Geologia Sudetica, 1998, 31: 289–305.

Geomorphic evolution of the mountain front of the Sudetes between Dobromierz and Paszowice and adjacent areas, with particular reference to the fluvial systems

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Key words: neotectonics, fluvial terraces, alluvial fans, differential erosion, Quaternary

Abstract The morphology of the marginal part of the Sudetes between Dobromierz and Paszowice reflects above all lithological and structural differences within bedrock. Major landforms include watershed surfaces of low relief, monadnocks and intramontane basins. Drainage pattern changes were associated with the decay of the early Saalian (Odranian) ice-sheet, whilst stages of further development of fluvial systems are well documented by multiple terrace levels. The mountain front of the Sudetes, genetically related to the Sudetic Marginal Fault, is only up to 100 m high and overall strongly degraded. In contrast to southern sectors of the Sudetic mountain front, active Quaternary tectonics played minor part in the landscape development.

Manuscript received 15 April 1998, accepted 30 October 1998.

INTRODUCTION

This paper presents results of research carried out in the marginal zone of the Sudetes Mts between Dobromierz and Paszowice and focuses on the geomorphology and Quaternary stratigraphy of this area. The study area includes the actual mountain front of the Sudetes Mts, sections of the Nysa Szalona and Nysa Mala valleys located close to the margin, together with intervening watershed surfaces (Bolków and Walbrzych Uplands), and the piedmont plain (Fig. 1). These investigations form a part of a wider project aimed at recognition of principal events in the evolution of the Sudetic Marginal Fault zone during the Quaternary, whose partial results have already been published (*cf.* Krzyszkowski & Pijet, 1993; Krzyszkowski & Stachura, 1993, 1998; Krzyszkowski *et al.*, 1995). In particular, the issue of neotectonic activity of the Sudetic Marginal Fault has been considered recently.

The mountain front of the Sudetes Mts between Dobromierz and Paszowice has a few specific features in comparison to other sectors of the fault. Above all, its morphological expression is rather weak because of very low scarp height, only 50–100 m. By contrast, both towards northwest and south-east the height of the scarp increases to at least 100 m. Another feature worth mentioning is the discrepancy between the location of the mountain front base and the course of the Sudetic Marginal Fault; the former is worn back for 200–500 m in respect to the latter. Moreover, two main river valleys in the area, the Nysa Szalona and Nysa Mala valley, have an anomalous width, up to 2 km. This in turn has enabled preservation of very complete terrace sequences. From the tectonic point of view, both valleys are located within trough-like structures of the Wolbromek and Świerzawa Grabens, filled with Permian sedimentary rocks (Fig. 2). It is not clear, however, whether the width of the valleys reflects influences of tectonics or low resistance of bedrock.

The features outlined above are quite rare along the 160 km long Sudetic Marginal Fault. Therefore, comparison of principles of valley evolution and watershed surface development between this, and other sectors of the fault may be a worthwhile exercise. An additional stimulus for detailed research has also been our very incomplete knowledge about Quaternary formations between Dobromierz, Paszowice, and Bolków. These were described long time ago, chiefly in the framework of geological mapping for map production purposes (Zimmermann & Haack, 1913, 1935; Zimmermann, 1926; von zur Mühlen *et al.*, 1925; von zur Mühlen, 1928; Zimmermann & von zur Mühlen, 1933; Genieser, 1936; Kural & Teisseyre, 1978). Papers by von zur Mühlen (1928) and Genieser (1936) are in fact the most recent works on the fluvial sediments in both major

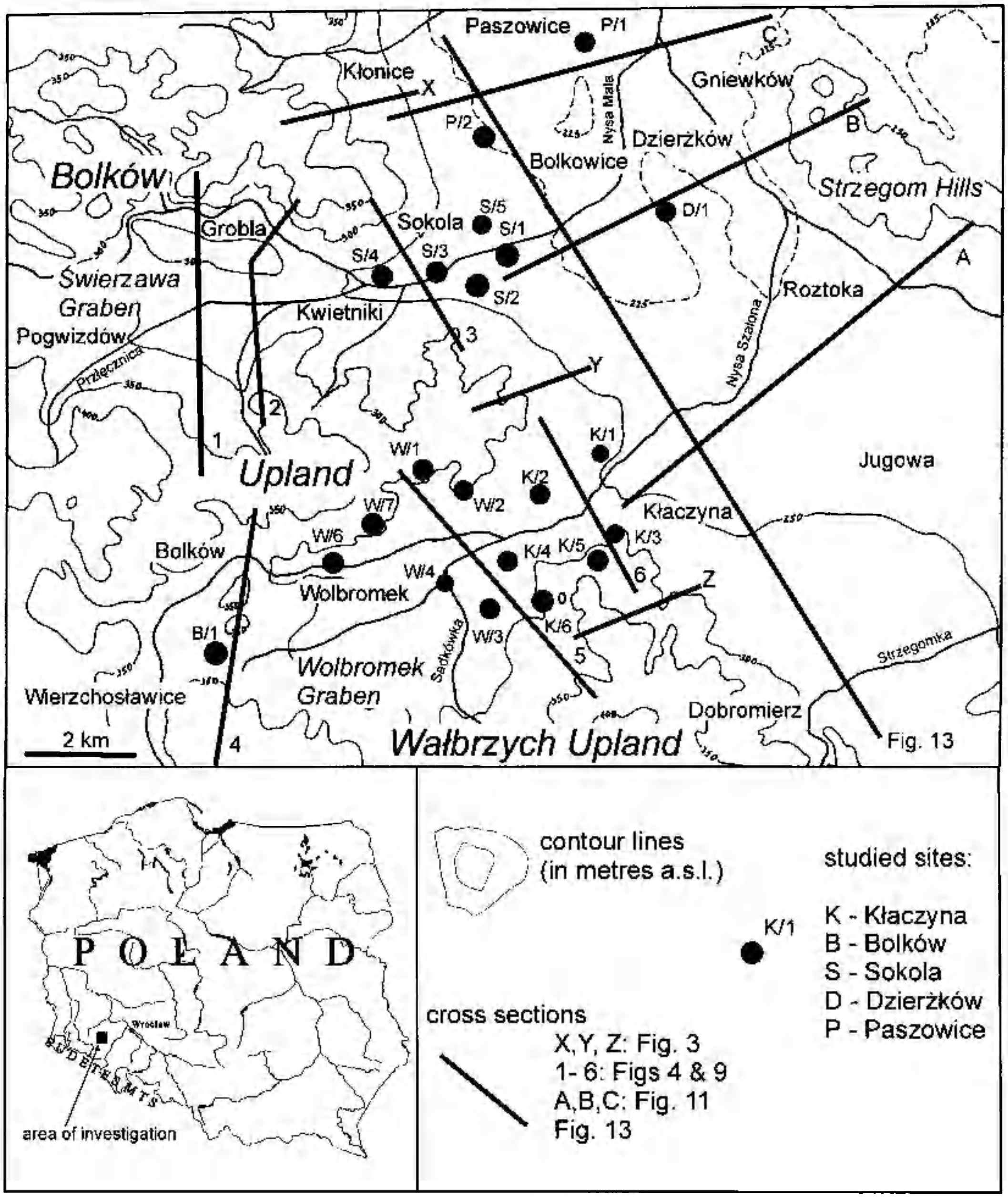

Fig. 1. Area of investigation: location of studied sites and geological cross sections.

valleys; however the glacial sediments have been investigated more recently (Genieser, 1936; Jahn, 1960; Dyjor & Sadowska, 1968, 1969; Teisseyre, 1969; Jaworska, 1973). There are a few papers focused on Tertiary deposits in the foreland area (Oberc & Dyjor, 1969; Dyjor & Kuszell, 1977; Kowalski, 1977; Kural, 1979), whilst the only geomorphological description of the area has been provided by Kowalski (1978). The possibility of tectonic reactivation of the Sudetic Marginal Fault during the Quaternary has never been seriously discussed.

GEOLOGICAL STRUCTURE

In the marginal area of the Sudetes Mts, within the Wałbrzych and Bolków Uplands, several geological units containing rocks of different ages and lithologies juxtapose (Fig. 2). They belong to two structural units. The lower one comprises a rock series of the Kaczawa Metamorphic Unit and includes greenschists, phyllites, sericite schists and diabase as dominant variants (Oberc, 1972; Baranowski *et al.*, 1982). Tectonic relationships within the Kaczawa Metamorphic Unit are very complex and not yet fully understood. Nevertheless, three sub-units are present in the study area, the Rzeszówek-Jakuszowa Unit in the north, the Dobromierz Unit in the south, and the Bolków Unit

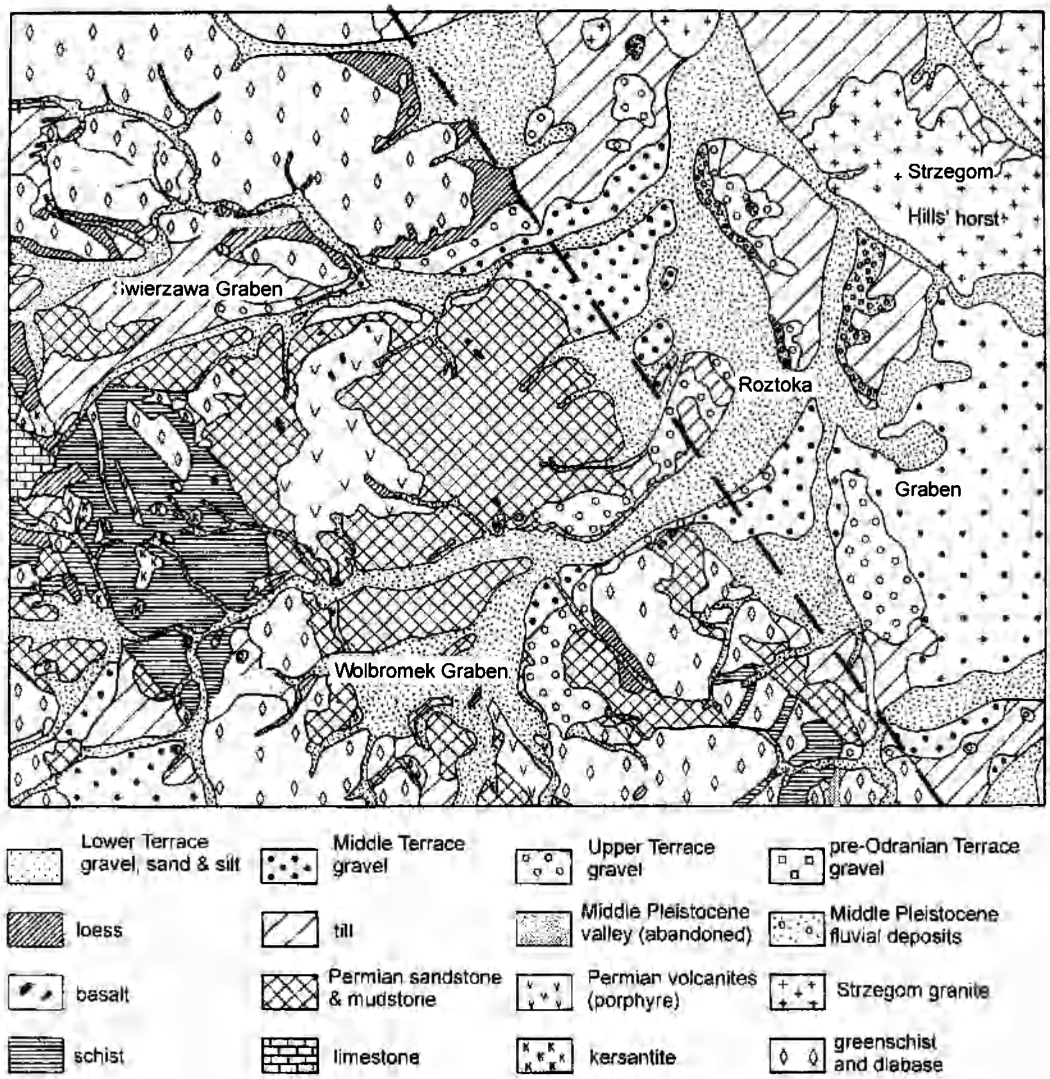

Fig. 2. Simplified geological map of the Bolków Upland and the Sudetic Foreland of the Roztoka Graben zone (after von zur Mühlen *et al.*, 1925; Zimmermann & Haack, 1935; Kural & Teisseyre, 1977, and Baranowski *et al.*, 1982).

in the west. Final consolidation of the lower unit took place during the Variscan movements in the Carboniferous.

The upper Laramian unit includes sedimentary rocks, whose ages span the time range from the Late Carboniferous up to the Cretaceous, yet in the area investigated it is only Lower Permian strata that crop out (Oberc, 1972). These are conglomerates, sandstones and mudstones, and the large rhyolitic massif between Bolków and Kwietniki (Fig. 2).

Permian sedimentary rocks occur within well defined graben structures, which themselves are south-eastern outliers of the North Sudetic Depression (Fig. 2). The 2–2.5 km wide Świerzawa Graben is the major structure and towards the east it widens into rhomboidal Wolbromek basin. This in turn terminates at the margin of the Sudetes. The Świerzawa Graben is bounded by two parallel fault systems, called the Northern and the Southern Świerzawa Fault respectively (Oberc, 1972), whilst the extent of Permian rocks in the Wolbromek Basin is controlled by tectonic lines only in part. The half-graben of Wierzchosławice is located in the south-western part of the area and is isolated from the other negative structures. The half-horst structure of Bolków separates the Wierzchosławice and the Wolbromek Basin. The age of graben structures is not determined with any great precision; they are likely be multistage features, developed in the Mesozoic (Kimmerian and Laramian movements) and reactivated in the Tertiary (Oberc, 1972).

No Tertiary sediments occur in the Sudetes Mts around Bolków. The only Tertiary rocks are a few small and isolated basalt outcrops south of Kwietniki and Sokola (Fig. 2). On the other hand, Quaternary deposits occupy quite extensive areas, particularly within low-lying areas. Most of them are genetically related to the advance of the Scandinavian ice-sheet into the Sudetes Mts. Alluvial sediments within river valleys are discussed in much more detail later in this paper.

A part of the Sudetic Foreland adjacent to the mountain front between Dobromierz and Paszowice area belongs to the Late Cainozoic tectonic structure of the Roztoka-Mokrzeszów Graben (Dyjor & Kuszell, 1977;

Kural, 1979). The graben is 5 km wide and the cumulative thickness of its Neogene and Quaternary infill is 100–300 m. At the ground surface there occur till and fluvial sediments laid down by rivers coming from the Sudetes.

GENERAL GEOMORPHOLOGY

MOUNTAIN FRONT OF THE SUDETES MTS

The sector of the mountain front of the Sudetes Mts between Dobromierz and Paszowice forms its least impressive part. This weak geomorphic expression is due to low height, not exceeding 100 m, and even more so due to rather gentle slopes, only occasionally steeper than 10°, and very rarely greater than 15° (Fig. 3). Adjacent parts of the mountain front nevertheless differ from each other, reflecting structural and lithological differentiation of the footwall.

In the northern part, the mountain front is developed in greenschists of the Rzeszówek-Jakuszowa Unit and is 100–110 m high. Its inclination increases from 5–10° to more than 15° in the upper slope (Fig. 3). There occurs a topographic embayment within the mountain margin near Kłonice that extends some 500 m into the footwall area (Fig. 1, 2). The mountain front sector between the outlet of the Nysa Mala and the Nysa Szalona valley is built of Permian sedimentary rocks and is the lowest and most flattened (Fig. 3). The watershed surfaces rise only 50–60 m above the margin footslope, whilst slope inclination only exceptionally exceeds 10°. The height of the front rises again southwards from the Nysa Szalona, within greenschists, diabase and phyllite of the Dobromierz Unit, locally covered by partially fault-bounded patches of Permian rocks (Kural & Teisseyre, 1978) (Fig. 3). The scarp is up to 100 m high and slope inclination varies between 5° and 15°. Slope inclination changes in accordance with lithological changes; slopes are steeper in metamorphic rocks.

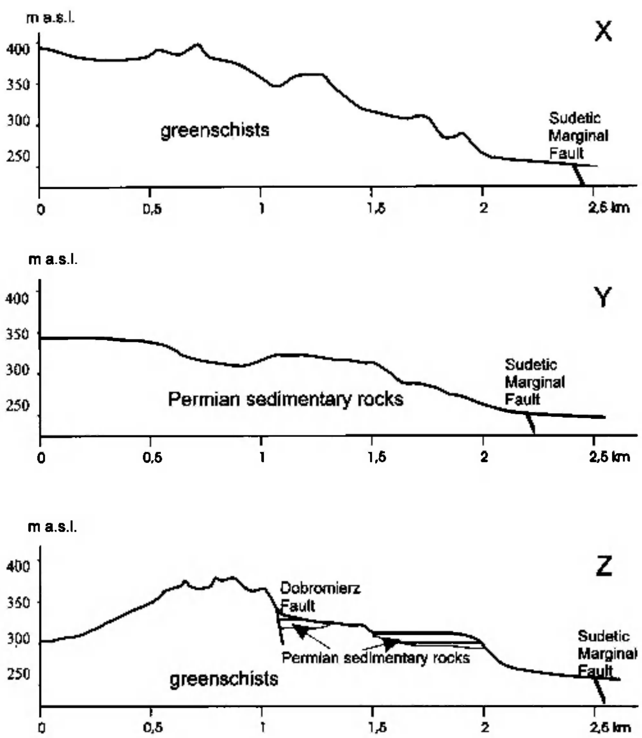

Fig. 3. Morphological cross sections through the scarp of the Sudetic Marginal Fault; location of cross sections is in Fig. 1.

Numerous small valleys, not longer than 2 km, dissect the mountain front of the Sudetes. Their detailed shape is also controlled by lithological differentiation of the footwall. Valleys, or their reaches, developed within sedimentary rocks are generally wider and less incised than their counterparts in the metamorphic rocks. The latter could take the form of 40 m deep ravines. Small valleys are distinctly asymmetric. Notwithstanding lithology, north-facing valley sides are 2–3 times steeper than the opposite ones (Gogól, 1993). Longitudinal profiles of small valleys do not show any disturbances while crossing the mountain front/foreland plain junction.

BOLKÓW-WALBRZYCH UPLAND AND ADJACENT AREAS

The landscape of the Bolków-Wałbrzych Upland is hilly and morphological contrasts within it are not very pronounced (Fig. 1). However, more distinct landforms such as escarpments, monadnocks, and deeply incised valleys and gorges do locally occur. Altitudinal differences between particular geomorphic units reflect structural and lithological heterogeneity of bedrock.

Watershed surfaces are undulating to hilly, and have been described as denudation palaeosurfaces (Piasecki, 1963; Kowalski, 1978). The altitude of palaeosurfaces is 360–400 m a.s.l. in greenschists and diabase of the Kaczawa Upland north of the Nysa Mala valley, 310–340 m a.s.l. in sedimentary rocks between the valleys of Nysa Mala and Nysa Szalona, 370–380 m a.s.l. in ryolites in the same area, and 360–380 m a.s.l. in metamorphic rocks of the Dobromierz Unit in the south-east (Fig. 1). The highest elevation of watershed surfaces occurs in the area north-west of Bolków; here the 410–450 m a.s.l. palaeosurface is developed upon phyllites, diabase and keratophyre. The occurrence of low-lying areas clearly reveals structural influence too. Their extent is identical with the extent of downthrown tectonic depressions of the Świerzawa Graben, Wierzchoslawice half-graben and of the southern part of the Wolbromek Basin (Fig. 1, 2). In all these cases, topographic basins have developed within Permian sedimentary rocks. Their floors are elevated only 280–350 m a.s.l., that is up to 150 m below the level of the upland palaeosurface. Depressions are bounded by distinct escarpments, up to 80 m high and locally of gradient as much as 30°, whose faces are built of metamorphic rocks. The most distinct is

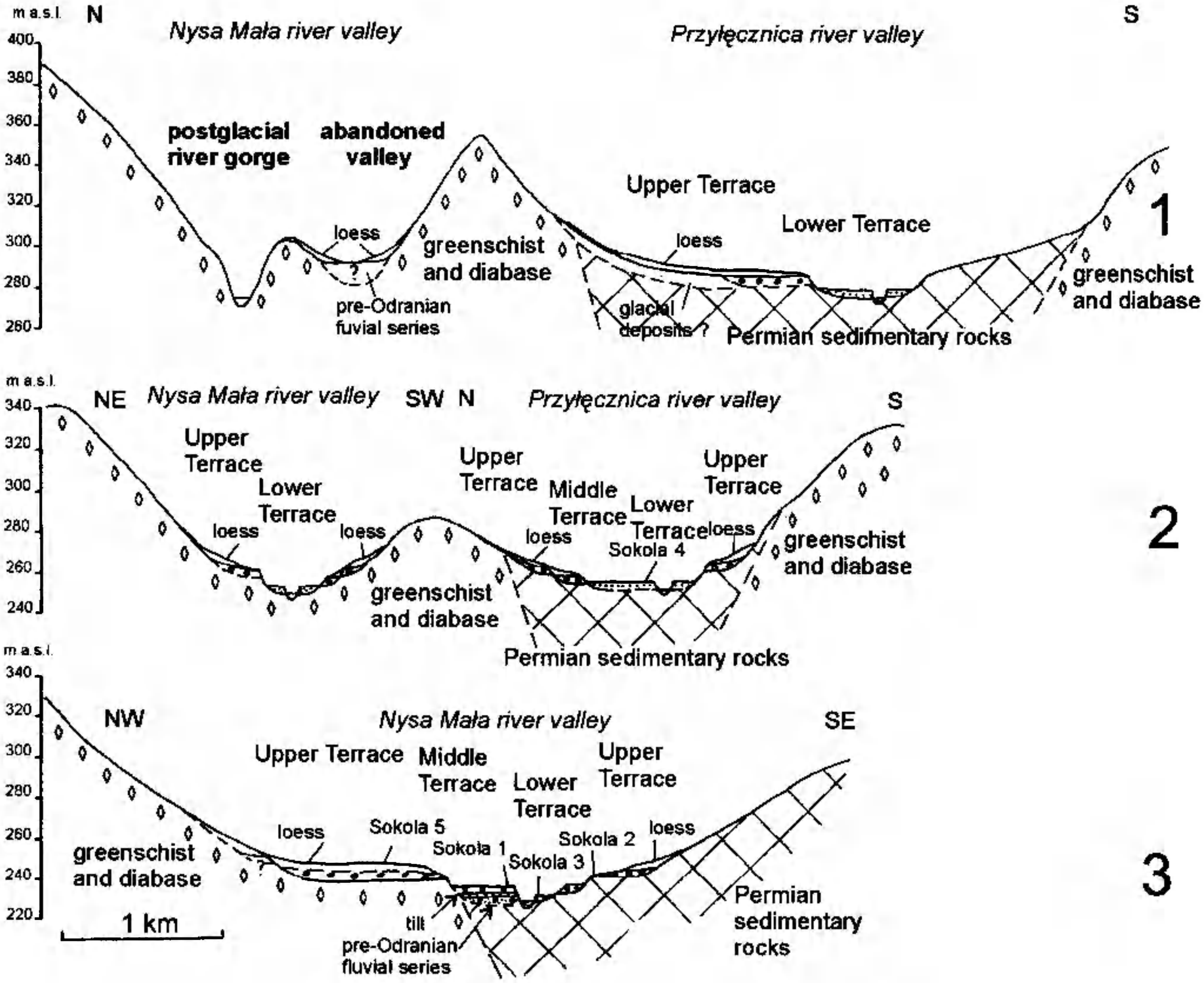

Fig. 4. Morphological and geological cross sections through the Nysa Mala river valley and the Świerzawa Graben, with position of discussed fluvial terraces; Location of cross sections are in Fig. 1.

the southern margin of the Kaczawa Upland in the vicinity of Pogwizdów. Lithological control of topographic basins is not evident everywhere. In the central part of the tectonic Wolbromek Basin there occurs an elevated terrain that overlooks basinal areas east of the Sadkówka river by 60 m, in spite of the same lithology (Fig. 1, 2). Smaller landforms to break monotony of undulating watershed surfaces are ryolite monadnocks north of Bolków, whose relative height comes up to 80 m, diabase and keratophyre hills around Gorzanowice, and deeply incised, by 60–80 m, reaches of river valleys in Bolków and upstream of Grobla (Fig. 1, 2).

MORPHOLOGY AND SEDIMENTS OF FLUVIAL VALLEYS

NYSA MALA VALLEY IN THE MOUNTAINOUS AREA

The Nysa Mała valley may be divided into three sections of different morphology. The western and eastern sections take the form of a flat-bottomed valley 1–2 km wide and bounded by gentle slopes, whilst the middle section is gorge-like, with a floodplain only 50–300 m wide and steep, rocky valley sides (Fig. 1, 4). The wide sections coincide with the area underlain by Permian sedimentary rocks of the eastern part of the Świerzawa Graben. The intervening gorge-like section is cut across outcrops of greenschists and locally diabase occurring north of the graben. However, morphological continuity of the topographic low of the Świerzawa Graben is not interrupted; the section of the graben not occupied by the Nysa Mała river is drained by its tributary the Przyłęcznica (Fig. 1, 2). A flat watershed surface between these two valleys is elevated by as little as 5–10 m and underlain by glacial depos-

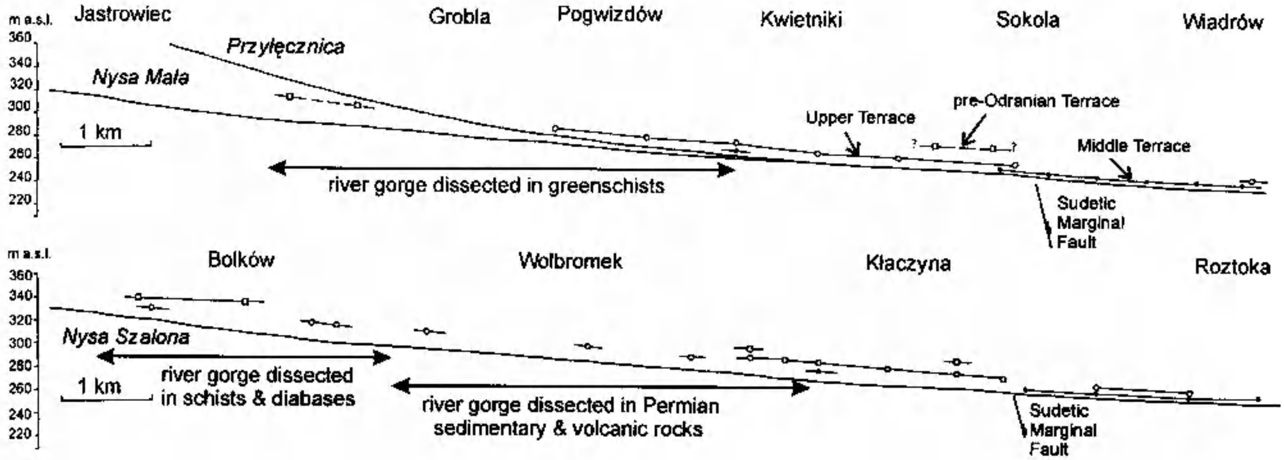

Fig. 5. Longitudinal profiles of the Nysa Mała and Nysa Szalona rivers and height of their terraces.

its (Zimmermann & Haack, 1913; Fig. 2). The longitudinal profile of Nysa Mala is generally graded, with the slope varying between 0.8 and 1.0% (Fig. 5). An increase in slope has not been recorded either within the gorge or at the Sudetic Marginal Fault.

In the Nysa Mała valley, there are recorded four different terrace levels; moreover, benches of supposedly fluvial origin, recently covered by glacial deposits or loess, have been recognised further upslope. The lowest and youngest terrace is 0.5–1.5 m high and forms a narrow strip parallel to the present-day channel; it is not described in any more detail here. The other terraces are the Lower Terrace (1–3 m high), Middle Terrace (4–7 m) and Upper Terrace (5–10 m high). The Upper Terrace is a strath terrace with an alluvial cover and is survived as extensive benches, 50–200 m wide, along both sides of the valley, and also within the valley of Przyłęcznica. Towards the margin of the Sudetes the width of the Upper Terrace bench increases to 500–800 m (Fig. 2). The Middle Terrace occurs only in close proximity of the Sudetic Marginal Fault, again on both valley sides, and a small remnant has been identified in the village of Kwietniki. The Lower Terrace surface is the most extensive and occurs also within the gorge-like section of the Nysa Mala valley (Fig. 2). Relative heights of terraces do not display any substantial changes along the valley. It is only the Upper Terrace that shows divergence, since its height rises from 5 m in Pogwizdów to 10 m in Kwietniki. Its relative height at the Sudetic Marginal Fault is about 10 m (Fig. 5).

Sediments of the above terraces are poorly exposed. At Sokola 2, a layer of 2 m thick, massive and poorly sorted gravels, with maximum diameter of clasts up to 20 cm, rest on a rock-cut surface built of Permian sandstones and conglomerates (Fig. 1, 4). At Sokola 5, fluvial gravels mixed with silt of probably aeolian origin have been found in a 1 m deep trench. Loess and loess-like deposits commonly cover the top surface of the Upper Terrace gravels.

Deposits of the Middle Terrace exposed at Sokola 1 show internal division into three layers. These are, from the top downwards, loess (1 m thick), fluvial sediments

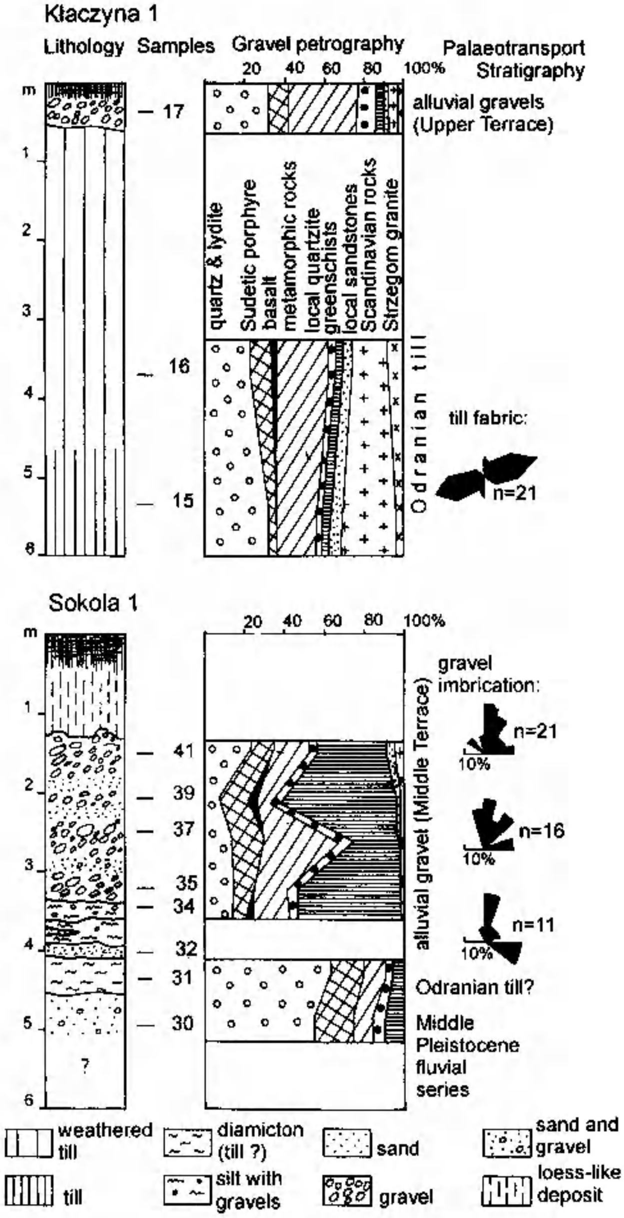

Fig. 6. Sediment sequence of the Upper Terrace at Kłaczyna 1 (upper) and the Middle Terrace at Sokola 1 (lower) and the results of petrographic studies and palaeotransport measurements.

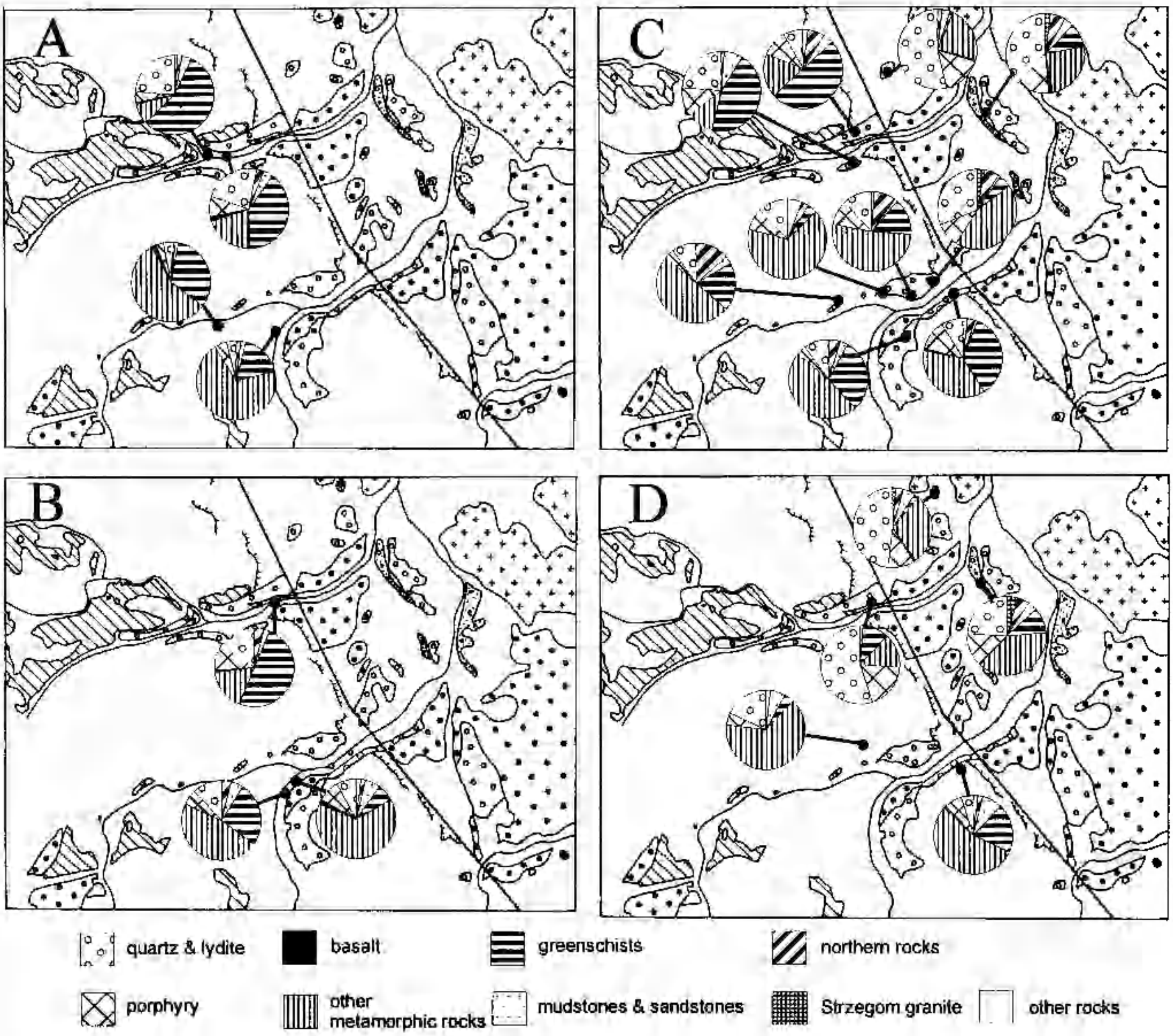

Fig. 7. Petrographic composition of fluvial gravels in fraction 10-35 mm in the Nysa Mała and Nysa Szalona river valleys: **A.** Lower Terrace, **B.** Middle Terrace, **C.** Upper Terrace, **D.** pre-Odranian (pre-early Saalian) fluvial deposits.

(about 3 m) and diamicton with older alluvial gravels (1 m). Water-laid sediments of the Middle Terrace consist of alternating massive and imbricated gravels and poorly sorted sands with gravels or coarse sand. Towards the bottom silty and silty-sandy layers locally occur. Gravel clasts are generally coarse, with maximum diameter of 35 cm, and are poorly rounded or sub-rounded. By contrast, older alluvial deposits are finer, with the mean diameter of clasts being 6 cm, and better rounded. They also differ in respect to clast lithology (Fig. 6). A diamicton that separates two gravel series might be of glacial origin, yet its lithology is identical to the underlying fluvial sediments and the absence of any northern material suggest fluvial origin.

Lower terrace deposits exposed at the Sokola 3 and Sokola 4 (Fig. 1, 4) cover a rock-cut surface which has been observed in the channel bed and are 2.5 m and 1.5 m thick respectively. They consist of massive and strongly imbricated gravel, with maximum diameter of 30 cm, in the bottom part, and alluvial sand and mud containing many pebbles 40–60 cm long in the upper part.

The clast lithology and mineralogy of alluvial gravel from different terraces of the Nysa Mała valley are very similar to each other (Fig. 7, 8). Greenschists and diabase are the dominant rocks (36–56%), and these are accompanied by quartz (15–25%), various metamorphic schists (11–20%), Permian volcanic (4–11%) and sedimentary rocks (2–8%). Exotic rocks from outside the Sudetes are very rare (1–3%). This composition is in good agreement with the geological structure of the Nysa Mała drainage basin and predominance of greenschists and diabase along the main valley (Fig. 2). At Sokola 1 granite from the Strzegom Massif and basalt have also been recognised (Fig. 6); both types of rocks do not occur in the upper part of the catchment and may have been derived from glacial deposits. As far as mineralogy is concerned, garnet and amphibole are dominant, and pyroxene, staurolite, andalusite, zircon, tourmaline and biotite occur in minor quantities. Abundance of pyroxene (8–50%) is noteworthy; it

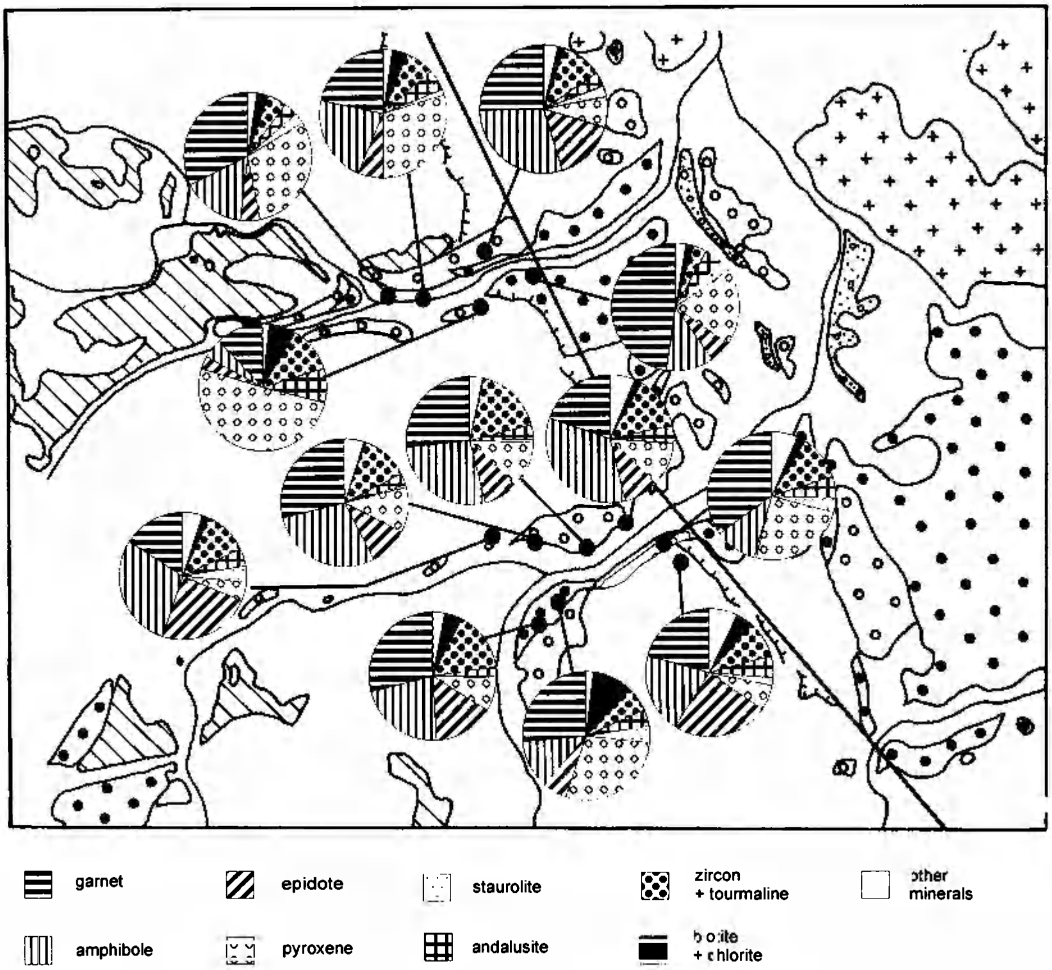

Fig. 8. Heavy minerals (fraction 0.1–0.25 mm) of fluvial sediments in the Nysa Mala and Nysa Szalona river valleys.

may have come from either Permian volcanic rocks or older mafic rocks, or both.

Along the Nysa Mala valley and its left-side tributary the Mlynówka, and within the gorge-like section in particular, there are distinct benches located about 20 m above the present-day floodplain. In three places they look like abandoned valley sections, now covered by Quaternary sediments of non-fluvial origin (Fig. 2, 4). Their courses are almost parallel to the present-day valley courses. It was not possible to investigate the sediments on the benches and within abandoned valley sections because of total absence of exposures, but it may be inferred from the available geological map (Zimmermann & Haack, 1913) that these comprise till and glaciofluvial sand and gravel, partially covered by loess.

NYSA SZALONA VALLEY IN THE MOUNTAINOUS AREA

The Nysa Szalona valley may be divided into two parts of contrasting morphology. The western part is a deeply incised, for about 3 km, with steep and rocky valley sides. In the town of Bolków, an area of Palaeozoic phyllites and diabase, the incision is up to 60 m deep and the valley floor is 100–200 m wide, however after entering outcrops of Permian sedimentary rocks in Wolbromek the valley widens to 200–500 m and incision is less pronounced. The eastern part of the valley, close to the margin of the Sudetes, is as much as 2 km wide and has a broad floodplain grading into gently inclined slopes (Fig. 1, 9). Tributaries of Nysa Szalona, namely Sadkówka and Wolbromek, occupy similarly wide valleys. They are all developed within the tectonic basin of Wolbromek, filled with Permian rocks (Fig. 2). Longitudinal profile of Nysa Szalona is graded, and its slope is 0.9–1.0%. No knickpoints at the Sudetic Marginal Fault have been observed (Fig. 5).

In the Nysa Szalona valley there occur five separate terrace levels and an abandoned valley section filled with glacial deposits (Fig. 9). The lowest and youngest terrace rises 0.5–1.5 m above the channel and can be traced all the way downstream. The Lower Terrace (1–3 m high) is widespread in both the lower, wide section of the valley, as well as in the upper, narrowly incised one. By contrast, the Middle Terrace (5–10 m) is laterally rather restricted and is developed along the Sadkówka valley and reappears in the border zone of the Sudetes Mts to continue in the foreland area (Fig. 2). Relative height of the Middle Terrace decreases downstream, from 10 m along Sadkówka to 5 m at the mountain front (Fig. 5). The Upper Terrace is a strath

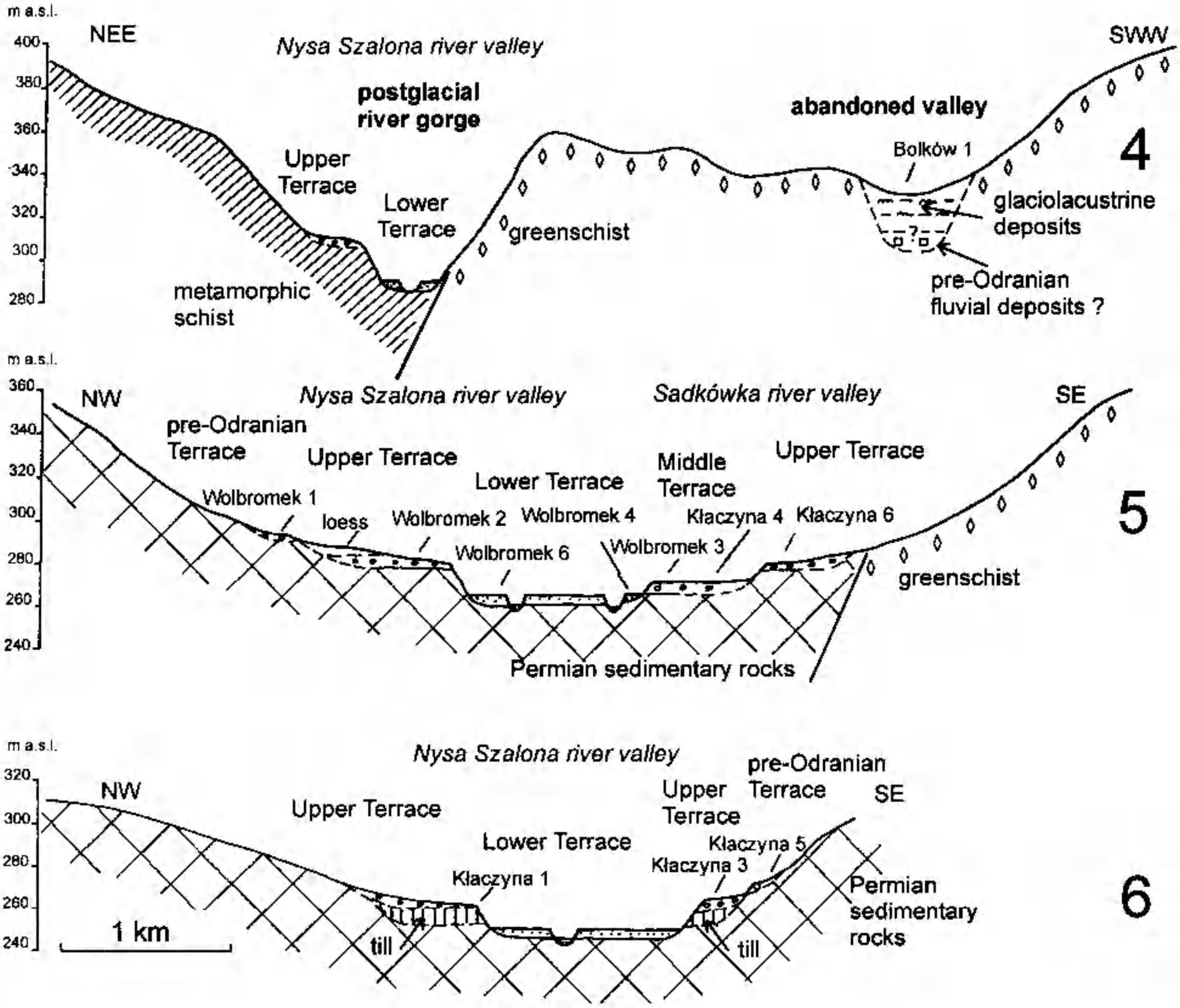

Fig. 9. Morphological and geological cross cections through the Nysa Szalona river valley and the Wolbromek Graben, with position of discussed fluvial terraces; Location of cross sections are in Fig. 1.

terrace and forms more or less extensive benches along the main valley and the tributaries. The benches are usually 50–200 m wide, but in two places, in the Sadkówka valley and close to margin of the Sudetes, they are almost 1 km wide (Fig. 2). The relative height of this terrace is not constant (Fig. 5). The terrace divergence is observed within the gorge between Bolków and Wolbromek, and the terrace height increases from 10–13 m up to 15–18 m. Another divergence is noticeable within Permian strata up to the mouth of Sadkówka; relative height rises there from 10–15 m to 20 m. However, further downstream towards the mountain front the terrace height decreases from 20 m through 12–15 m in the village of Kłaczyna to 10–12 m at the Sudetic Marginal Fault. Apart from these four terraces, two higher benches with alluvial gravel occur. One of these is located in Kłaczyna, close to the mountain front, 20 m above the floodplain; the other one occurs in Wolbromek and is 25 m high. The supposed section of valley near Bolków, now left abandoned, is elevated 20–30 m above the valley floor (Genieser, 1936; Fig. 2, 9).

Fluvial deposits in the Nysa Szalona valley are poorly exposed. There have only been two natural outcrops available for detailed investigation, one of the Lower Terrace sediments (Wolbromek 4), and another one of the Upper Terrace sediments (Kłaczyna 1); they both comprise the entire profile of alluvial deposits. In addition, fluvial sediments have been unearthed in 10 test trenches, 0.6–1.8 m deep; in one case the bottom of gravel series and bedrock beneath has been reached (Kłaczyna 6). The thickness of the gravels of the Upper Terrace varies from 0.4–0.5 m (Kłaczyna 1, Kłaczyna 6) to 0.8–1.0 m (Kłaczyna 3, Kłaczyna 2, Wolbromek 2, Wolbromek 7). Total thickness of the Middle Terrace deposits is not known; though it is at least 0.5–0.6 m (Kłaczyna 4, Wolbromek 3). Gravels of both the Upper and the Middle Terraces are covered by loess or loess-like deposits (Zimmermann & Haack, 1913, Zimmermann & von zur Mühlen, 1933). Lower Terrace deposits are more than 1 m (Wolbromek 6) and 1.3 m thick (Wolbromek 4); in the latter case gravels lie on the bedrock surface and the total height of the terrace is 2.3 m. Alluvial deposits in all outcrops and pits are very similar to each other. They are poorly sorted, massive coarse gravels

Fig. 10. Glaciolacustrine deposits at Bolków 1 (new brickyard) in 1991; arrows show the base and top of the glaciolacustrine sequence.

with sand and fine gravel as matrix. Clasts are up to 15–20 cm in diameter. Imbrication has been recognised in the Lower Terrace deposits.

Sediments on benches above the terrace flight have been investigated in two trenches (Wolbromek 1, Klaczyna 5), 1.7 m and 1.5 m deep. In both profiles, two separate series occur. At Klaczyna 5 the top part consists of 1.0–1.1 m thick layer of poorly sorted mixed gravels, including angular debris, with silty matrix. This is underlain by rounded and sub-rounded massive gravels with sandy matrix. The upper layer is likely to be a mixture of slope and fluvial deposits, whilst the lower one would be an alluvial deposit. At the Wolbromek 1, alluvial gravels are capped by deposits, whose glacial or glacifluvial origin may be inferred.

Lithological and mineralogical composition of alluvial deposits in the Nysa Szalona valley is similar for samples from all terrace levels (Figs 7, 8). Clasts of metamorphic rocks dominate (37–71%), and these are accompanied by greenschists and diabase (4–35%), quartz (3–18%), Permian volcanic (2–10%) and sedimentary rocks (1–6%). Clasts of northern derivation make up 1–8%. In comparison to the Nysa Mała valley, the percentage of greenschists is much lower, whilst that of other metamorphic schists increases, reflecting outcrop areas of both rock types within the adjacent drainage basins (Fig. 2). Moreover, there is a clear difference between the petrographic composition of alluvial sediments on the left and right side of the valley (Fig. 7). Among the heavy minerals garnet and amphibole occur in the largest proportions; pyroxene, staurolite, andalusite, zircon, tourmaline and biotite are present in lower quantities. Pyroxene occurs in considerable percentage (5–29%) and is likely derived from Permian volcanic rocks or older mafic rocks.

Glacial deposits occur in the new brickyard in Bolków (Bolków 1) and at the Klaczyna 1 and Wolbromek 1 sites (Fig. 1). During our fieldwork (1992–1993) in Bolków, only ice-dammed lake deposits were exposed to a total thickness of 10 m (Fig. 10). These are strongly deformed, alternating layers of black clay, brown and grey clayey mud and brownish sandy mud. The base of these deposits has not been reached. According to Genieser (1936), clays in the old brickyard in Bolków are underlain by fluvial gravel with no Scandinavian component. In the vicinity of the new brickyard, Bolków 1, clays are covered by angular slope debris, about 2 m thick. In the central part of the abandoned valley Zimmermann & Haack (1913) mapped a till at the topographic surface. Genieser (1936) points out a difference in colour between lower and upper part of the till bed; the former is black and the latter is brown.

Till is also exposed in the Nysa Szalona valley, within the strath of the Upper Terrace at Kłaczyna 1 site (Fig. 6). The exposure comprises a 5.5 m thick layer of sandy till, massive and locally laminated, grey-brownish (bottom) to brown (top). This is overlain by alluvial gravels 0.5 m thick. There have been numerous pebbles and one large erratic boulder of 1 m in diameter found in the till, which is weathered and decalcified throughout the profile. Measurements of long axes of clasts indicate local glacial transport from the NEE. The gravel fraction comprises, beside local rocks derived from reworking of older fluvial deposits, northern crystalline rocks (17–28%), granites from the Strzegom Massif (4–9%) and a single basalt clast (0.5%). Presence of the two latter components confirms direction of ice movement inferred from axis measurements. If the ice sheet had to advance from NW and N, a much larger proportion of basalt would be expected. Basalt is very common immediately north of the study area (vicinity of Myślibórz and Jawor), but quite rare in the southern part of the Strzegom Hills.

MOUNTAIN FORELAND AREA

The land surface of the foreland of the Sudetes Mts within the study area is developed across extensive sheets of alluvial deposits derived from three valleys, Nysa Mala, Nysa Szalona and Strzegomka (Fig. 1, 2). In between, higher ground occurs made up locally of glacial deposits. Quaternary sediments overlie Tertiary clay and kaolinic loam, sands and gravel, and brown coal seams (Fig. 11). The top of the Tertiary strata is located at 210–220 m a.s.l. and is dissected down to 190–200 m a.s.l. in the central part of the area. The alluvial plain is inclined towards the east and north, hence its altitude decreases from 250–260 m a.s.l. near the mountain front to about 210 m a.s.l. close to Gniewków (Fig. 1). The few glacial plateaux are a few metres up to 15 m high (maximum altitude at 251 m a.s.l.) and are most extensive in the northern and eastern part of the foreland area, near Bolkowice and Dierżków (Fig. 1, 2).

In the Dobromierz area, in the foremountain part of the Strzegomka valley, all three till horizons recognised in the region are thought to occur. The two lower horizons would represent two separate ice sheet advances during the Elsterian, whilst the upper one is likely to be deposited during the Odranian stage of the Saalian (early Saalian) (Krzyszkowski & Czech, 1995). Another sequence of Quaternary deposits has been found to underlie a higher ground surface between Bolkowice and Dzierżków (Fig. 11). There are two horizons of till separated by sand and

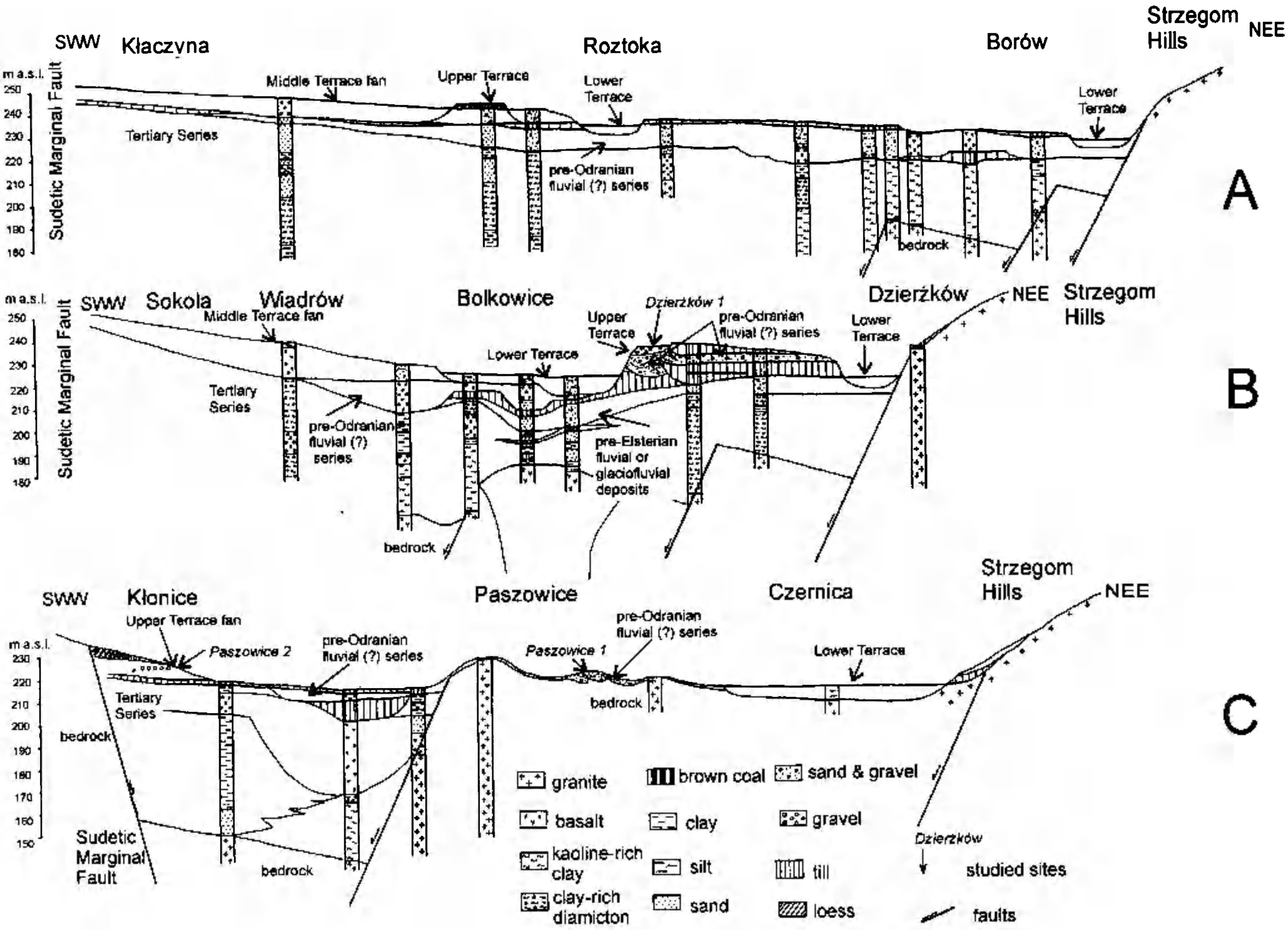

Fig. 11. Geological cross sections through the Roztoka Graben, location of sections in Fig. 1.

gravel, and the lower till is underlain by sand and gravel. It is likely that these tills represent the Saalian (upper one) and the Elsterian (lower one) glaciations. This profile is supplemented by the outcrop at Dierżków 1 (Fig. 12), where intra-till deposits are exposed and alluvial gravels of the Upper Terrace lie discordantly above them. The intra-till series is subjected to deformation of probable glaciotectonic origin. From a petrological point of view it is dominated by rocks of local provenance, thus it is similar to the Upper Terrace gravel composition (Fig. 7). Baltic limestones have not been identified and only most resistant northern rocks have been found, *i.e.* crystalline rocks and red quartzites. These properties are indicative of a fluvial origin for the intra-till series that would be older than the last ice sheet advance in the Sudetic Foreland, known to be of the early Saalian age (Krzyszkowski & Czech, 1995). Absence of any datable organic deposits in between till horizons does not allow one to determine the age of the sand and gravel series with any greater precision. Fluvial sediments of the intra-till horizon are also exposed within erosional margins of the higher ground surface and form a basement for alluvial deposits of the Upper Terrace (Fig. 2, 11).

Within other plateau surfaces in the foreland area, the sequence of Quaternary deposits is much reduced and usually consists of only one till horizon and sand and gravel series (Fig. 11). It is often difficult to determine whether the latter are of fluvial or glaciofluvial origin. Sediments recovered from boreholes have not been subjected to detailed petrological analysis, and there are only two outcrops in Paszowice (1 and 2; Fig. 12), where petrological properties suggest fluvial origin (Fig. 7). Sediments in the Paszowice 1 outcrop are deformed and might be of the same age as the deformed intra-till series at Dierżków, yet the isolated setting of the outcrop (Fig. 11) and limited thickness of deposits (Fig. 12) do not permit a more unequivocal interpretation. Sediments at Paszowice 2 are not deformed and may represent a remnant of the Upper Terrace.

Alluvial series of the Upper, Middle and Lower Terrace lie above the upper till horizon; hence, they are younger than the age of the last glaciation in the area, *i.e.* are younger than the Odranian (early Saalian) stage (Fig. 13). Sediments of the Upper and Middle Terrace form distinct alluvial fans and, in the case of the Upper Terrace fan, rest directly above the till. This implies that no phase of deep erosion preceded alluvial fan deposition and it was only deposits from ice sheet recession and the topmost part of the till that might have been eroded away (Fig. 13). Further away from the mountain front, the depth of incision increases as evidenced by the absence of the entire till horizon at the Dierżków 1 (Fig. 12). Apices of the Upper

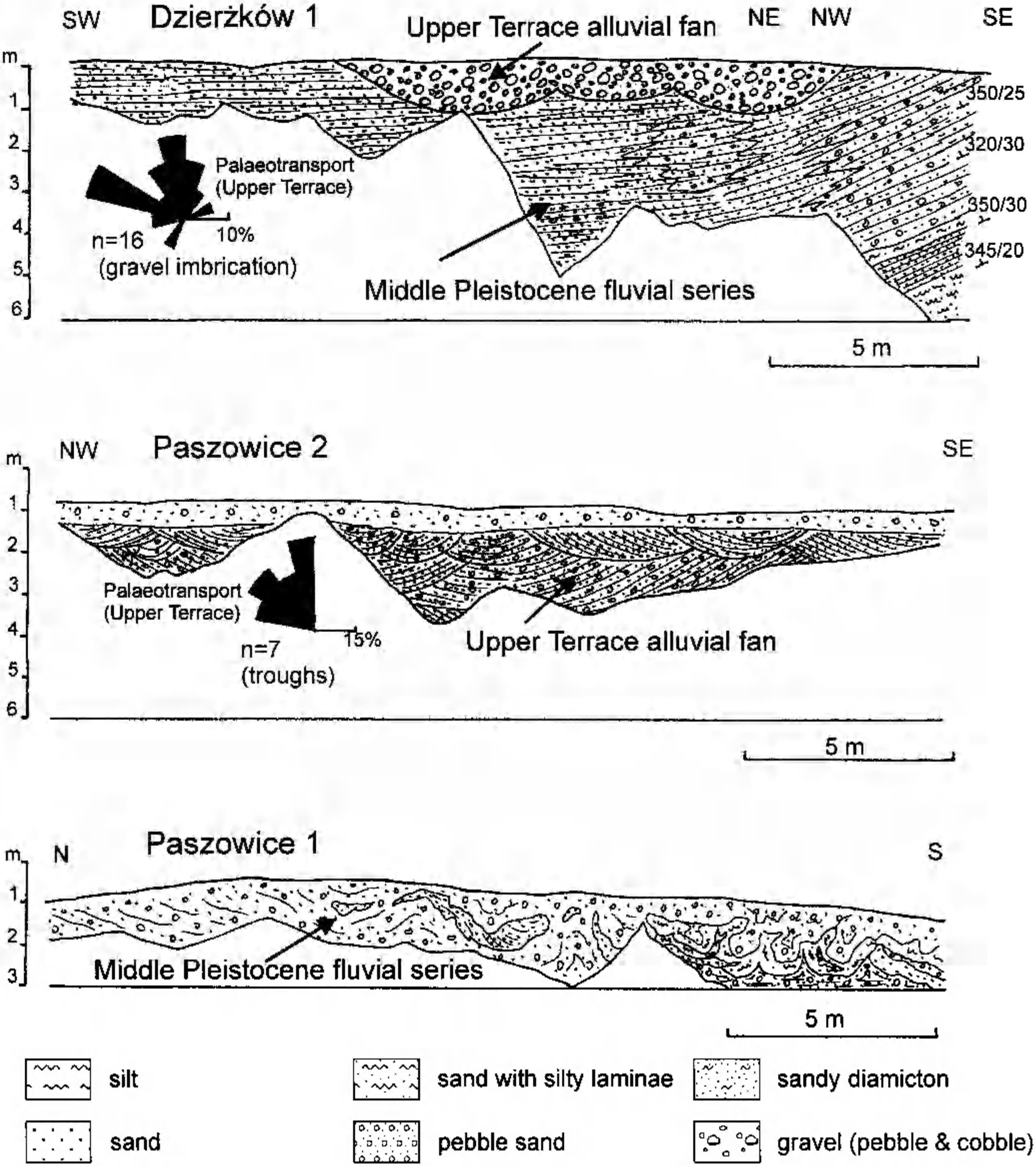

Fig. 12. Sediment successions and palaeotransport of fluvial deposits in the Roztoka Graben; note that Dzierżków 1 sequence comprises two fluvial series in superposition with the lower one being partly deformed (strata orientations are listed on the right side of the section).

Terrace fans are located at the mountain front (Strzegomka valley) or even within the mountainous area, 1–2 km upstream from the mountain front (Nysa Szalona and Nysa Mała valley), if one considers wide terraces in both valleys as upper segments of alluvial fans.

In turn, deposition of the Middle Terrace fans was preceded by an erosional phase, whose effects included dissection of older fans, development of new valley forms in the foreland, and partial removal of fluvial sediments outside the zone of most intensive erosion (Fig. 2, 13). The Middle Terrace sediments fill these erosional incisions, either fully (Nysa Mała) or partially (Nysa Szalona, Strzegomka; Fig. 13). Apices of the Middle Terrace fans are distinctly shifted downstream in respect to those of the older fans. They

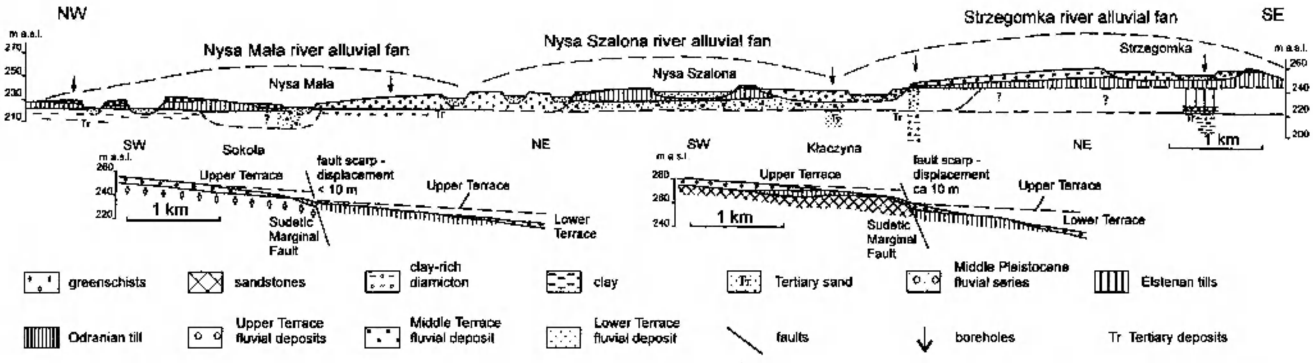

Fig. 13. Cross section through alluvial fans in the Sudetic Foreland between Dobromierz and Paszowice (the section is located ca 1.5 km from the mountain margin (*see* Fig. 1). Below: cross sections along the Upper Terrace levels in the Nysa Mała and Nysa Szalona river valleys indicating faults scarps and removal of Upper Terrace fluvial gravels (detailed discussion in the text).

occur right at the mountain front in the case of the Nysa Mala and Nysa Szalona valley, and 1.0–1.5 km away from the mountain margin, in the foreland area, in the Strzegomka valley (Fig. 2).

Distinct fans in the level of the Lower Terrace have not developed; instead, gravels of the Lower Terrace fill shallow dissections in the Middle Terrace fan surface (Fig. 13). Nonetheless, the areal extent of the Lower Terrace surface in the foreland is quite considerable and this surface may be interpreted as a fan surface too. At outlets of minor valleys, the Lower Terrace level is represented by small fans superimposed onto sand and gravel series of the Upper or the Middle Terrace (Fig. 2).

EVOLUTION OF WATERSHED SURFACES AND MOUNTAIN FRONT MORPHOLOGY

The late Cainozoic denudation history of the mountain front of the Sudetes Mts between Dobromierz and Paszowice and adjacent parts of the mountainous area can only be crudely outlined because no sedimentary series predating glaciation during the Middle Pleistocene exist which might be correlated over longer distances. Therefore, uncertain dating of erosional landforms is the only available key to long-term landscape development.

The abundance of rolling watershed surfaces of low relief indicates that planation processes have played an important part, yet because of considerable lithological and structural bedrock differentiation landscape lowering occurred simultaneously at different altitudes. Permian sedimentary rocks are less resistant and therefore the altitude of planation remnants is 50–150 m lower than that of their counterparts on more resistant volcanic and metamorphic rocks. Locally, basins have been excavated in outcrops of sedimentary rocks, whose margin follow lithological contacts (Sady, Wierzchosławice). Permian ryolites were least prone to planation processes and now they form a group of monadnocks north of Bolków; similarly, outcrops of Early Palaeozoic keratophyres around Gorzanowic occupy an elevated setting.

The issue of neotectonic activity of ancient fault lines, and of those bounding tectonic basins of Wolbromek and Świerzawa in particular, remains unclear. There exist distinct escarpments along margins of these tectonic basins, yet morphological features they show are common for both fault scarps and fault-line scarps (Migoń, 1995). Therefore, it is hardly possible to determine whether the origin of escarpments is causally related to differential uplift or to different denudation rates within adjacent rock complexes. However, some indications of spatially varying uplift in the Late Tertiary do exist, especially along the Southern Świerzawa Fault. These include scattered outcrops of Tertiary basalt south of Sokola and elevated position of denudation surfaces on Permian sedimentary rocks between the Nysa Szalona and Nysa Mała valley. Its altitude comes up to 340 m a.s.l., whilst around Sokola and Pogwizdów in the north and Sady and Wolbromek in the south the altitude is only 280–300 m a.s.l. in spite of the same bedrock lithology.

Evidence for the geomorphological development of the mountain front of the Sudetes is also sparse. The morphological escarpment is clearly of tectonic origin (Oberc & Dyjor, 1969), but it is now considerably lowered and worn back. Lithological differences within the footwall correspond with varying height of the escarpment, from 100 m near Dobromierz through 50–60 m for the area between the valleys of Nysa Mała and Nysa Szalona to 100 m again in the Kaczawa Upland. Therefore, differential uplift of the Sudetes in this area is but one possibility. On the other hand, it is likely that along some sections of the Sudetic Marginal Fault a few secondary faults parallel to each other have been active and its activity resulted in stepped morphology of the scarp. The idea of long-term punctuated uplift history inferred from alleged stepped arrangement of planation surfaces (Kowalski, 1978) is not sustainable. This arrangement does not occur everywhere and if it does, it reflects varying resistance of different lithologies to denudation processes (*see also* Migoń & Lach, 1998).

EVOLUTION OF THE FLUVIAL SYSTEM DURING THE QUATERNARY

Evolution of the fluvial system in the study area may be outlined through the analysis of drainage patterns and their changes in four time intervals. First reconstruction is possible for the period immediately predating the early Saalian (Odranian) glaciation, and subsequently for the periods of deposition of the Upper, Middle and Lower Terrace. These periods can be dated for Late Saalian (Wartanian) to Eemian, Middle Weichselian and Lateglacial/ Holocene respectively, but this dating is based on regional analogies (Krzyszkowski *et al.*, 1995) rather than on firm age determination in the study area. Relics of the oldest, pre-Odranian system in the mountainous area comprise most elevated terrace levels and abandoned valley sections, now filled with glacial deposits to some extent. The intra-till fluvial series would be its equivalent in the foreland. These landforms and sediments are likely to have originated during the temperate and cold periods between the Elsterian and Saalian glaciations. Till horizons indicate at least two, and probably three separate advances of the Scandinavian ice sheet in the foreland area, whilst it is only the early-Saalian (Odranian) glaciation that certainly invaded into the mountain area. By contrast to the adjacent Wałbrzych Upland (Krzyszkowski & Stachura, 1998), older till horizons and pre-Odranian abandoned valleys have not been found in the Bolków Upland and therefore any testable reconstruction of pre-Elsterian drainage pattern can not be suggested. It may only be speculated that no significant drainage pattern changes took place before the early-Saalian.

Fluvial valleys in existence prior to the advance of the early Saalian ice sheet occupied topographic lows originated by selective denudation of weak Permian sedimentary rocks. The Nysa Mala valley was then running along the Swierzawa Graben towards Pogwizdów and Kwietniki, and its outlet from the Sudetes was located in Sokola (Fig. 2, 14A). At that time, Przylęcznica was a short, right-side tributary joining the Nysa Mala in Pogwizdów. The Mlynówka, however, had much greater length and was the main river draining the south-eastern part of the Kaczawa Upland (Fig. 14A).

The Nysa Szalona was running east of Wzgórze Zamkowe (Castle Hill) in Bolków to the Wolbromek Graben, and it is only from Klaczyna downstream where pre-early Saalian and post-early Saalian valley is identical (Fig. 14A). North of the former Nysa Szalona valley and parallel to it another large stream cut its valley. This one was draining the eastern part of the Kaczawa Mountains and the northern part of the Wierzchoslawice Basin, entered phyllite outcrops around Bolków to form a narrow gorge-like section, and occupied much wider valley within Permian strata outcrops in Wolbromek (Fig. 2, 14A). Petrological composition of the lower fluvial series of the uppermost terrace at Wolbromek 1, with a dominance of clasts of metamorphic rocks, testifies to incision into resistant phyllites and greenstones.

Subsequent drainage pattern changes and the origin of new valley sections of gorge-like character have been associated with advance and then decay of the Scandinavian ice sheet. Varied bedrock morphology, with relative relief up to 150 m, is likely to have induced spatially different rates of ice sheet melting. This, coupled with unequal thickness of glacial cover, may have caused local changes of the former drainage pattern. Superimposition from glacial sedimentary surface is perhaps responsible for the formation of Nysa Szalona incision below the Castle Hill in Bolków (Walczak, 1968), and of Nysa Mala incision upstream of Grobla (Fig. 14B). It can not be ruled out, however, that the exact location of gorges is to some extent controlled by neotectonic movements, genetically related to glacio-isostasy.

Postglacial stages of fluvial systems evolution are documented by different terrace levels. Since terrace surfaces are fairly continuous along the valleys, an opportunity exists to assess the role of neotectonic influence. Active tectonics may be inferred from divergence of the Upper Terrace level between Bolków and Wolbromek in the Nysa Szalona valley and in Kwietniki in the Nysa Mala valley, truncation of the Upper Terrace surface at the Sudetic Marginal Fault, and from behaviour of alluvial fans in the foreland area. At the mountain front, distinct deformation of longitudinal profiles of the Upper Terrace takes place in both main valleys. Increase in gradient is accompanied by the occurrence of low topographic scarps and absence of fluvial sediments on terrace benches. Instead, till (Nysa Szalona valley) or greenstone bedrock (Nysa Mala) that normally underlies alluvial sediments is exposed (Fig. 13).

Scarps referred to above are likely to be residual fault scarps, whose cumulative amplitude of throw may be estimated at about 10 m for the Nysa Szalona valley and less than 10 m for the Nysa Mala valley. Rejuvenation of the mountain front during deposition of the Upper Terrace sand and gravel may also be deduced from onlapping of the Upper Terrace fan on the top of older sediments, without separating phase of erosion. Such a situation is usually interpreted as evidence of uplift rates exceeding erosion rates (Bull, 1977). Terrace divergence in Bolków is slight, being only about 5 m; similar values are recorded for the Nysa Mala valley.

No scarps of possible tectonic origin have been found to displace younger terrace levels. Declining tectonic activity along the Sudetic Marginal Fault may also be inferred from successive entrenchment of older fan surfaces and formation of younger fans within these incisions (*cf.* Bull, 1977). On the other hand, drainage arrangement on the Middle Terrace fan below the margin of the Sudetes is clearly asymmetrical for both Nysa Szalona and Nysa Mala, and also for neighbouring Strzegomka. In all these cases deflection to the right took place. Some minor tectonics may have been responsible but endogenic influence has disappeared since, as no comparable deflection is observed for the Lower Terrace fan formation.

Comparative analysis of fluvial system development in three neighbouring valleys, Nysa Mala, Nysa Szalona and Strzegomka, reveals some similarities between them.

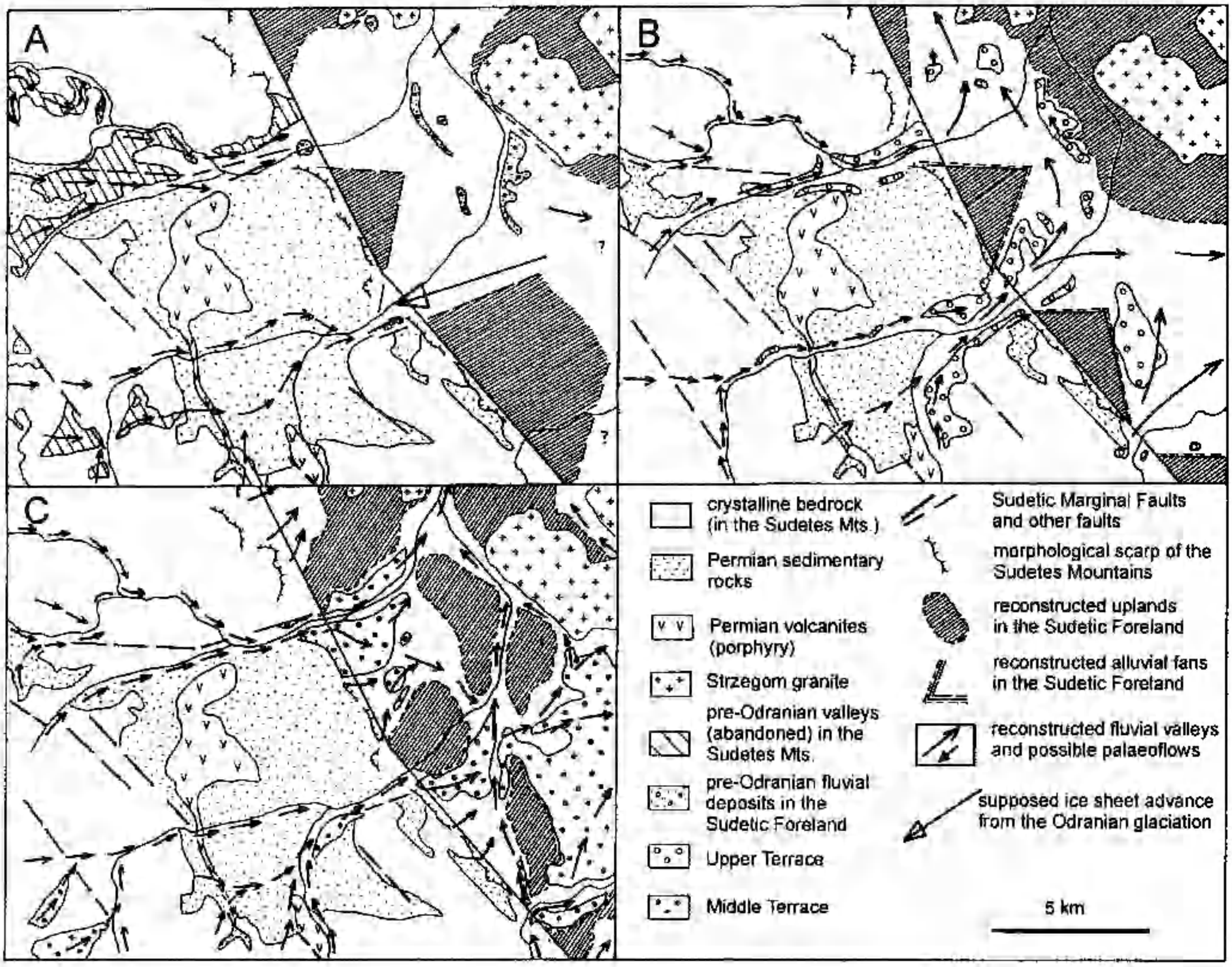

Fig. 14. Reconstruction of fluvial system of the Bolków Upland and the Roztoka Graben: **A** – pre-Odranian (pre-early Saalian) rivers, river courses follow tectonic depressions; **B** – rivers from the Late Saalian/Eemian time (Upper Terrace), shifting of the river coures and formation of deep gorges beyond tectonic depressions; **C** – rivers from the Middle Weichselian time (Middle Terrace). Note an extensive distribution of alluvial fans in the foremountain area during all discussed stages (detailed discussion in the text).

These include: divergence within the Upper Terrace level in the inner mountainous part of the catchments and its convergence towards the margin of the Sudetes Mts; the occurrence of 1–2 km wide valley sections at the mountain front and development of alluvial fill within them, which is particularly well seen for the Upper Terrace; development of extensive alluvial fans in the foreland area, where they merge into a one continuous alluvial piedmont surface; bifurcation of drainage lines in the foreland, to the Kaczawa and Wierzbiak valleys to the north, and to the Strzegomka valley to the south. It is only the youngest, Holocene stage for which similar bifurcation does not occur.

A few of the features listed above, *i.e.* terrace divergence and convergence, fault scarp formation and successive deposition and erosion of alluvial fans, suggest some degree of neotectonic activity and endogenic control exerted on fluvial systems development.

CONCLUSIONS

Neotectonic control of Late Cainozoic development of fluvial and denudational morphology in the marginal part of the Sudetes Mts between Dobromierz and Paszowice has been rather limited, particularly in comparison to other sectors of the Sudetic Marginal Fault located further towards south-east. More influential were long-term selective denudation of bedrock of varying resistance and ice sheet advance and subsequent decay. The amount of tectonic displacement, recorded in the oldest postglacial (post-early Saalian) deposits only, did not exceed 10 m. No signs of tectonic activity have been recognised in small valleys dissecting the mountain front of the Sudetes, although these landforms have proved to be very sensitive indicators of neotectonics elsewhere along the Sudetic Marginal

Fault. Also, the morphology of the mountain front itself, now much degraded and retreated away from the fault line, points to the long-term denudation regime and recent tectonic stability. The landscape of the study area bears more similarities to the adjacent area of Chelmy, located north of the Nysa Mala valley (Migoń & Łach, 1998), rather than to morphology of the Wałbrzych Upland in the south. In the latter area Late Quaternary uplift has been estimated at 40-50 m, the mountain front is steeper and the entire landscape is more varied, especially close to deep gorges incised into bedrock elevations (Krzyszkowski & Stachura, 1993, 1998). Evidence of the Quaternary history of the northern sectors of the Sudetic Marginal Fault presented above, if considered alongside the evidence obtained in more southerly parts of the marginal zone of the Sudetes, seems to confirm the hypothesis that the role played by active tectonics in Quaternary mountain front development decreases to the north-west and is replaced by lithologically- and structurally-controlled relief differentiation, itself inherited from the Tertiary to quite a considerable extent (Krzyszkowski *et al.*, 1995).

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