed before the first glaciation in the Sudeten, were not affected by extensive tectonic movements during/directly after their deposition. This terrace level was only uplifted *en block* during the younger tectonic phases (Fig. 11).

FLUVIAL AND GLACIAL DEPOSITS BEYOND THE BARDO GORGE

Several sites in the Nysa Kłodzka river drainge basin comprise complex late Cainozoic sequences, that only in part are related to terraces. However, as they contain fluvial and glacial deposits, correlation with terrace stratigraphy is possible.

Kłodzko (Glatz)

This is a regional stratotype section, known since the late 19th century (Dathe, 1895; Berger, 1932; Walczak, 1952, 1968, 1975; Jahn *et al.*, 1984; Jahn, 1985). The profile is located in the central part of the Kłodzko Basin (Fig. 1). The section comprises three fluvial series in superposition, with a thin loess cover on top (Fig. 13). At the top of the lower series at site Kłodzko 1 Walczak (1952) and Jahn *et al.* (1984) found an organic bed, age of which was determined using pollen and macrofossil analysis (Fig. 13A). Recently investigated, Kłodzko 2 site is located 200–300 m northwards and comprises the same beds, except the organic deposits (Fig. 13B).

White Gravels. This is a series at least 3.3 m thick at the bottom of sequence. These gravels are quartz-dominated, poorly sorted and comprise kaolin matrix with silty and clayey intraclasts. The series was probably deposited in a sinuous river. The series comprises mainly quartz (36–71%), porphyry (7–44%), red and grey gneiss (4–18%), siliceous rocks (5–18%) and Createaceous sandstones (0–3%) (Fig. 13C; Table 4). All these components indicate transport from the NW part of the Kłodzko Basin, along the Ścinawka river valley, where both volcanic rocks (porphyry) and Createaceous sandstones occur. The main heavy minerals are garnets (33–35%), accompanied by amphibole, pyroxene, staurolite and especially resistant minerals such as zircon, tourmalline and rutile (altogether 21–24%) (Fig. 13C). Moreover, the sediments indicate wheathering

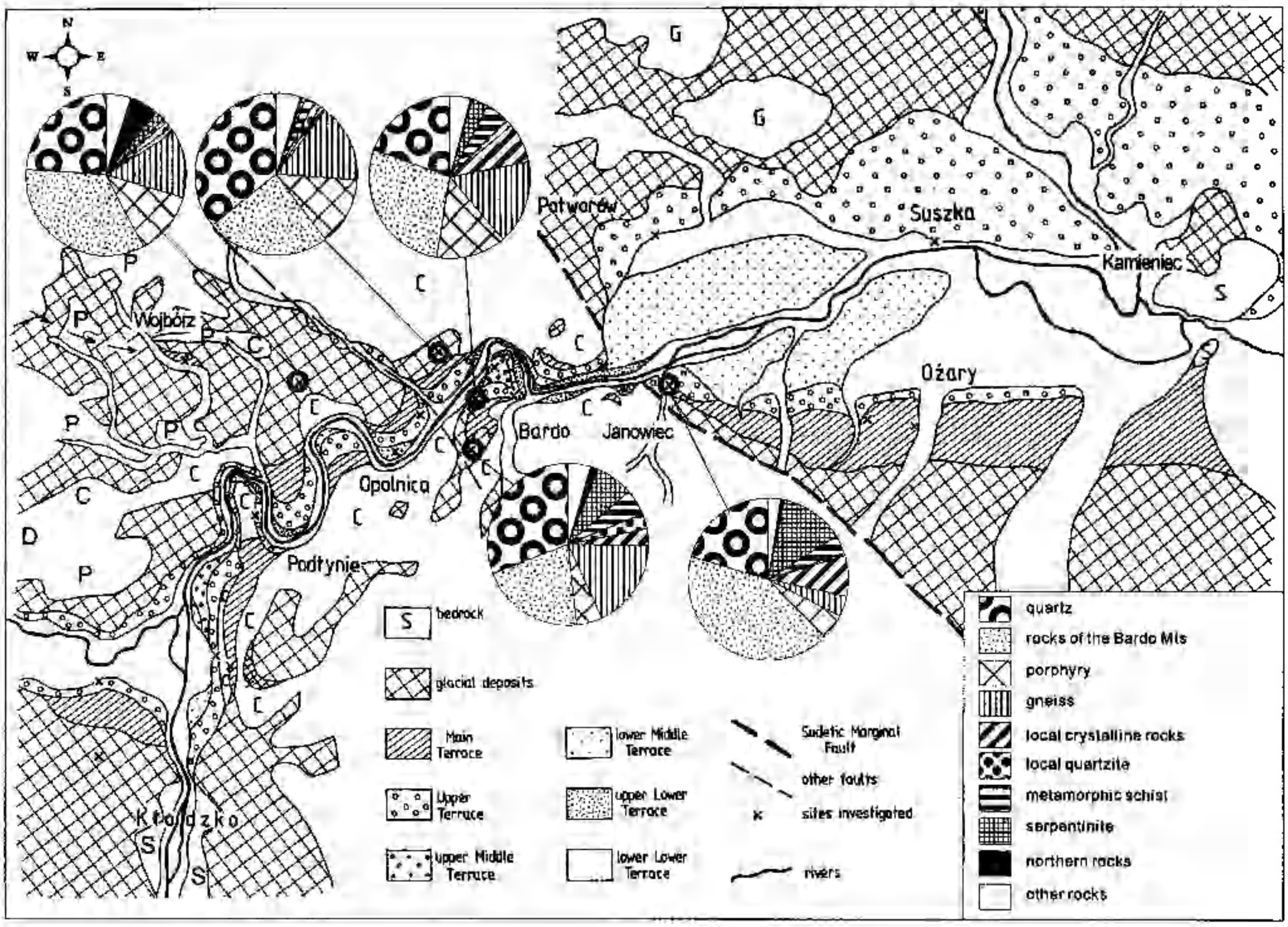

Fig. 9. Location of sites investigated and petrographic composition of glaciofluvial deposits along the Bardo gorge.

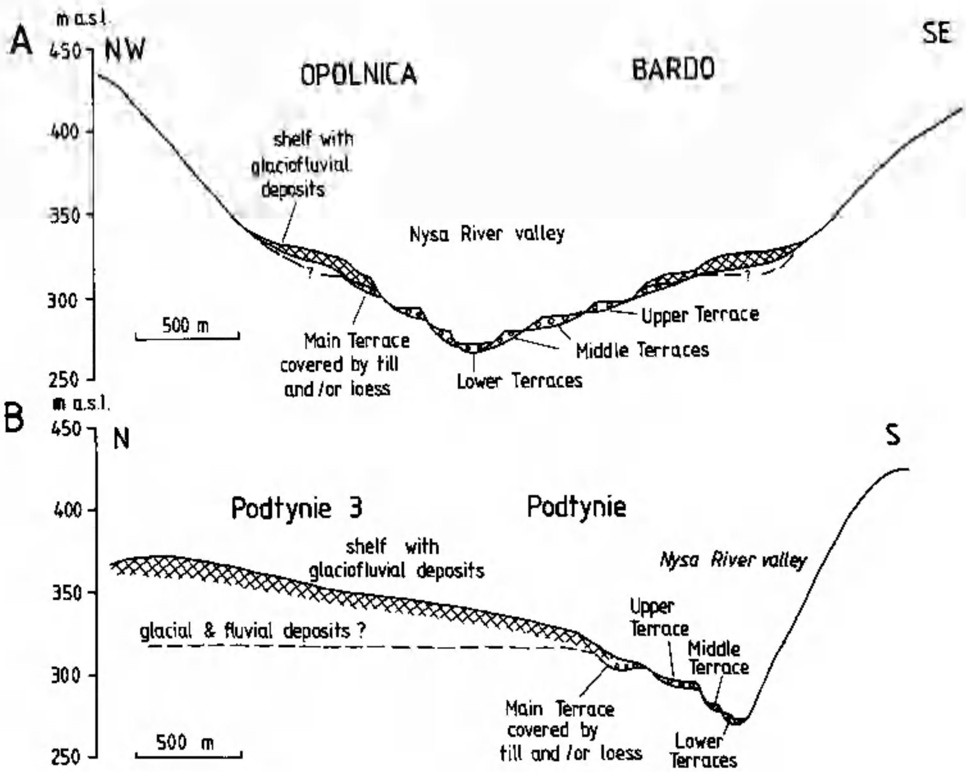

Fig. 10. Valley cross sections through the Nysa Kłodzka river valley in the Bardo gorge: A – near Podtynie, B – between Opolnica and Bardo (location of sections in Fig. 1).

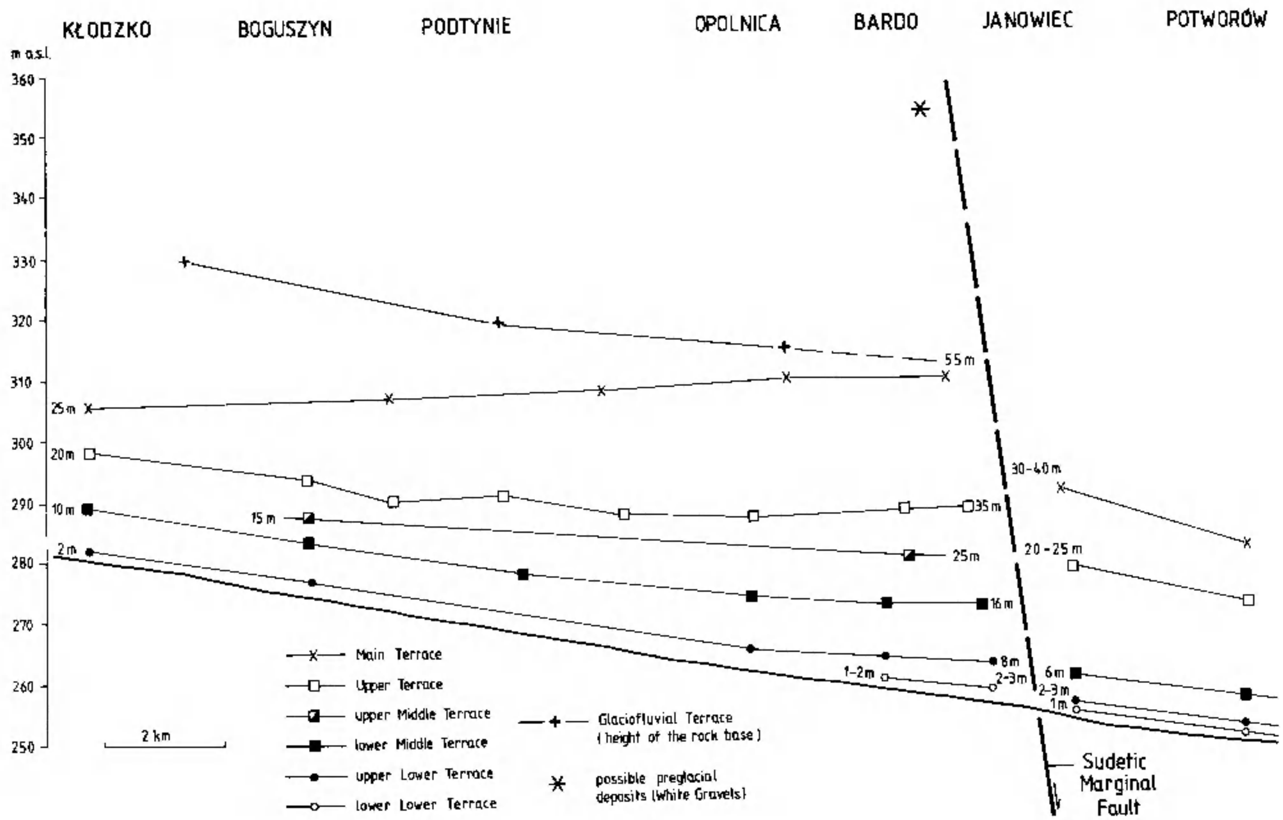

Fig. 11. Height of terraces along the Nysa Kłodzka river valley. Note that heights of all levels are from terrace surfaces (each with 2–8 m of loess or slope deposit cover), except the Glaciofluvial Terrace, where the height of rock base has been measured.

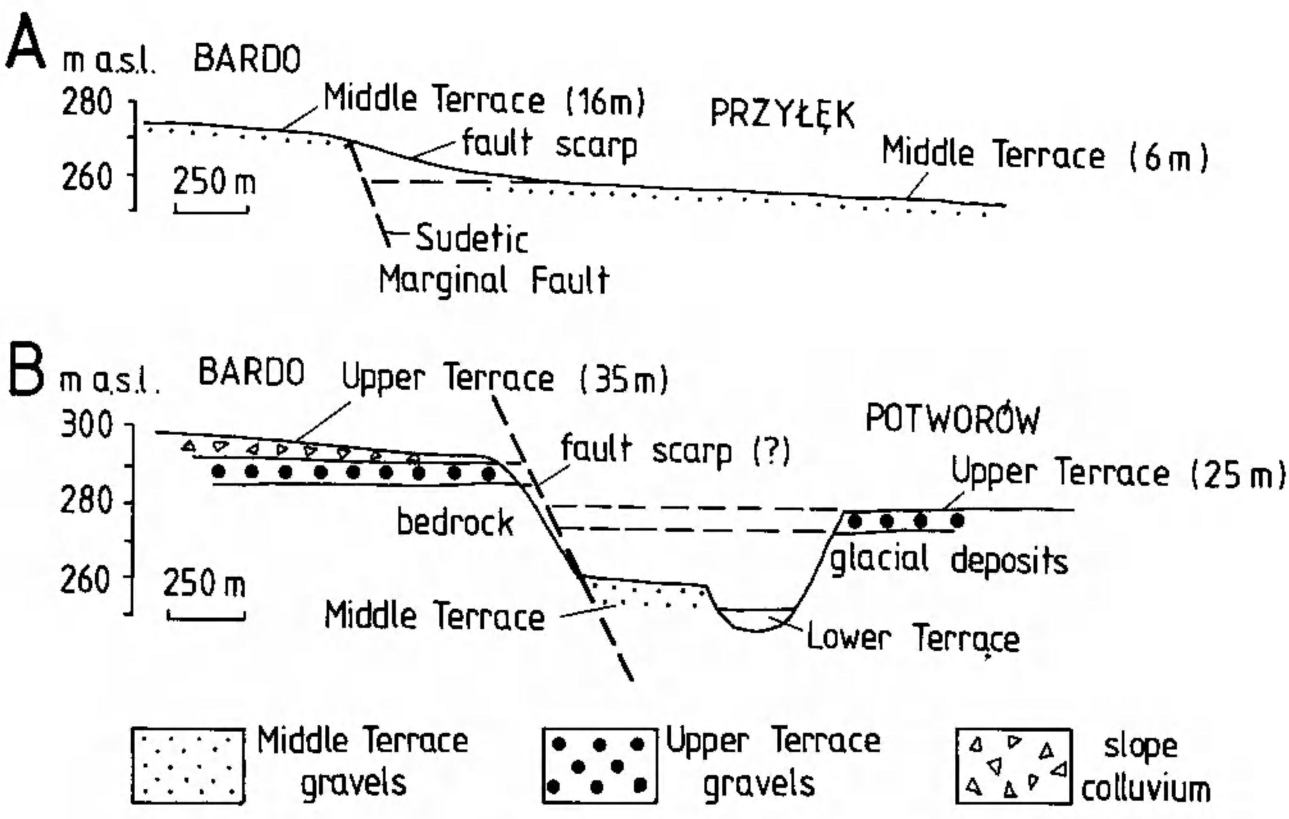

Fig. 12. Fault scarps along the Sudetic Marginal Fault: A. Lower Lower Terrace at Bardo, B. Upper Terrace between Bardo nad Potworów.

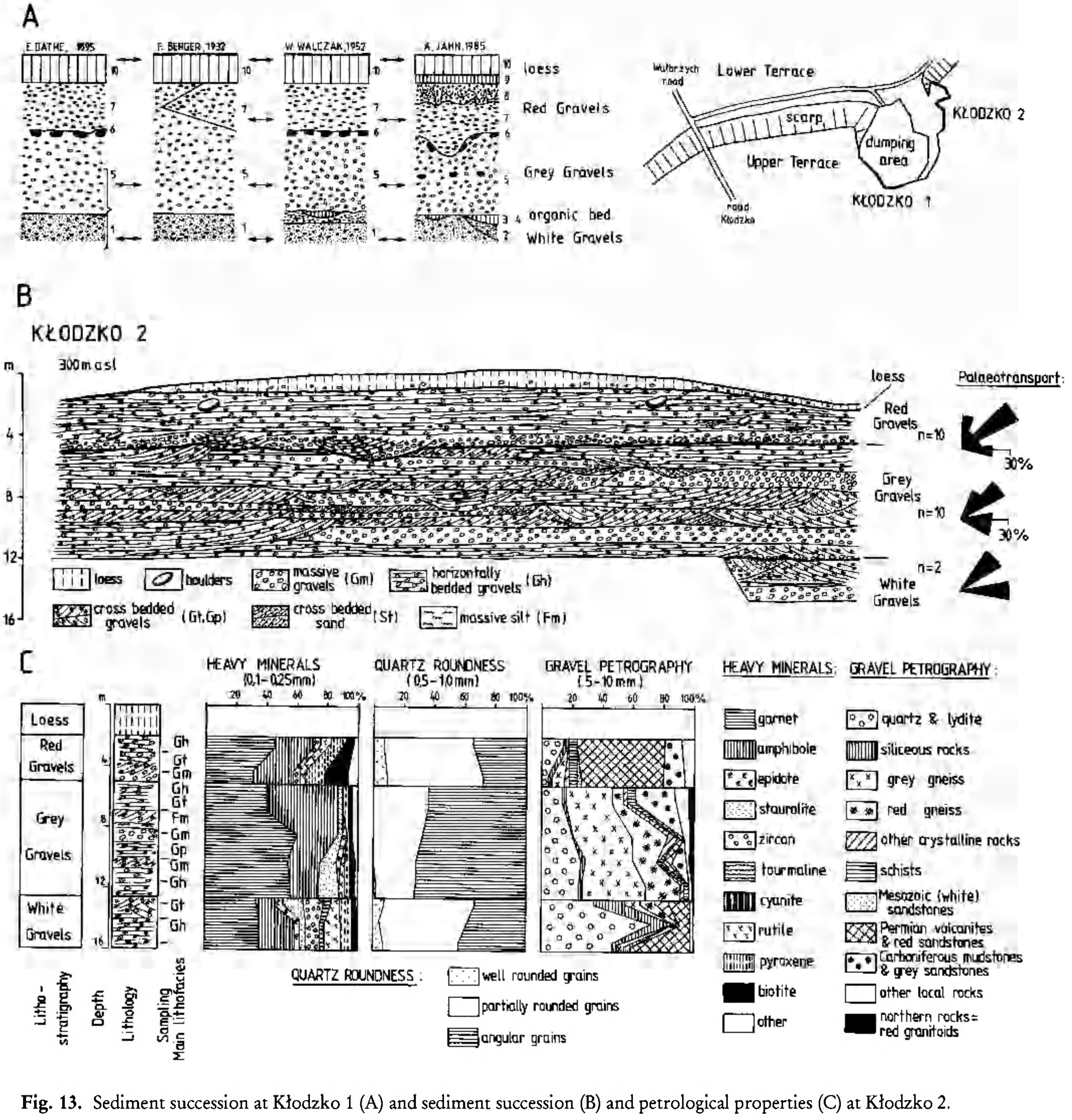

Fig. 13. Sediment succession at Kłodzko 1 (A) and sediment succession (B) and petrological properties (C) at Kłodzko 2.

in situ, as confirmed by clay mineral analysis (Jahn *et al.*, 1984).

At the top of the series, the organic deposits have been documented and dated floristically to Reuverian (Walczak, 1952; Jahn *et al.*, 1984). Thus, the White Gravels represent the so-called "preglacial" series of Pliocene age and were deposited by the ancient Ścinawka river system.

Grey Gravels. This series is 7 m thick and its base is erosional. It comprises mainly gravels, with occasional lenses of coarse-grained sand and silt. The series is composed of the following lithofacies: massive gravels (Gm), poorly sorted, imbricated, with beds up to 1 m thick and with lateral extension up to several metres; horizontally bedded, well sorted gravels (Gh) with beds up to 2–3 m thick; trough (Gt) and planar (Gp) cross bedded gravels with the thicknesss of sets up to 1.5 m, usually 0.5–0.8 m; trough cross bedded sand (St) that occur as single, up to 0.5 m thick, sand lenses within gravels; and massive, sandy silt (Fm), with thickness up to several centimetres and lateral extension up to 1–2 m. These lithofacies form sedimentary cycles. The most common one comprises, at the bottom, Gm and Gh facies, followed by Gt and/or Gp facies and finally by Fm facies. Moreover, cosets with Gt and St are present as well as thick beds with Gh facies with single St facies. The series was deposited by high a energy, gravel-bearing braided river with well developed longitudinal

Table 4

Petrographic composition of fluvial gravels in the fraction 5–10 mm of sites containing the preglacial series (White Gravels) near Kłodzko

Site	Stratigraphy	sample no.	quartz	lydite	siliceous rocks	grey Carboniferous sandstones	Carboniferous mudstones	white Cretaceous sandstones	Permian rocks, including porphyry	grey gneiss	red gneiss	local granitoid (light grey)	feldspar	dark crystalline rocks	local quartzite	metamorphic schists	serpentinite	Scandinavian granitoid (red)	Scandinavian quartzite (red)	flint from the Polish Lowland	concretions	undetermined
Kłodzko 2	Red Gravels	z/286	16.7	–	2.8	8.3	2.8	–	58.3	–	–	5.6	–	–	–	5.6	–	–	–	–	–	–
		z/285	3.6	–	1.8	9.1	5.5	1.8	54.5	9.1	–	5.5	–	1.8	1.8	5.5	–	–	–	–	–	–
	Grey Gravels	z/284	13.0	1.9	1.9	–	27.8	–	–	29.6	9.3	3.7	–	1.9	–	5.6	–	1.9	–	–	3.7	–
		z/283	19.3	3.5	–	–	–	–	3.5	38.6	24.6	3.5	–	3.5	–	–	–	1.8	–	–	1.8	–
		z/282	26.4	1.9	1.9	1.9	7.5	–	5.7	32.1	17.0	–	–	–	–	1.9	–	3.8	–	–	–	–
		z/281	24.7	–	1.4	1.4	–	–	–	41.1	23.3	–	1.4	–	1.4	4.1	–	1.4	–	–	–	–
	White Gravels	z/280	36.4	–	18.2	–	–	–	18.2	9.1	9.1	–	9.1	–	–	–	–	–	–	–	–	–
		z/279	71.4	2.4	14.3	–	–	–	7.1	–	4.8	–	–	–	–	–	–	–	–	–	–	–
		z/278	44.7	–	4.7	–	–	2.4	43.5	3.5	–	1.2	–	–	–	–	–	–	–	–	–	–
Gorzu-chow	Red Gravels	z/277	19.2	–	1.5	13.8	4.9	–	41.9	10.3	1.5	4.4	–	1.5	1.0	–	–	–	–	–	–	–
		z/276	14.7	2.1	4.9	–	–	–	49.7	24.5	0.7	0.7	–	–	0.7	0.7	–	1.4	–	–	–	–
		z/275	34.3	–	1.0	–	–	–	55.1	5.6	–	1.0	–	1.0	1.0	1.0	–	–	–	–	–	–
	White Gravels	z/273	53.3	1.5	1.5	–	–	3.0	37.0	3.0	–	–	–	–	0.7	–	–	–	–	–	–	–
		z/272	60.6	3.0	–	–	–	–	30.3	–	–	–	–	–	6.1	–	–	–	–	–	–	–
		z/271	49.6	–	1.8	–	–	0.9	35.4	1.8	–	7.1	–	–	1.8	1.8	–	–	–	–	–	–
		z/270	12.5	–	–	–	–	–	70.8	–	–	12.5	–	–	4.2	–	–	–	–	–	–	–
Lądek Szary Kamień	White Gravels	z/291	59.8	–	–	–	–	–	–	17.9	2.2	1.7	1.3	–	–	11.8	–	–	–	–	–	5.2
		z/290	21.5	–	–	–	0.7	–	–	14.6	–	1.3	–	–	–	61.9	–	–	–	–	–	–
		z/287	27.3	–	–	–	–	–	–	59.6	–	–	–	–	–	13.1	–	–	–	–	–	–
Ozary	Grey Gravels	z/298	1.4	–	–	11.1	51.4	–	–	5.6	–	15.3	–	–	1.4	–	–	13.9	–	–	–	–
		z/297	1.7	–	–	15.3	59.3	–	–	–	–	10.2	–	–	1.7	–	–	11.9	–	–	–	–
	White Gravels	z/296	61.6	–	2.7	€.8	4.1	–	15.1	2.7	–	2.7	–	–	1.4	2.7	–	–	–	–	–	–
		z/294	52.8	1.9	3.8	9.4	9.4	1.9	9.4	5.7	–	–	–	–	–	5.7	–	–	–	–	–	–
		z/293	64.3	1.9	1.3	2.6	3.9	–	10.4	2.6	–	11.7	0.6	–	–	0.6	–	–	–	–	–	–
		z/336	55.7	1.6	4.1	0.8	3.3	0.8	13.1	5.7	–	10.7	–	–	1.6	2.5	–	–	–	–	–	–
		z/337	44.3	–	4.5	10.0	12.4	2.5	10.0	5.5	–	4.0	–	–	1.0	6.0	–	–	–	–	–	–
		z/338	59.5	–	5.4	8.1	5.4	2.7	10.8	2.7	–	–	–	–	–	5.4	–	–	–	–	–	–
		z/340	62.2	0.6	4.7	4.1	6.9	0.6	7.5	3.8	–	5.6	–	–	1.6	2.5	–	–	–	–	–	–

The Red Gravel series is age-equivalent with the Upper Terrace; the Grey Gravel series is age-equivalent with the Main Terrace

bars. Local palaeotransport measured in troughs is from the SW (Fig. 13B)

The series is gneiss-dominated, with grey gneiss (30–41%), red gneiss (9–23%), quartz (13–26%), porphyry (0–6%), siliceous rocks (0–2%) and Scandinavian crystalline rocks (2–4%) (Fig. 13C; Table 4). This suggests that the source area is in the southern part of the Kłodzko Basin, with mainly gneiss, and where porphyry is derived from redeposition of older fluvial sediments and Scandinavin rocks from redeposition of a till. The main heavy minerals are garnet and amphibole, which are accompanied by pyroxene, staurolite and biotite (Fig. 13C).

Dathe (1895), Walczak (1952) and Jahn *et al.* (1984) observed a boulder lag at the top of the series, which was interpreted as the remnant of a till. Neither Berger (1932) nor the present authors observe such a lag (Fig. 13A).

Table 5

Stratigraphy of the Cainozoic deposits in the Kłodzko region

Units	Kłodzko Basin	Bardo gorge	Paczków Graben	Age
lower Lower Terrace	+	+	+	Holocene
upper Lower Terrace		+		Lateglacial?
lower Middle Terrace	+	+	+	Weichselian
upper Middle Terrace		+		Weichselian
loess	+	+	+	Weichselian
Upper Terrace	=Red Gravels of Klodzko	+	+	Late Saalian/Eemian
till	+	+	+	Early Saalian
glaciofluvial deposits	+	+	+	Early Saalian
varved clay	+	+	+	Early Saalian
Main Terrace	=Grey Gravels of Kłodzko	+	+	Holsteinian?
till			+ (Janowiec ?)	Elsterian II
fluvial gravels			+ (Janowiec ?)	Interstadial
till with serpentinites	+	+ (Jurandów ?)	+ (Janowiec)	Elsterian I
glaciofluvial deposits with serpentinites		+		Elsterian I
Janowiec Gravels	+		+ (Janowiec)	Cromerian ?
peat from Janowiec			+	Cromerian ?
basalt from Szary Kamień	+			Upper Pliocene (Gauss epoch)
organic mud from Klodzko	+			Reuverian (Upper Pliocene)
White Gravels from Kłodzko	+ (Szary Kamień)	+ (Bardo)	+ (Ożary, Suszka)	Upper or Middle Pliocene
green clay			+	Upper Miocene

Thus, the presence of glacial deposits in between the Grey and Red Gravels is ambiguous, although provisionally the series may be correlated with the Main Terrace of the Bardo gorge. It was deposited by the ancient Nysa Kłodzka and/or Bystrzyca Dusznicka river systems.

Red Gravels. This series is 3–4 m thick and its base is erosional (Fig. 13B). The series is formed maily of pebbles and cobbles, with a maximum diameter of clasts up to 1.0 m. Silty intraclasts are also common. Lithofacies are similar to those of Grey Gravels. The lithofacies Gm, Gt and St are concentrated at the base of series, whereas Gh facies forms its upper part (Fig. 13B). The Red Gravels were deposited by a high energy, gravel-bearing braided river, but, in contrast to Grey Gravels, longitudinal bars were poorly developed. Local palaeotransport measured in troughs is from the SW (Fig. 13B).

The series is porphyry-dominated (54–58%), with also Carboniferous sedimentary rocks (10–14%), schists (5–6%) siliceous rocks (2–3%) and grey gneiss (0–9%) (Fig. 13C; Table 4). This composition suggests source area in the northwestern part of the Kłodzko Basin. The main heavy minerals are very similar to those of Grey Gravels (Fig. 13BC).

The Red Gravels form a 20 m high terrace level, that can be correlated with the Upper Terrace from the Bardo gorge. They were deposited by the ancient Ścinawka river system with a minor role of rivers flowing from the Bardo Mts range.

Loess. There is a 1–2 m thick loess-like sediment at the top of the sequence. This sediment contains single clasts, especially at the base of the layer. Walczak (1952, 1968, 1975) has interpreted this gravel-rich loess-like material as

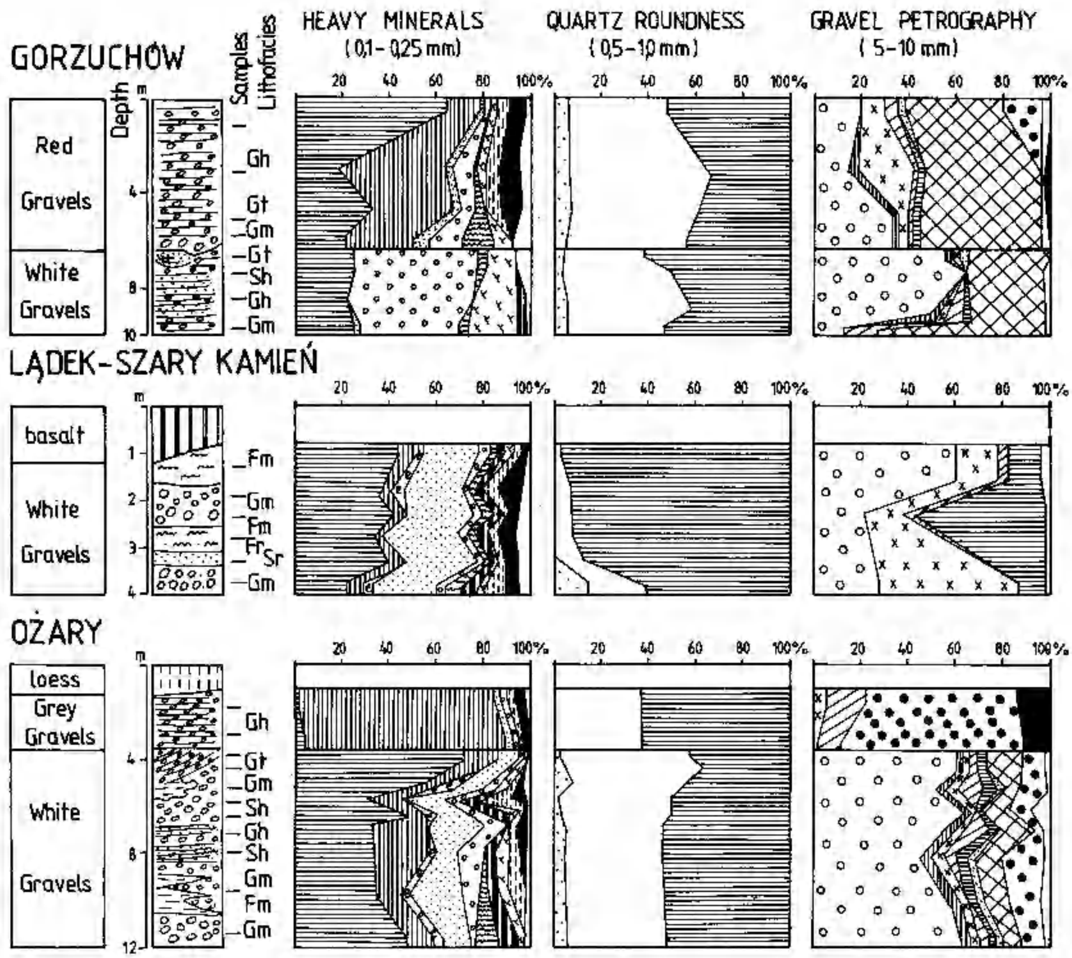

Fig. 14. Sediment succession and petrological properties at sites with preglacial (Pliocene) deposits near Kłodzko.

a till. Jahn *et al.* (1984) and Jahn (1985) have interpreted this sediment as colluvium formed under the periglacial climate. Recently, we have observed that the loess-like deposit from the top of 20 m terrace is interdigitated with slope coluvium covering the terrace slope and younger terraces.

Gorzuchów

The section at Gorzuchów is located in the NW part of the Kłodzko Basin, in the Ścinawka river valley (Fig. 1). It comprises White and Red Gravels in superposition (Fig. 14). Sedimentological and petrographical characteristics are almost the same as in Kłodzko profile (Table 4). Only the heavy mineral content of the White Gravel series is different; at Gorzuchów only resistant minerals, zircon, tourmalline and rutile (50–80%) and garnet (24–27%) occur (Fig. 14). Hence, it seems that the White Gravels at Gorzuchów are more weatered than those of Klodzko (Jahn, 1985). Stratigraphic interpretation is similar to that at Klodzko (Table 5).

Lądek-Szary Kamień (Landeck-Grauen Stein)

This is a basalt quarry in the NE part of the Kłodzko Basin (Fig. 1), where Finckh (1925) originally found fluvial deposits below the basalt lava (Fig. 14). Berger (1932) interpreted this series as the Late Pliocene to Early Pleistocene, and Walczak (1968) to the Early Pleistocene one. Palaeomagnetic investigations of the basalt lava have indicated normal magnetic polarity (Birkenmajer *et al.* 1970), and thus either Gauss or Brunhes epoch.

The fluvial series lie at 40–45 m above the present valley floor. It consists of several beds, from the bottom: massive, poorly sorted gravels (Gm) with a maximum clast size of 1-3 cm (50 cm); fine grained sand with ripplemarks, at the top sandy silt with ripplemarks (Sr, Fr)(30 cm); grey, massive silt (Fm) (30 cm); massive, poorly sorted gravels (Gm) with a maximum clast size up to 5 cm and a kaolin matrix (65 cm); green, massive silt with single gravels (Fm), partly thermally altered (65 cm); basalt lava and volcanic breccia (1 m and more) (Fig. 14).

Gravels comprise only local components (gneiss, schists) and quartz (Fig. 14, Table 4), which suggest a local source area in the Biala Lądecka river valley (Fig. 1). Main heavy minerals are garnet (23–44%) and staurolite (22–33%), which are accompanied by amphibole, pyroxene, biotite, zircon, tourmalline and rutile. A similar heavy mineral composition has been reported in preglacial (Pliocene) fluvial deposits of the Sudetic Foreland (Czerwonka, 1994, 1996; Przybylski *et al.*, 1998). Thus, taking into account results of palaeomagnetic research, sedimentary features and heavy minerals, we interprete the fluvial deposits at Lądek as the preglacial series, an age equivalent series to

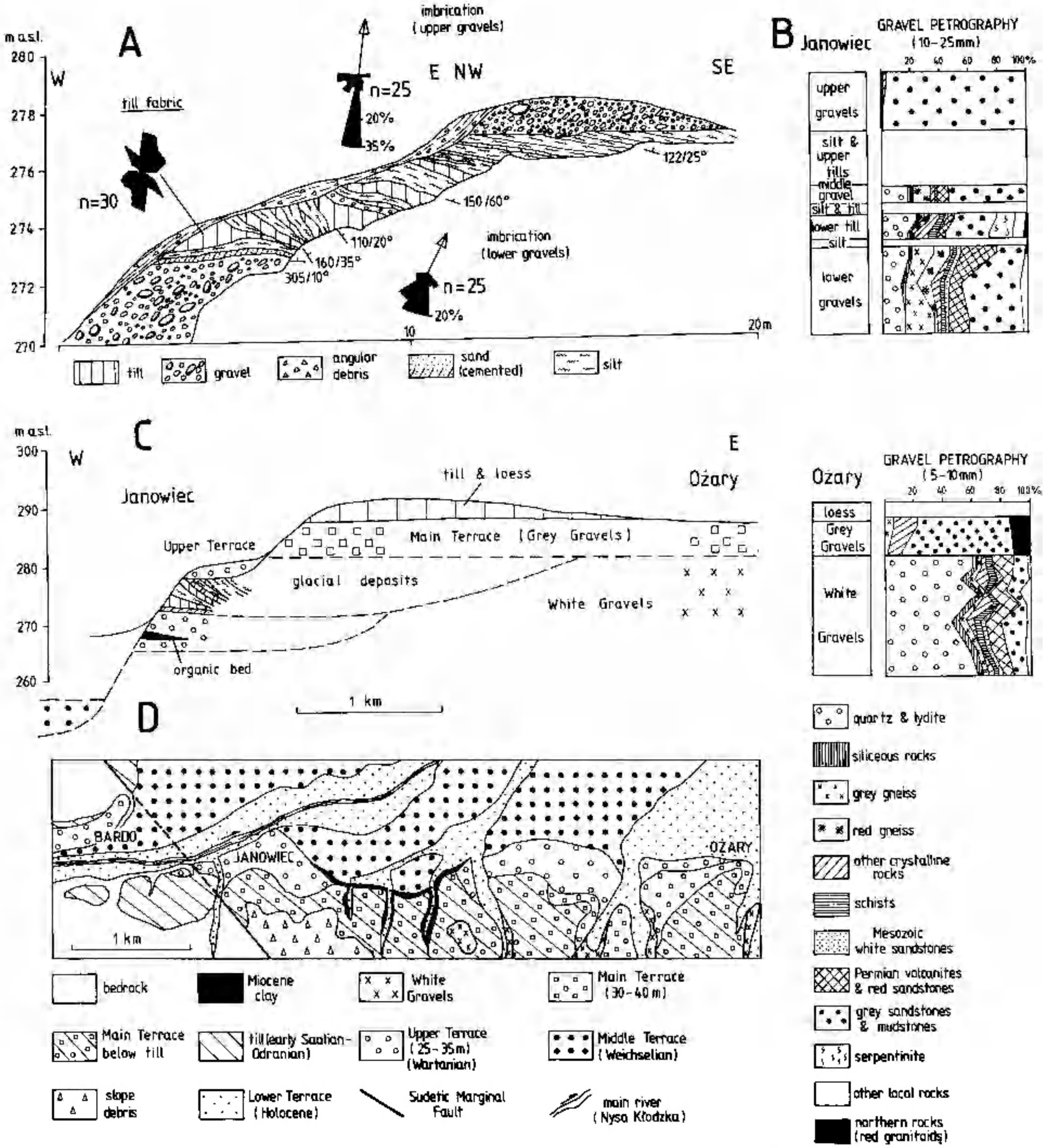

Fig. 15. Pleistocene deposits at Janowiec (A) in relation to regional geology (C) and the distribution of terraces of the river Nysa Kłodzka (D); and petrographic composition of fluvial and glacial deposits (B).

the White Gravels at Kłodzko and Gorzuchów (Table 5). The series at Lądek is not weathered, preserving original heavy mineral composition.

Ożary

This section is located in the Sudetic Foreland (Fig. 1) and comprises White and Grey Gravels in superposition (Fig. 14). The White Gravels are 8–9 m thick. These are poorly sorted, horizontally or cross-bedded gravels with a kaolin matrix and clay balls or clay lenses. Maximum size of the gravels clasts is up to 10 cm, and clay balls up to 20 cm. The White Gravels of Ożary are characterized by a mixed petrographic composition. Besides the dominant quartz, there occur rocks typical of the NW (Kłodzko, Gorzuchów) and NE (Lądek) parts of the Kłodzko Basin as well as rocks from the Bardo gorge. Heavy minerals are almost identical to those of the preglacial series at Lądek. Thus, the White Gravels were undoubtedly deposited in the Sudetic Foreland by the Nysa Kłodzka river system, which acquired additional components in the Bardo gorge.

The Grey Gravels are 2–3 m thick and form a distinct terrace level (Main Terrace) covered at this site by loess. This terrace is elsewhere covered by a few metres of glacial deposits and loess (Fig. 15).

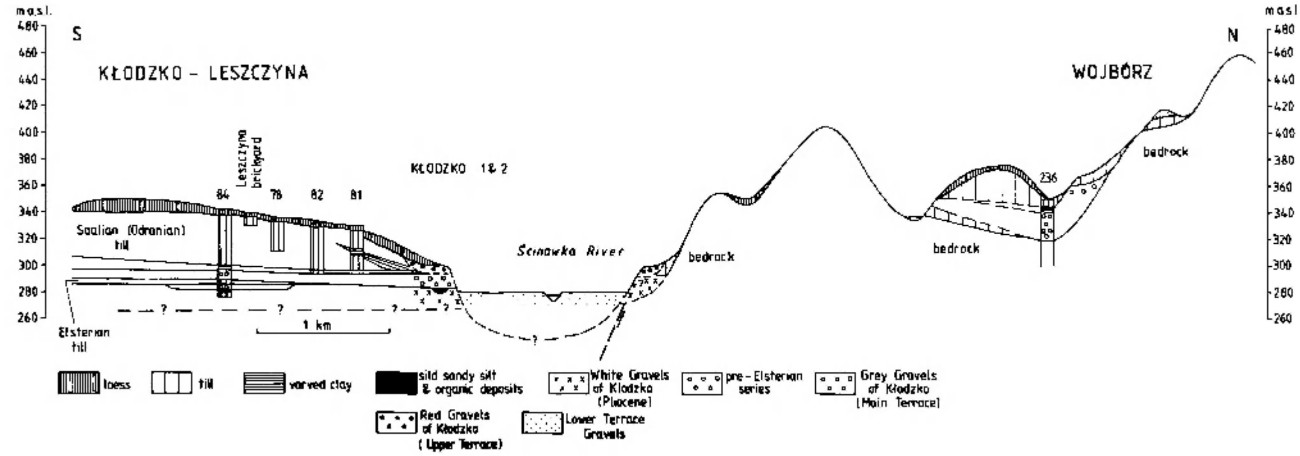

Fig. 16. Geological cross section through the northern part of the Kłodzko Basin (Kłodzko–Wojbórz).

Janowiec (Jonsbach)

This is another regional stratotype section, described originally by Zeuner (1929) (Fig. 15A). The profile is located near the Sudetic Marginal Fault, close to Bardo (Fig. 1). This section comprises at least 11 m of a Pleistocene series, with Miocene clay in the substratum. The Pleistocene series can be subdivided into three parts, and comprising (Fig. 15A, B):

- the lower, reddish-brown fluvial series (Janowiec Gravels) consisting of massive, poorly sorted, and strongly imbricated gravels. Maximum clast size varies from 30 to 40 cm. The series is 3.5 m thick; its base has not been reached. At the top of gravels, there is a 0.1–0.15 m thick, red, strongly cemented, sandy bed, that is inclined to the west (280°/10°). A similar bed was described by Zeuner (1929).

- the complex glacial sequence containing a series of till beds, glaciolacustrine silty deposits and one gravel bed. The silty beds are from 5 to 70 cm thick. They are massive to laminated and may contain single clasts. The lowest, black till bed is 1.3 m thick and is massive. Other till beds are from several centimetres to 0.5 m thick and are usually laminated. The gravel bed is 15–20 cm thick and contains massive gravels with clasts up to 1–3 cm in diameter. All these deposits are carbonate-free and deformed. The beds are inclined to the southeast (110°–160°/20°–60°).

- the upper, grey gravels are mainly angular and partly rounded clasts and form a massive bed with strong imbrication. Maximum clast size is up to 40 cm, though the dominant size is between 3 and 10 cm. This series lies discordantly over the glacial deposits.

The lowest till bed represents the early Elsterian deposit, indicated by the high number of serpentinite and its correlation with regional, glacial type sections (Badura *et al.*, 1998). Hence, the Janowiec Gravels must represent the pre-Elsterian fluvial deposit, although it differs from the preglacial series (White Gravels). This fluvial series is quartz-poor and is characterised by mixed gravel petrography, with rocks from all parts of the Klodzko Basin and the Bardo gorge. Main heavy minerals are amphibole and garnet. Also, it does not contain the kaolin matrix. Zeuner (1929) described a 0.5–0.75 m thick organic bed within this series. Pollen analysis indicated at least boreal to warm climate at that time, with dominant pine, spruce and adler and a 6–7% admixture of decidous trees, such as oak, elm, lime, beech and hazel but with no Tertiary exotics (Stark & Overbeck, 1932; Badura *et al.*, 1998). Hence, the age of Janowiec floras may be roughly from the Cromerian stage, rather than from the Early Pleistocene. The Janowiec Gravels may correlate with the lower gravels at Jurandów (Table 5).

The Janowiec profile may also be correlated with the terrace system of the Nysa Kłodzka river valley in the Sudetic Foreland. The upper gravels of the sequence form the Upper Terrace level (25 m) (Fig. 15C, D) (Zeuner, 1928; Berger, 1932; Walczak, 1954; Krzyszkowski *et al.*, 1995). The Main Terrace deposits probably lie above the Elsterian glacial deposits and are covered by the early Saalian (Odranian) till (Fig. 15C) (Badura *et al.*, 1998). In turn, the preglacial deposits (White Gravels) and Miocene clay have been described at the base of the Main Terrace northeast of Jano-wiec (Finckh, 1929) (Fig. 15C, D).

Summarizing, the integrated stratigraphic sequence of the Janowiec profile and neighbouring terraces comprise the following units: Miocene clay, Preglacial series (Pliocene White Gravels), Cromerian Janowiec Gravels (lower gravels) and the organic bed, Elsterian glacial deposits, Main Terrace gravels, early Saalian glacial deposits and the Upper Terrace gravels (upper gravels) (Fig. 15C, Table 5).

Glacial and fluvial sediments near Klodzko

Figure 16 presents the geological cross section throughout the northern part of the Klodzko Basin. It is based on several borehole profiles and data from outcrops. The borehole near Klodzko reveals more than 60 m of the late Cainozoic deposits and represents a regional stratotype profile. This comprises, from the top:

0.0 – 40.0 m of Saalian till, with probably 3–4 m of loess at the top; Walczak (1968, 1975) differentiates this bed into two glacial horizons separated by fluvial gravels (not present in the profile description !);

40.0–43.0 m of varved clay;

43.0–50.0 m of fluvial gravel (Grey Gravels ?);

50.0–53.0 m of diamicton, probably the Elsterian till; Walczak (1968, 1975) interpreted this layer as belonging to the White Gravels;

53.0–58.0 m of fluvial gravels (Janowiec Gravels ?);

58.0–61.0 m of silty sand;

61.0–63.0 m of fluvial gravels (unambiguous White Gravels); the base of series has not been reached.

The importance of this profile is that it probably contains two till beds in superposition and the Grey Gravels in the inter-till position. Also, the White Gravels and possible Janowiec Gravels are in superposition below the oldest till. The lower part of this sequence is very similar to that of Janowiec, and suggests that at least until the first glaciation (lower till), the Kłodzko Basin and the Sudetic Foreland possess a similar geological history. Also, the occurrence of two tills in superposition undoubtedly indicates that at least two Scandinavian ice sheets entered the Sudetes. This is also in agreement with the occurrence of two types of glaciofluvial covers (serpentinite-rich and serpentinite-poor one) in the Bardo gorge.

Another important borehole profile is located near Wojbórz (Fig. 16). It comprises 31 m of Pleistocene deposits, with gravels or sandy gravels at the bottom and varved clay and till at the top. The upper part of these gravels corresponds with the Main Terrace gravels at the Wojbórz outcrop (Fig. 1, 16). Dathe (1899) and Fischer & Meister (1934) described tills at the tops of the hills and in the valley bottoms. These may represent two different glacial horizons, as indicated in the cross section (Fig. 16). If so, the Main Terrace gravels may occur here also in the inter-till position. This series is at least 30 m thick and its base lies at 320 m a.s.l., 50 m above the present Ścinawka river (Fig. 16). Very probably, the Main Terrace fluvial gravels partly fill a deep palaeovalley representing the re-modelled glacial tunnel valley.

REGIONAL STRATIGRAPHIC CORRELATION AND PALAEOGEOGRAPHY

From the terrace and sediment successions, there are three Pliocene and 15 Quaternary lithostratigraphic units in the investigated region (Table 5). However, only some units have unambigous dating. These are all the Pliocene units, as both the bed with Reuverian flora and the basalt lava overlie the White Gravels, which are underlain, in turn, by the Miocene clay, as well as the lower Lower Terrace deposits that contained wood, dated to the Holocene. Other units may be correlated with the regional stratotype profiles or their ages can be approximated from their regional context (Badura *et al.*, 1998). The lower, serpentinite-rich till represents the oldest glacial horizon in the region and hence, most probably, the early Elsterian ice advance. The Janowiec Gravels represent, most probably, the Cromerian stage. However, further pollen analysis is necessary to confirm this interpretation. The Main Terrace and the Grey Gravels that occur in the position between two tills may represent roughly the Holsteinian. The Upper Terrace and the Red Gravels represent the first fluvial deposit which is not covered by glacial sequences. Hence, they must have been formed after the last glaciation in the region, *i.e.* after the early Saalian (Odranian), probably during the late Saalian (Wartanian) and Eemian. Middle Terraces were probably formed during the Weichselian and Lower Terraces during the Lateglacial and the Holocene. The last two have no loess cover, which itself is dated to the Middle and Late Weichselian (Ciszek, 1997). There are no unambiguous Early Pleistocene deposits/forms in the investigated region, and a *ca* 2 ma yrs long stratigraphic gap between the White Gravels and the Janowiec Gravels is very probable.

The fluvial pattern has been reconstructed for the late Pliocene (White Gravels), early Middle Pleistocene (pre-Elsterian, Cromerian; Janowiec Gravels), Holsteinian (Elsterian/Saalian ice-free period; Main Terrace/Grey Gravels) and for the post-glacial time (late Saalian, Upper Pleistocene) (Fig. 17).

The late Pliocene rivers collected material from all parts of the Kłodzko Basin (Fig. 18), with a fluvial pattern presumably similar to today. Only the pre-Biała river (no porphyry) and pre-Ścinawka river (porphyry-rich) have been documented by deposits (Fig. 17A). A high amount of material from the Bardo Mts range within the White Gravels at Ozary (Fig. 18) shows undoubtedly, that the river must have crossed the present mountain ridge. However, a detailed reconstruction of the Pliocene river in the mountainous area is almost impossible – the White Gravels have yet not been found in this zone. Przybylski (1997) proposed the fluvial tract north of Bardo, at the height +95 m (*ca* 340 m a.s.l.), which facilitated the joining of all sites with preglacial deposits in the mountain foreland into one fluvial system (alluvial fan) (Fig. 17A). The Cromerian (pre-Elsterian) fluvial pattern is poorly documented, with only one certain (Janowiec) and two possible sites. However, it seems that the fluvial pattern was very similar to that of the Pliocene, except some changes near the Sudetic Marginal Fault (Fig. 17A). The mixed petrography of the Janowiec Gravels at Janowiec also suggests similar source areas.

The fluvial pattern was slighty re-organized after the Elsterian glaciation, and this is documented in several sites. First of all, the pre-Ścinawka river (porphyry-rich) was shifted to the north, probably using the post-glacial tunnel valley near Wojbórz. Also, the Biała river (Boguszyn, quartz-rich gravels) and the Nysa Kłodzka river (Kłodzko; gneiss-rich gravels) have been documented by separate gravel assemblages (Fig. 17B). These rivers joined before Bardo, as all gravel assemblages of the Main Terrace near Bardo indicate a mixed character. The post-early Saalian rivers roughly followed the Pliocene fluvial pattern, although the rivers indicated greater sinusoity, which increased with time, reaching a maximum during the Holocene (Fig. 17C).

A characteristic feature of the fluvial pattern is its sta-

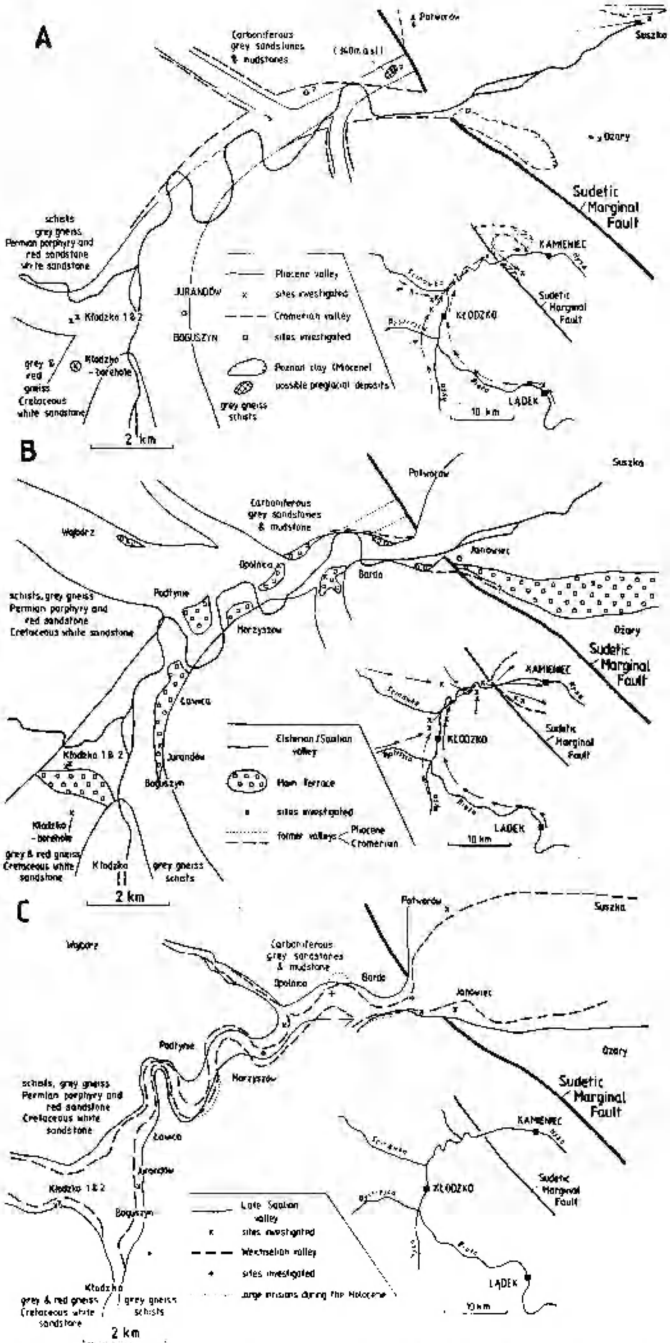

Fig. 17. Palaeogeography of the Nysa Klodzka river valley and ancient fluvial tracts: A – Late Pliocene nad Cromerian (pre-Elsterian), B – Elsterian/Saalian stages (pre-Odranian, pre-early Saalian), C – postglacial (post-Odranian, post-early Saalian) stages.

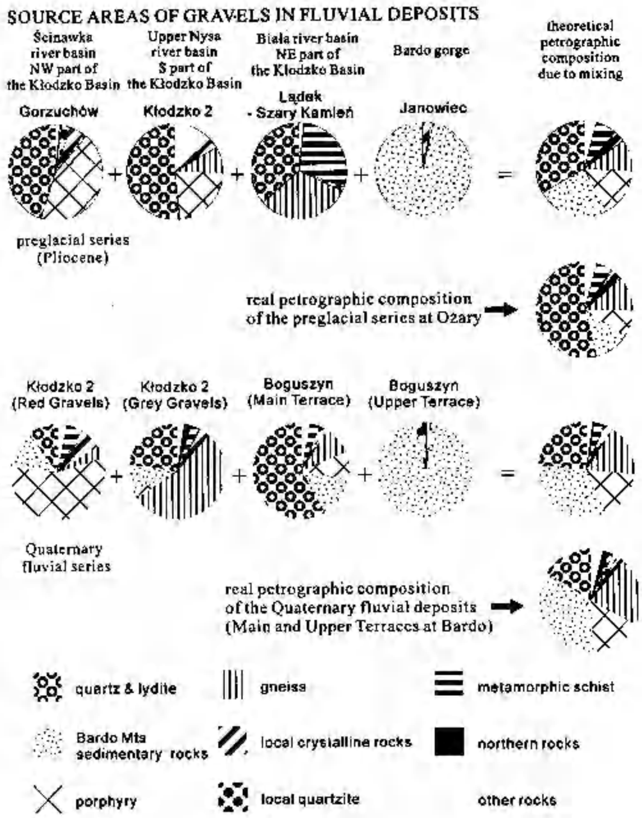

Fig. 18. Petrographic composition of gravels of rivers forming the pre-Nysa Klodzka fluvial system and formation of a series with mixed petrography: examples from the Pliocene (upper) and Pleistocene (lower) series.

bility. Once formed during the Pliocene, it continued roughly with the same valley alignments until recently. This is valid also for the Bardo Mts range, where a 1.0–1.5 km wide gorge has existed since the Pliocene (Fig. 17). This suggests an antecedent origin for the valley, formed due to continuous mountain uplift during the late Cainozoic.

The old valleys (Pliocene, Cromerian) were up to 3.0 km wide, characterized by low sinusoity and very low gradients (0.09–0.12%; the modern one 0.17%). These facts infer a quite different landscape from today's, most probably, with a much lower mountain range, less steep slopes and wider valleys. The Pliocene and Cromerian fluvial deposits lie at similar altitudes in the Kłodzko Basin and the Sudetic Foreland, and only 60–70 m (Pliocene) and 40–50 m (Cromerian) higher in the Bardo gorge (Fig. 19A, B). We suspect, that the Pliocene river, which occupied very wide valley, indicated similar and relatively low gradient in the mountain gorge as in basins beyond it. Also, besides the wide valley, terrace divergence has not been observed within the Cromerian fluvial system, as the base of the Glaciofluvial Terrace is similar throughout the Bardo gorge (Fig. 19B). These facts infer slow uplift rates during the Pliocene and Cromerian. The erosion phases, which caused the oldest terrace systems and displacement of Pliocene and Cromerian sediments in tne Bardo gorge, took place during the later periods, probably the Early Pleistocene and late Middle Pleistocene, respectively (Fig. 20).

The Holsteinian rivers partly follow the older valleys, being 0.5–2.0 km wide and characterized by low sinusoity and low gradients (0.09%), but in part, formed new valleys with steep gradients (pre-Ścinawka river, up to 0.25%). This infers strong erosional processes after the Elsterian glaciation at least in a part of the drainage basin and formation of the epigenetic valleys. The latter were cut within the bedrock, partly using the subglacial tunnel valleys and then filled with the Main Terrace deposits. The total amount of erosion after the Elsterian glaciation was up to 40–50 m, including the epigenetic valley near Wojbórz

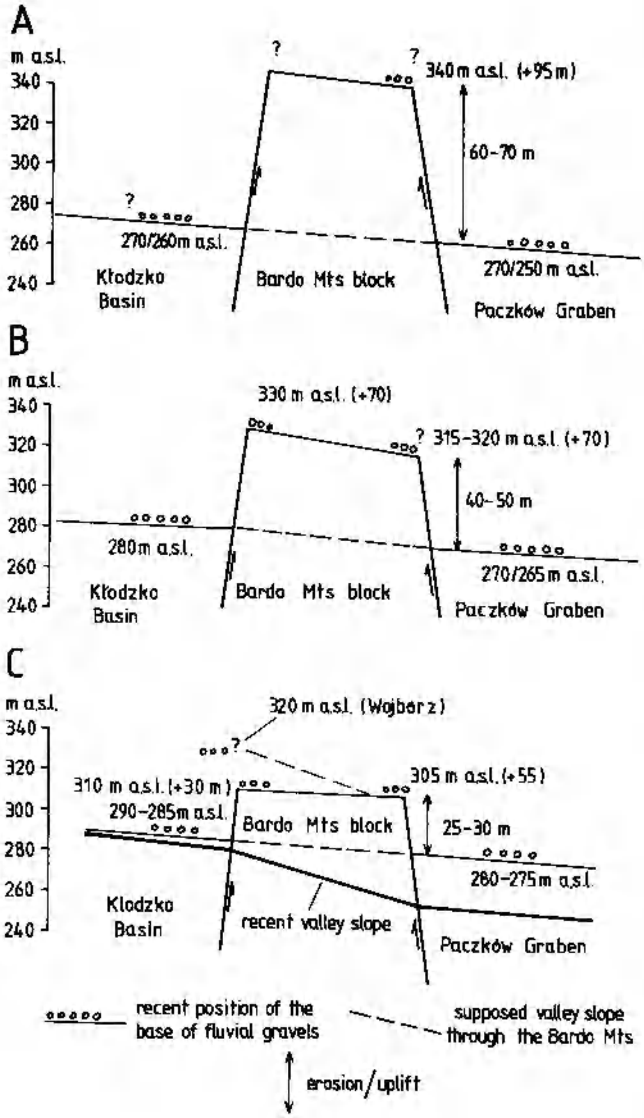

Fig. 19. Fluvial erosion and (neo)tectonic uplift along the Nysa Kłodzka river: A – Late Pliocene, B – pre-Elsterian stage (Glaciofluvial Terrace), C – pre-early Saalian stage (Main Terrace).

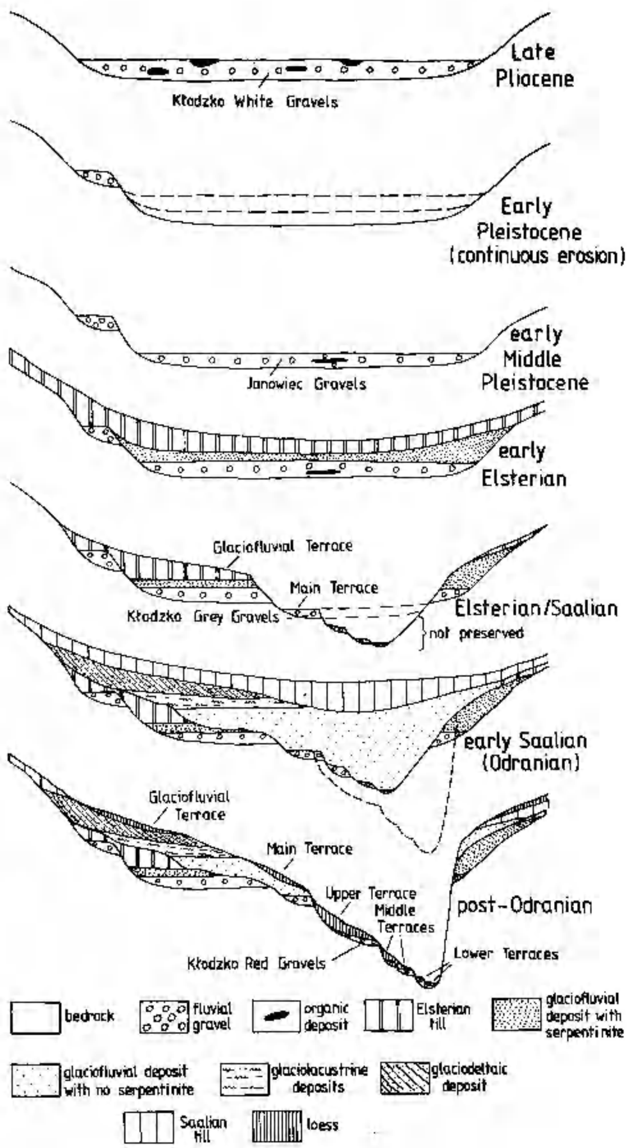

Fig. 20. A model of fluvial erosion and sedimentation in the Bardo gorge.

(Fig. 19B, C). Glacio-isostatically induced tectonic movements were highly possible, as the Main Terrace indicates clear divergence and it was thrown 5–10 m along the Sudetic Marginal Fault. These facts infer two types of tectonic movements after the Elsterian glaciation, fast uplift which possibly formed 5–10 m high fault scarps and relatively slow uplift and erosion mainly due to base level changes (Fig. 20).

The features of the post-early Saalian (post-Odranian) river valleys clearly indicate tectonic movements in the drainage basin and deep erosion. These are terrace divergence, steep river gradients, the high sinuosity of river valley, formation of epigenetic valleys strongly dependent on bedrock structure and common fault scarps along the Sudetic Marginal Fault (Wilczyński, 1991; Krzyszkowski *et al.*, 1995). The total erosion was about 55 m, with the greatest erosion directly followed the early Salian (Odranian) glaciation. It was about 15–20 m during late Saalian, and then slowly diminishing (10–15 m during the Eemian and Weichselian, 5 m during the Holocene). The neotectonic uplift measured in the fault scarps is, however, only about 10 m and 5 m, respectively. Hence it seems that another 20–30 m of the erosion depth is due to base level changes in the drainage basin after the early Saalian glaciation. The post-early Saalian glacio-isostatic rebound is the most probable trigger for the uplift and strong erosion, although it must have been supplied by some endogenic forces as the intensive faulting continued until Weichselian (8–10 m high fault scarp in the lower Middle Terrace).

It must be stressed, that all the erosion phases are of a similar order: Early Pleistocene 60–70 m, post-Elsterian 40–50 m and post-early Saalian 55 m (Fig. 20). This probably suggests similar causes and processes. It seems that the major erosion was due to changes of base level, which was supplied partly by neotectonic movements. The neotectonic movements were larger during the Early Pleistocene and smaller during post-glacial times, but the latter indicated larger uplift rates due to fast glacio-isostatic rebound. The post-Elsterian uplift could have been similar to the post-early Saalian, but it is less well documented. The post-Saalian uplift phases refreshed finally the morphology, mainly due to formation of epigenetic gorges (Wilczyński, 1991). Recent morphology of the Bardo gorge comes mainly from the post-Saalian period, with only minor changes from Weichselian and Holocene times (Fig. 17). The Pleistocene uplift phases could have produced together a maximum of about 100 m uplift. The complete lack of Early Pleistocene deposits in the Nysa Kłodzka river drainage basin may suggest the strongest erosional processes and major Pleistocene uplift that time. This well correlates with the suspected 60–70 m displacement of the Pliocene deposits in the Bargo gorge. The recent morphological scarp along the Sudetic Marginal Fault is, however, 400 m high near Bardo. Thus, the main uplift phase of the Sudetes, that formed the major part of the 400 m high scarp of the Sudeten took place before Pliocene. The total Middle and Late Pleistocene displacement was about 25 m, and it was of similar order in both post-glacial periods.

CONCLUSIONS

1. The Nysa Kłodzka river drainge basin preserves a complex late Cainozoic sequence that includes eight fluvial series/terraces and deposits from two glacial episodes as well as local volcanic rocks, slope deposits and loess. Sedimentation took place during the Late Pliocene and since the early Middle Pleistocene (Cromerian), with a long erosion phase (hiatus) during the Early Pleistocene. The fluvial series are from the late Pliocene, Cromerian, Holsteinian, late Saalian/Eemian, Weichselian and the Holocene. The glacial deposits represent the early Elsterian and early Saalian (Odranian) stages. Almost all these stratigraphic units can been observed in all geomorphic zones: the mountainous Kłodzko Basin, the Bardo Mts (Bardo gorge) and in the mountain foreland.

2. The main phase of tectonic uplift and strong erosion was during the Early Pleistocene, during which the Pliocene fluvial sediments probably reached at least 60–70 m higher position in the Bardo gorge than in the surronding basins. Small amounts of uplift was occurred during the post-early Saalian time, very probably also during the post-Elsterian time. The post-early Saalian and post-Elstrian uplift phases are most probably due to glacio-isostatic rebound, and together produced up to 25 m displacement.

3. The Quaternary terrace sequence has been formed due to base level changes, epigenetic erosion after glaciations and neotectonic movements. The Cromerian fluvial deposits/terraces do not indicate tectonic influence at all. All other Quaternary terraces indicate clear divergence and the post-early Saalian terraces fault scarps also.

4. The fluvial pattern is stable. Once formed during the Pliocene, it continued in the same place until the present, with only minor changes within the uplifted block in the Bardo gorge. All rivers, including during the Pliocene, had source areas from the entire Kłodzko Basin. The material was collected into one river along the Bardo gorge, as sites both along it and in the Sudetic Foreland indicate a mixed petrographic composition. These facts infer the antecedent origin of the Bardo gorge. Only during post-glacial times have epigenetic incisions slightly modified the valley.

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