Geologia Sudetica, 1998, 31: 157–170.

The preglacial fluvial deposits in the southern part of the Upper Nysa Depression, central Sudetes Mts, southwestern Poland

Waldemar Sroka & Anna Kowalska

Instytut Nauk Geologicznych, Uniwersytet Wrocławski, pl. Maxa Borna 9, 50-204 Wrocław, Poland

Key words: gravel-bearing rivers, stratigraphy, fluvial palaeoenvironments

Abstract Three fluvial series have been distinguished in the Upper Nysa Depression, Kłodzko Basin, central Sudetes. The oldest, the Červeny Potok series, of probable Late Pliocene age, contains fluvial facies, mainly gravelly but also sandy and silty. It is quartz-rich and characterized by strong chemical decomposition of gneiss clasts. The Lichkov series, of probable Early to early Middle Pleistocene age, contains similar lithofacies to the Červeny Potok series, with locally abundant debris-flow deposits. The Boboszów series, of probable late Middle Pleistocene age, consists of a monotonous series of fluvial gravels. The pebbles in both, the Lichkov and Boboszów series are gneiss-rich and are characterised by a lack of significant chemical clast decomposition. The coarse-grained fluvial sediments of the southern part of the Upper Nysa Depression were mainly deposited in gravel-dominated braided rivers of Donjek and Scott type, and locally on alluvial fans. The material was transported from N or NE to S or SW, with the source area only in the adjacent metamorphic massif, despite the fact that the series lie on Late Cretaceous rocks. The studied area constituted a small intramontane depression subjected to limited subsidence, surrounded by episodically active faults. The variability of sedimentary process reflected climatic changes rather than tectonic activity. The northern part of the studied area, which now belongs to the Baltic Sea drainage area, was drained to the south, either to the North or Black Seas, during the Late Pliocene to Middle Pleistocene. The capture of this area by the Nysa Kłodzka river took place in the Late Pleistocene as a result of upstream erosion reflecting glacio-isostatic rebound and fault activity after the early Saalian glaciation.

Manuscript received 15 April 1998, accepted 30 October 1998.

INTRODUCTION

There is little data on the preglacial, Pliocene to Early Pleistocene, deposits of the southern part of the Upper Nysa Graben, with the most recent presentation only on geological maps and in explanations to them (Sawicki & Radwański, 1957; Svoboda & Chaloupský, 1961). In older works, the preglacial sediments of this area were described very roughly, always as a part of a general description of the whole Sudetes (Leppla, 1900; Tietze, 1901; Meissner, 1911). However, preglacial sediments have been described from areas north and south of the Upper Nysa Graben, in the northern part of the Klodzko Basin and in the Sudetic Foreland (Jahn *et al.*, 1984; Krzyszkowski *et al.*, 1998; Przybylski *et al.*, 1998), and in the Upper Moravia Graben (Hornomoravsky Uval) (Ru ička, 1973, 1989).

This paper presents so far the first detailed stratigraphic and sedimentological analysis of the preglacial deposits of the Upper Nysa Graben. The main purpose of this work is to describe the sediment stratigraphy and to reconstruct the sedimentary environments and ancient drainage patterns. Finally, the paleogeographic evolution of the area during the Pliocene and the Quaternary will be discussed in relation to adjacent areas. The studied area, which has about 55 square kilometre area, is situated on the Polish/Czech border, between Králiky and Międzylesie. It lies in the southern part of the Upper Nysa Depression, a part of the Klodzko Basin in the central Sudetes (Fig. 1).

MORPHOLOGICAL AND GEOLOGICAL SETTING

The Upper Nysa Depression comprises three morphological units in its southern part: the Międzylesie Upland in the north; the Králiky–Lichkov Lowland in the middle; and the Štity Depression in its southernmost part. The whole area constitutes itself as a long, narrow (ca 5–15 km) and relatively flat zone, surrounded by mountain ranges and separated from them by steep and distinct morphological scarps up to 300 meters high. The Upper Nysa Depression is between 450 and 600 m a.s.l., whereas the surrounding mountain ranges reach 800–1425 m a.s.l.

Despite being a morphological depression, the area is crossed by the main continental watersheds and therefore belongs to three different fluvial basins. The Międzylesie Upland is drained to the north by the Nysa Kłodzka river, a tributary of the Odra river, to the Baltic Sea; the Králiky–Lichkov Lowland to the west by the Ticha Orlice river, a tributary of the Elbe river, to the North Sea; and the Štity Graben to the east by the Březná and Morava rivers, tributaries of the Danube river, to the Black Sea.

The Nysa Kłodzka river and its tributaries flow in relatively narrow valleys, up to 50 meters deep, which dissect the flat surface of the Międzylesie Upland. The valley floor is eroded into the Cretaceous rocks and partly filled with Holocene alluvial deposits. The Ticha Orlice river valley is shallow and wide, often with extensive swamps and muddy alluvial deposits on floodplains, and does not constitute any significant element of the relief in the Králiky–Lichkov Depression. These systems differ from each other in their drainage pattern: the Nysa Kłodzka system is asymmetric, with parallel streams trending NE–SW; while the Ticha Orlice system is almost radial, with streams flowing from NE, E, SE and S. The drainage density is much larger in the Nysa Kłodzka system.

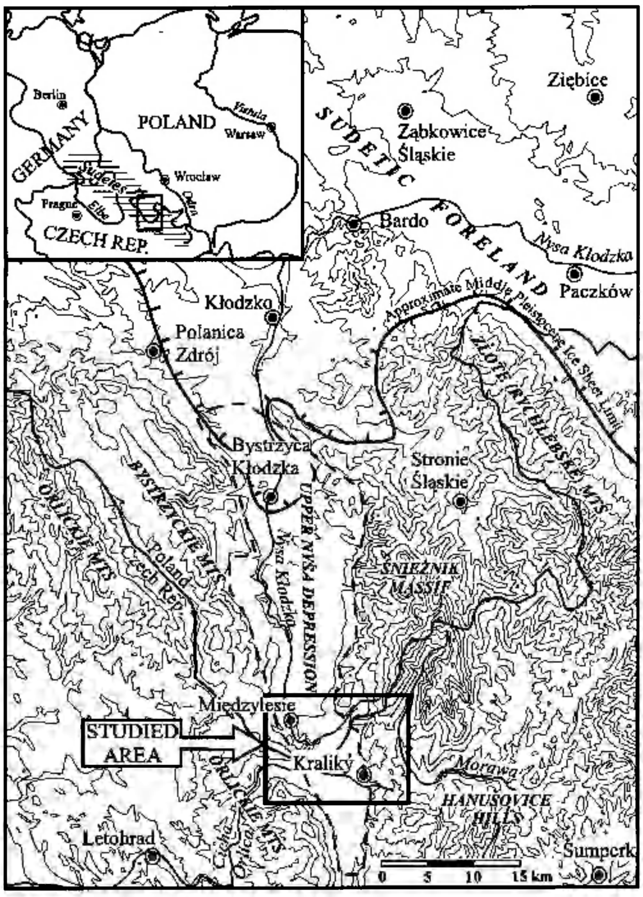

Fig. 1. Location of the studied area in the Upper Nysa Depression, Kłodzko Basin, central Sudetes Mts.

The Upper Nysa Depression is a morphological unit which is entirely contained within the tectonic Upper Nysa Graben, filled with Upper Cretaceous sediments. The graben is bounded by a system of NE–SW and N–S faults, which separate it from the metamorphic units of the Bystrzyckie and Orlickie Mountains in the west and from the Śnieznik metamorphic massif in the east (Fig. 2). The total thickness of the Cretaceous series is about 900 m. The sediments are mainly Turonian pelites of varying, calcareous-siliceous-clay-quartzose composition, and less frequent sandstones at the base of the Cenomanian to Early Turonian and at the top of the Late Coniacian to Santonian. Generally, grey marls and shales dominate in the studied area. Metamorphic rocks are represented by gneiss and locally by schists, quartzites and amphibolites.

A cover of Late Cainozoic deposits, mainly of fluvial origin (but in places also slope deposits) is common in valleys in the whole area, but is never more than 20 meters thick and usually less than 3 meters thick.

The present-day river valleys are filled with Late Pleistocene and Holocene alluvial deposits. The Late Pleistocene deposits, most probably of Weichselian age, are represented by gravels of the Nysa Kłodzka river terraces and alluvial fans of its tributaries. These gravels are generally massive, sometimes with crude horizontal bedding. This clastic material is poorly sorted, subangular and composed mainly of gneissic clasts, with a significant admixture of large angular clasts of Cretaceous sandstones and mudstones. The Holocene deposits are represented by contemporary valley floor deposits (floodplain), mainly gravel and sand, and sometimes silt. Generally, in contrast to the Late Pleistocene gravels, the Holocene deposits are rich in Cretaceous material.

Besides the late Quaternary deposits in the valleys, there are other fluvial gravels in the region. They are situated in watershed position, in places over 100 m above the present-day valley floor and are underlain by Cretaceous or metamorphic rocks (Fig. 2). A detailed description of these deposits is the main purpose of this paper.

METHODS

The field study was concentrated on the geological mapping and description and sampling of seven outcrops. 75 samples of gravelly and sandy material were collected and then analysed in the laboratory.

Textural analysis was based on grain-size distribution and grain morphology. Grain-size data (40 samples) were plotted on histograms and cumulative curves, from which

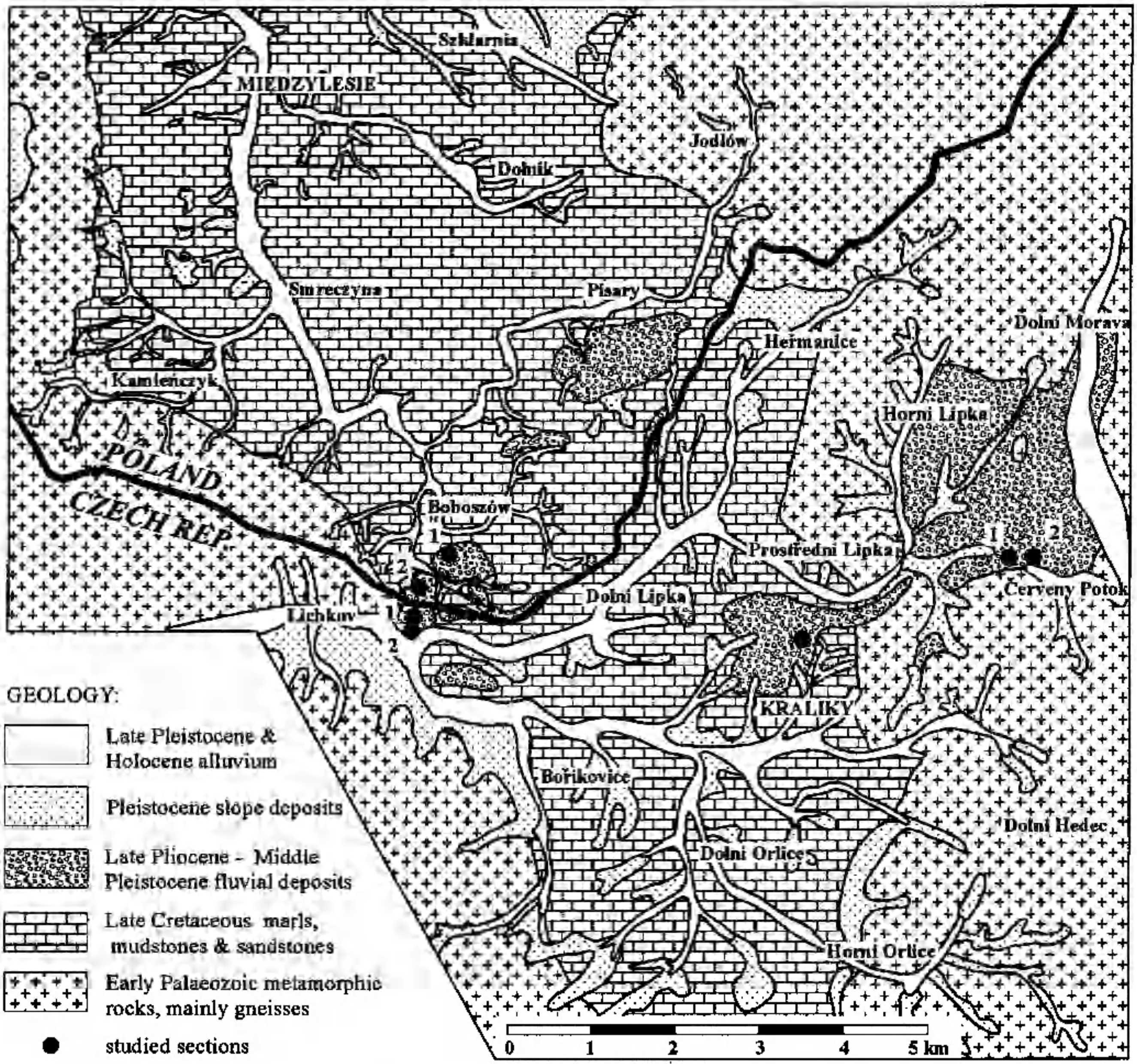

Fig. 2. Geological setting of the studied fluvial series.

percentage of main classes was calculated. The main statistical parameters were computed: median grain size and quartiles, sorting coefficient (Q_3/Q_1; where Q_3 and Q_1 are quartiles and $Q_3 > Q_1$), standard deviation, skewness and kurtosis. Morphological features, *i.e.* roundness of grains and grain shape according to the Zingg classification were estimated for pebbles from gravelly deposits. Petrographic analysis of clastic material (35 samples) was performed in order to find differences in gravel assemblages and to define the source areas. Particles of different size were studied separately. Pebbles over 8 mm in diameter were taken into account in a standard analysis and smaller particles, down to coarse sand class (1–2 mm) were studied under the binocular microscope to establish the degree of stability of the material. Approximately 50–100 pebble clasts over 8 mm across were examined in each sample and 50 grains per class in each sample of the finer material. Sand and granule particles (1–2 mm, 2–4 mm, 4–8 mm) were classified into three categories of stability: A_1 – unstable (*e.g.* mica schists, sandstones, mudstones, micas), A_2 – moderately stable (mainly gneisses, feldspars, quartz/feldspar aggregates), A_3 – very stable (mainly quartz, and quartzite) and coefficients of the petrographic stability were calculated: $S = (A_1+2A_2+3A_3) / N$; where N is the total number of grains in the class (Grodzicki, 1989).

Structural analysis of the sediments was carried out in the field, where lithofacies were described according to Miall (1985). Palaeotransport directions were measured in two different ways, axes of preferred orientation of pebbles and imbricate structures and orientaion of troughs. In total, the orientation of 194 pebbles was measured. The orientation is usually scattered but the azimuth is determined on 10 performed diagrams.

TEXTURAL CHARACTERISTICS OF SEDIMENTS

The analysed preglacial sediments are polymictic gravel dominated, with an average composition of 65–75% gravel-sized material, 20–30% sand-sized material and less than 5% fine particles (Fig. 3, Table 1). Sediments with larger contents of gravel-sized grains are less common. Sandy sediments, locally interbedded with gravel, contain various amount of pebbles (5–30%), and very often, they include a large admixture of silt (20–30%). In some sections, silty sand beds (>30% of silt), with individual pebbles, and in other sections mud beds (>65% of fine particles) are present. The gravels are usually moderately well-sorted and clast-supported, but thick beds of matrix-supported gravel are also present, particularly in lower parts of the sequences.

The pebbles are usually blade-shaped, which is connected with the dominant petrography of foliated gneiss and schist. Only the quartz and quartzite pebbles are equant or tabular. The predominance of spherical pebbles in some sections is simply connected with the lithology and maturity of the gravelly material. The gravel clasts are usually angular to subangular and exceptionally subrounded. Gneiss pebbles are generally better rounded than quartz pebbles.

PETROGRAPHIC COMPOSITION

All the analysed sections contain similar pebbles. The clasts are only of local provenance and there is no doubt that the source area is in the surrounding metamorphic Śnieżnik and Bystrzyckie Mts massif (Fig. 2). The main component is the Śnieżnik gneiss, light grey- and rose-coloured, foliated (but only slightly laminated) or augen. Less common is the Gierałtów gneiss, biotite rich, dark, fine laminated. Other metamorphic rocks are represented by schists of the Stronie Formation, dark mica schists, with relatively large feldspar contents, amphibolites, two types of quartzites (light with muscovite and black with graphite) and leptynites (leukogneiss, quartz-feldspar rocks). Quartz pebbles, probably derived from veins in the gneiss, are present in all the examined samples, but their content is extremely variable. Feldspar pebbles (quartz/feldspar aggregates were also included in this category) are usually fine (max. 10 mm) and probably derived from feldspar augens in gneiss. The content of Cretaceous material, which forms the underlying bedrock (mudstone, marl, sandstone), is surprisingly very low, even in the lowest parts of the sequences, situated directly over the basement. This anomaly may reflect the poor stability of Cretaceous material, as only better cemented sandstone and fragments of ferruginous concretions are represented.

The petrographic composition of the analysed sediments shows three different gravel assemblages, which define three sedimentary series. Two of them are gneiss-dominated and one is quartz-dominated (Table 2). The Boboszów series contains 67–90% gneiss and 2–15% quartz whereas the Lichkov series contains 56–74% gneiss and more quartz (11–23%). In both these series other types of rocks occur in stable admixtures: feldspar up to 14%, metamorphic rocks up to 8% and Cretaceous sedimentary rocks up to 5%. In contrast, the Červeny Potok series contains 50–65% quartz and only 32–38% gneiss, while feldspar and Cretaceous rocks are absent.

In small fractions, the non-quartz grain contents definitely decrease (Table 3). The contents of quartz in granule particles (2–4 mm) is approximately 25–50%, and in the coarse sand fraction (1–2 mm) up to 35%–65%. The sand-sized particles contain small fragments of siliceous marls, and the matrix generally lacks clay minerals and calcium carbonate.

There is a distinct difference in mean values of quartz content in the analysed sediments, and therefore they may be classified into three categories of material maturity, which generally follow their subdivision based on the petrographic composition: the Boboszów series is characterised by 35–45% quartz grains (in 1–2 mm particles), and

Table 1

Average grain-size distribution characteristics of lithofacies

	average diameter (mm)	maximum diameter (mm)	standard deviation	sorting coefficient	gravel-sized grains content (%)	sand-sized grains content (%)	silt/clay-sized grains content (%)
Gm	4.17	74	0.16	4.28	69.1	24.8	6.1
Gt	4.60	55	0.25	2.52	77.5	19.8	2.7
Gms	5.34	11.5	0.14	4.77	66.1	25.7	8.2
St	0.99	40	0.15	4.42	40.8	41.3	17.9
Se	0.75	20	0.12	6.04	35.8	37.4	26.7
Ss&Sh	0.35	12	0.32	2.29	10.9	70.5	18.7
fl	0.23	21	0.22	3.05	9.3	53.2	37.6
fm	0.14	4	0.26	2.44	6.4	26.2	67.3

Table 2
Average petrographic composition of pebles (> 8 mm)

	quartz	feldspar	gneiss	other metamor-phic	sandstone mudstone
Boboszów series (%)					
Boboszów 1	7.21	8.49	74.5	6.41	3.31
Boboszów 2 – uper unit	15.38	10.99	67.03	4.40	2.20
Lichkov 1 – upper unit	2.22	3.46	89.62	6.10	4.60
Lichkov 2 – upper unit	4.72	4.81	83.78	5.36	5.33
Average	7.38	6.94	78.75	5.57	3.86
Lichkov series (%)					
Boboszów 2 – lower unit	22.58	14.52	56.45	1.61	4.84
Kraliky	11.46	9.38	66.67	8.33	3.17
Lichkov 1 – lower unit	15.75	1.93	71.06	8.22	3.05
Lichkov 2 – lower unit	14.54	4.25	74.74	4.17	2.30
Average	16.08	7.52	67.23	5.58	3.34
Červeny Potok series (%)					
Červeny Potok 1	64.65	–	32.32	3.03	–
Červeny Potok 2	50.73	–	37.43	11.84	–
Average	57.69	–	34.88	7.44	–

Table 3
Average composition of coarse sand and granule class grains

	A_3 (%)	A_2 (%)	A_1 (%)	S	A_3 (%)	A_2 (%)	A_1 (%)	S
	1–2 mm grains				2–4 mm grains			
Boboszów series								
Boboszów 1	38.50	47.00	14.50	2.24	32.65	55.90	11.45	2.21
Boboszów 2 – upper unit	36.00	56.00	8.00	2.28	28.90	68.33	2.77	2.26
Lichkov 1 – upper unit	49.33	40.67	10.00	2.39	45.71	47.01	7.28	2.38
Lichkov 2 – upper unit	43.00	42.00	15.00	2.28	45.00	43.00	12.00	2.33
Average	41.71	46.42	11.88	2.30	38.07	53.56	8.37	2.30
Lichkov series								
Boboszów 2 – lower unit	48.00	44.00	8.00	2.40	27.67	68.37	3.96	2.24
Kraliky	39.28	60.72	–	2.39	41.61	58.39	–	2.42
Lichkov 1 -lower unit	53.64	31.68	9.13	2.46	43.38	36.31	12.67	2.39
Lichkov 2 – lower unit	57.69	32.37	9.94	2.48	50.22	37.34	12.44	2.38
Average	49.65	42.19	6.77	2.43	40.72	50.10	7.27	2.36
Červeny Potok series								
Červeny Potok 1	56.50	42.50	1.00	2.56	41.29	57.22	1.49	2.40
Červeny Potok 2	61.58	30.92	7.50	2.54	54.00	38.67	7.33	2.47
Average	59.04	36.71	4.25	2.55	47.65	47.94	4.41	2.43

an average S (petrographic stability coefficient)of 2.30. In comparison, a pure quartz sediment has an S of 3.0. The Lichkov series is characterizedby 40–55% quartz grains and S of about 2.45; and the Červeny Potok series by more than 55% quartz grains, and an S of about 2.55 (Table 3).

LITHOFACIES

The gravel facies Gm and Gt are undoubtedly the most common in the studied sections, except the profiles in Červeny Potok. Units of Gm facies are over 0.5 m thick and usually alternate with thinner lenticular Gt facies units. The Gms facies accompanies the Gt and Gm facies in almost all profiles, but is definitely less common. Various sandy lithofacies (Ss, Se, Sh, St) and fine-grained lithofacies (F, Fm) are present in very thin units, and are generally of minor importance (Fig. 3).

Lithofacies Gm

The Gm facies is represented by fine to medium, sandy gravel. There is 65–75% gravel-sized and 20–30% sand-sized material. The gravels are usually clast-supported, but partly rich in fine sand and silt matrix, and massive or crudely horizontally bedded. Bedding consists of several thin (<20 cm), fining upward sequences. The average size of pebbles is less than 8 mm, but at the base of each sequence cobble horizons (clasts up to 70–90 mm in diameter) occur. Sorting is generally poor, with a sorting coefficient of ca 4.3, but in some horizons it is moderately good. Imbrication and preferred orientation of clast is well visible due to the common bladed or prolate pebbles of foliated gneisses. The pebbles are subrounded or subangular. The base of the Gm units is usually rough with scours and troughs. Partly, in the upper parts of the Gm units, very poorly sorted (coefficient ca 6.0), matrix supported sediment occurs, that may be interpreted as sieve structures.

The Gm facies is commonly interpreted as the longitu-

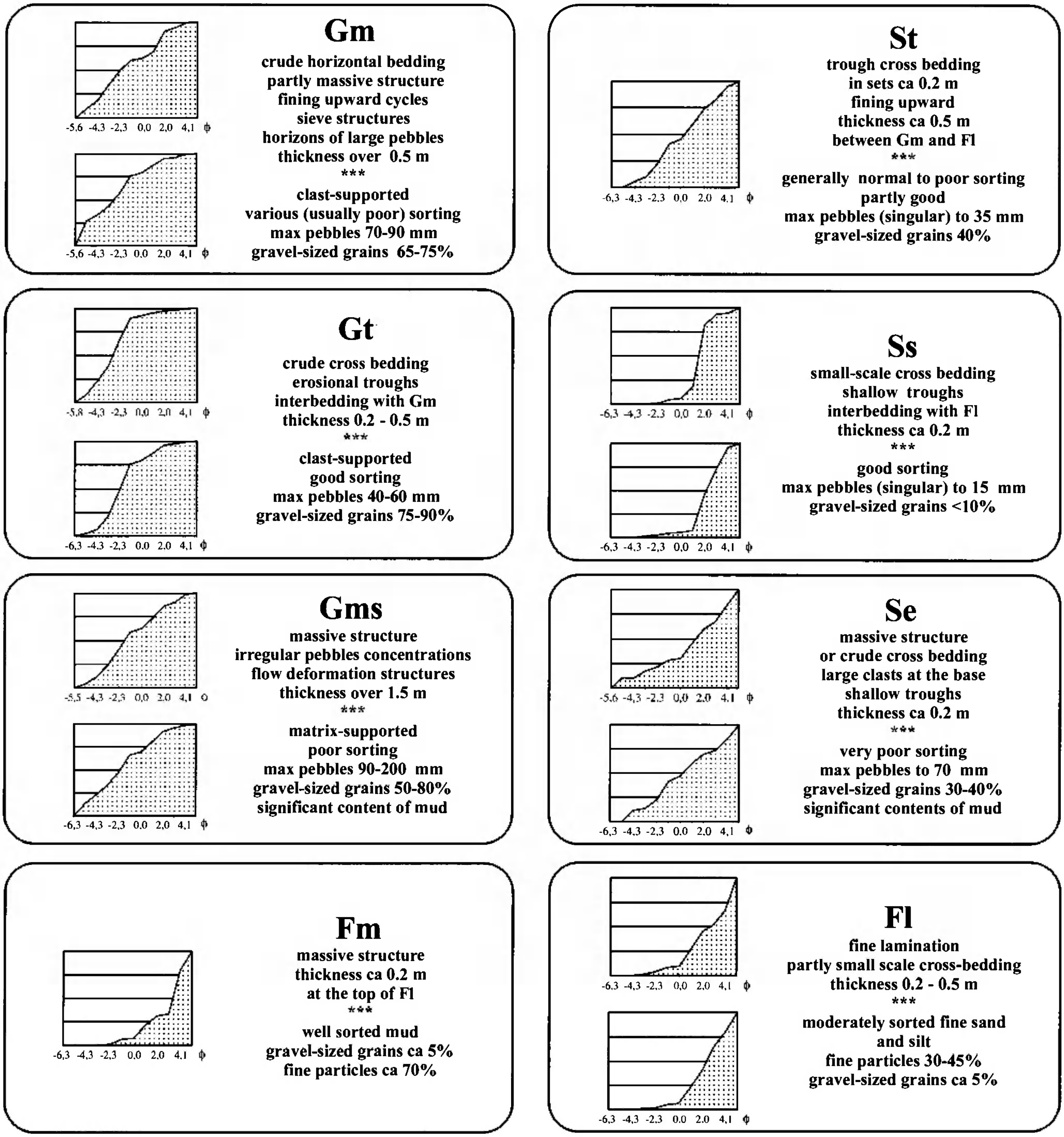

Fig. 3. Main textural and structural characteristics of lithofacies found in fluvial deposits of the southern part of the Upper Nysa Depression; facies code after Miall 1978, semi-logarythmic cumulative curves show typical examples of grain size distribution of the lithofacies.

dinal bar deposit of a braided river, deposited in the upper flow regime. Its strong link with the Gt facies in all the investigated sections confirms this interpretation.

Lithofacies Gt

The Gt facies is represented by fine to medium gravel, generally not coarser than Gm, but virtually containing more gravel-sized material (approximately 75–90%) and less sand-sized grains (10–15%). The gravel is clast-supported, well sorted (coefficient < 2.5) and without any admixture of fine sand or silt. Fine gravel grains (2–8 mm) dominate and, as a rule, the skewness of grain size distribution is positive (*i.e.* medium sized gravel prevails over sand). The only sedimentary structure is crude cross bedding in small erosional troughs (0.2–0.5 m deep, over 1.5 m wide) which is clearly visible in all the sections. The fining upward tendency is locally visible in the troughs, but generally the grain size is uniform in the whole sequence. The

Gt facies is commonly associated with the Gm facies with troughs often cut into the top of Gm units. Some lenticular concentrations of well-sorted pebbles within the Gm units may in fact represent the Gt facies.

The Gt facies is deposited in the shallow channels of a braided river, as a result of the migration of small crescentic gravel dunes, most preferably in distal conditions in relation to longitudinal bars.

Lithofacies Gms

The Gms facies contains matrix supported, sandy gravel and with large admixture of fine sand and silt (up to 20%) compared to the Gm and Gt facies. Gravel-sized particles are about 60% and sand about 20–30%. The sorting is apparently poor (coefficient >4.5). Large pebbles up to 200 mm in diameter are usually dispersed throughout the whole sequences. Small, deformed sand bodies with good sorting form irregular concentrations, particularly at the tops of units. No depositional structures are present. Massive Gms units are thick in comparison with the other facies and may reach thicknesses of about 1.5–1.8 m. The bases of Gms units are flat or inclined. The Gms facies is mostly associated with the Gm (or Gt) facies, but in some profiles lies on Fl units. Pebbles roundness is variable; from very angular to subrounded. The facies contains strongly decomposed gneiss pebbles in some sections. They are light grey due to their kaolin contents.

The Gms facies is a debris flow deposit, connected with gravity slumps of clastic material on valley margins or on the surface of alluvial fan. The Gms gravels contain deformed beds of other facies occurring in profiles (probably Gm, Gt, Se) and particles of the Fl facies in matrix. This facies was probably formed in the alluvial fan environment.

Lithofacies St

The St facies is represented by pebble sand. The gravel-sized and sand-sized ranges are almost equal (both 40–45%). The admixture of fine sand and silt is also large and therefore sorting is generally poor, although near the base of units sorting is moderate to good. Structurally St is similar to the Gt facies, consisting of large scale trough cross bedding. The troughs are cut into the Gm gravels and clasts up to 35 mm across are present at the base of the troughs. Very often, at the top of troughs, fine sand prevails and the facies gradually transists into the Fl facies.

The St facies is connected with crescentic dunes migrating in lower flow regime conditions. The lowering energy of the braided river is reflected by the topmost Fl facies.

Lithofacies Se

The Se facies contains silty sand with pebbles. It consists of, in almost equal proportions, gravel particles, sand particles and fine sand to silt. This sorting is extremely poor (coefficient ca 6.0). Singular pebbles up to 50 mm are present at the base of facies units. The sediment is massive or reveals crude cross bedding at the top of the unit. The lower surface is sharp and erosional, with scours and troughs. In the Kraliký section, the Se facies lies directly on the Cretaceous bedrock, and contains singular clasts of mudstone. In other sections, it is underlain by Gms facies units.

The Se facies is connected with short erosional episodes, reflecting scouring of the basement, short-distance redeposition of its material and scour filling.

Lithofacies Ss

The Ss facies is represented by medium sand (0.25–0.5 mm), very well-sorted (70–90% of sand-sized particles, sorting coefficient – ca 2.3) that contains a small admixture of silt and single pebbles (< 10%, up to 15 mm in diameter). The Ss units are thin (10–20 cm) and are interbedded with the Fl facies. Small-scale cross bedding is present together with climbing ripplemarks. The thickness of the Ss beds is variable, suggesting that they were deposited in shallow and wide troughs.

The Ss facies may be interpreted as lower flow regime sediment formed in shallow erosional scours due to the redeposition and sorting of underlying material (Fl facies) during episodes of increased flow energy (during the flooding of the overbank areas).

Lithofacies Sh

The Sh facies is generally similar to the Ss facies. The main difference is that it exhibites horizontal bedding. Its sorting is worse and its average grain size larger (0.5–1.0 mm).

The Sh facies was formed in relatively high energy conditions, at the transition from lower to upper flow regime, in the shallow channels of a braided river.

Lithofacies Fl

The Fl facies contains mainly medium or fine sand and silt (45–65% sand-sized particles and 30–45% silt). Its gravel admixture is negligible. The sorting is moderate (coefficient 3.0) and skewness of grain size distribution is negative. Units of Fl are 0.2–0.5 m thick. The main depositional structure is horizontal lamination with sets of small-scale cross bedding. The Fl facies is associated with the Se and Sh facies, and is usually underlain by the St or Gt facies.

The Fl facies represents overbank deposits formed in a very low energy regime, probably during vaning flood conditions.

Lithofacies Fm

The Fm facies is represented by fine-grained deposit, mainly silt (ca 70%), but with a significant admixture of medium sand (30%) and even single granules (2–4 mm). Generally its sorting is good (coefficient ca 2.4). The Fm facies is massive and light grey. This facies is usually superimposed over the Fl facies.

The Fm facies is undoubtedly an overbank deposit of the flood basin, connected with quiet waters. Admixture of larger particles may indicate secondary redeposition and mixing of material during floods.

DESCRIPTION OF SECTIONS

The studied sediments occur in several small, isolated patches. The sediments are poorly exposed due to small thickness and location in high areas, 50–100 m above the river valleys, where there is poor erosion, and due to thick cover of recent soil.

Boboszów 1

A small, abandoned gravel-pit (530 m a.s.l.) south of the village, contains a 2–3 m package of reddish gravel that overlies an erosional surface of Early Coniacian mudstones (Fig. 4A). The whole sequence consists of alternating Gm and Gt layers. Large clasts in the pebbly horizons of Gm display imbrication and parallel orientation of long axes. The palaeocurrent directions are constant throughout the sequence, from ENE to WSW. This direction is consistent with the orientation of the trough axes in the Gt gravels. The sediment is gneiss-dominated. The clasts seem be fresh, without significant chemical decomposition. The contents of quartz pebbles is 2–10% in the Gm facies and about 15% in the Gt facies.

Boboszów 2

This large gravel-pit (525 m a.s.l.) is situated close to the Polish/Czech state border, on the right side of the railway to Lichkov. The well exposed NE wall of the outcrop is 50 m long and 6 m high. Only gravels are present, but the sequence may be subdivided in two slightly different units (Fig. 4B). The Cretaceous mudstones are exposed in the vicinity on the valley slope, about 5 meters below the gravel-pit floor.

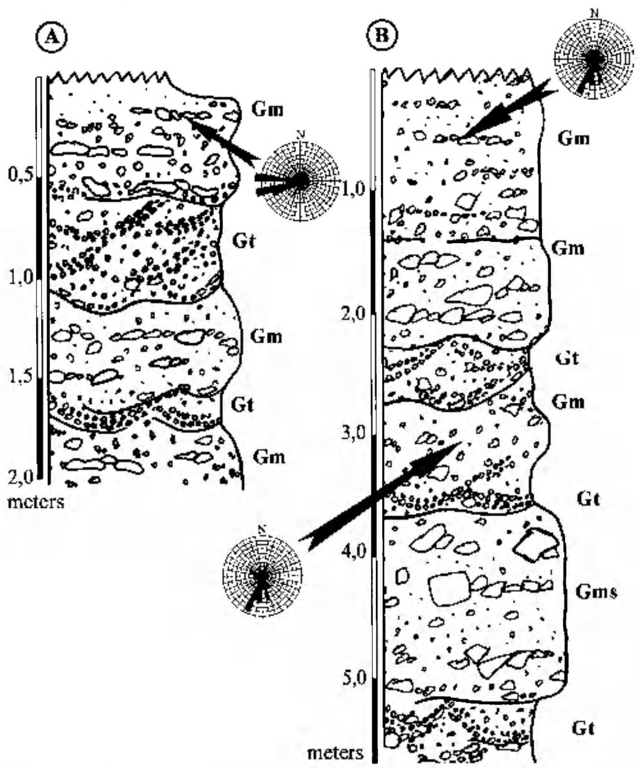

Fig. 4. Sedimentological logs of sections at Boboszów 1 (A) and Boboszów 2 (B). Palaeotransport diagrams show measurements of the a-axes of pebbles.

The Lower unit consists of Gt gravel covered by a 1.5 m thick, massive, poorly sorted, grey coloured gravel (Gms). Small, irregular, well-sorted gravelly lenses near the base may represent deformed Gt beds. Near the top, subangular, large (up to 20 cm in diameter) gneiss pebbles are present. The lower part of the profile is gneiss-dominated, though it contains about 20% quartz in pebble material.

The upper unit is very similar to the Boboszów 1 sequence, and consists of alternating Gm and Gt layers of reddish gravel (Fig. 4B). A very thick unit of Gm facies is present at the top of the sequence. This unit contains several distinct pebbly horizons. Pebbles display preferred orientation N–S, and imbricated clasts suggest transport from NNE (or N to NNW in places). Gt cosets display evident trough shape up to 2 m in width. The trough axes orientation is consistent with the direction derived from clast imbrication in the top unit. The upper unit of the sequence is also gneiss-dominated, but contains less quartz.

Kraliký

This exposure (585 m a.s.l.) is located 1 km north of the town centre, in a 3 meter high scarp of the "Tesla" factory car park. The 0.5–1.5 m thick sand and gravel lies here on an erosional surface of Cretaceous marls (Fig. 5A). Troughs in the basement consist of poorly sorted sand material (Se facies) rich in small gneiss pebbles, with only a small amount of material from the bedrock. The Gt gravel trough axes are oriented NNE–SSW. The sediments are gneiss-dominated with a quartz content of about 20%, except the lowermost part of the sequence.

Červeny Potok 1

This small outcrop (605 m a.s.l.) is situated in the railway scarp, close to the station. Sediments of the exposed sequence are 2 m thick and lie on the strongly weathered gneiss (loam). The sequence consists of gravel, sand and even silt material (Fig. 5B). Alternating units of Gm, Se, Ss and Fl occur in the lower part of the sequence whereas the upper part contains a thick, uniform unit of Gms gravel. These two units are separated from each other by a slightly inclined erosional surface. Th Gms unit is light grey and contains clay minerals in the matrix. In the whole sequence quartz predominates over gneiss (Table 2). The gneiss pebbles are strongly weathered. The clast orientation in the Gm facies indicates general transport from north to south, though directions are highly dispersed (Fig. 5B).

Červeny Potok 2

This outcrop is situated 100 m east from the outcrop Červeny Potok 1, in the railway scarp. Only the Gms unit overlying the Fl unit is visible here (Fig. 5C). The sequence may be directly correlated with the top of the sequence at Červeny Potok 1. Large cobbles (over 25 cm) of weathered gneiss are present in the uppermost part of the Gms layer, but generally the sequence is quartz-dominated (over 60%).

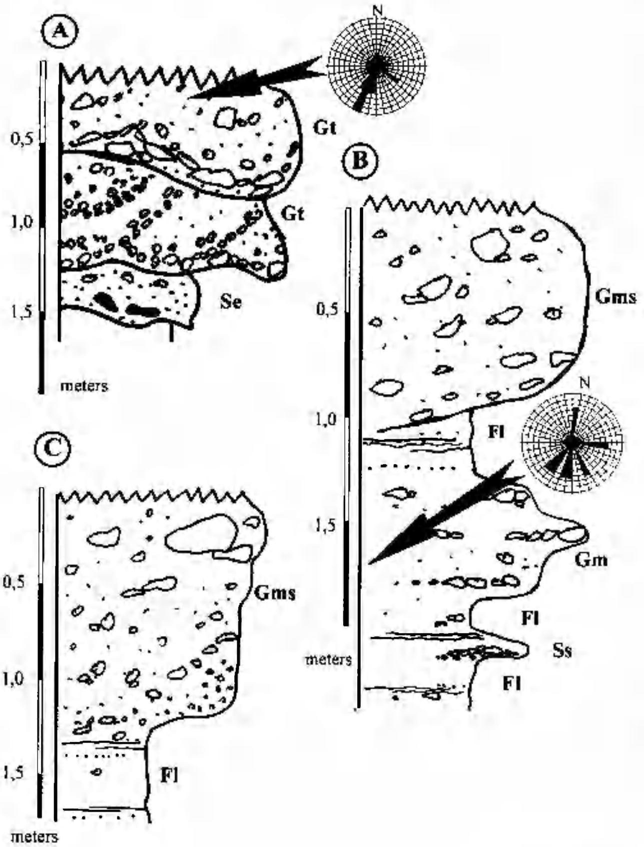

Fig. 5. Sedimentological logs of sections at Kraliky (A), Cerveny Potok 1 (B) and Cerveny Potok 2 (C). Palaeotransport diagrams show measurements of the a-axes of pebbles.

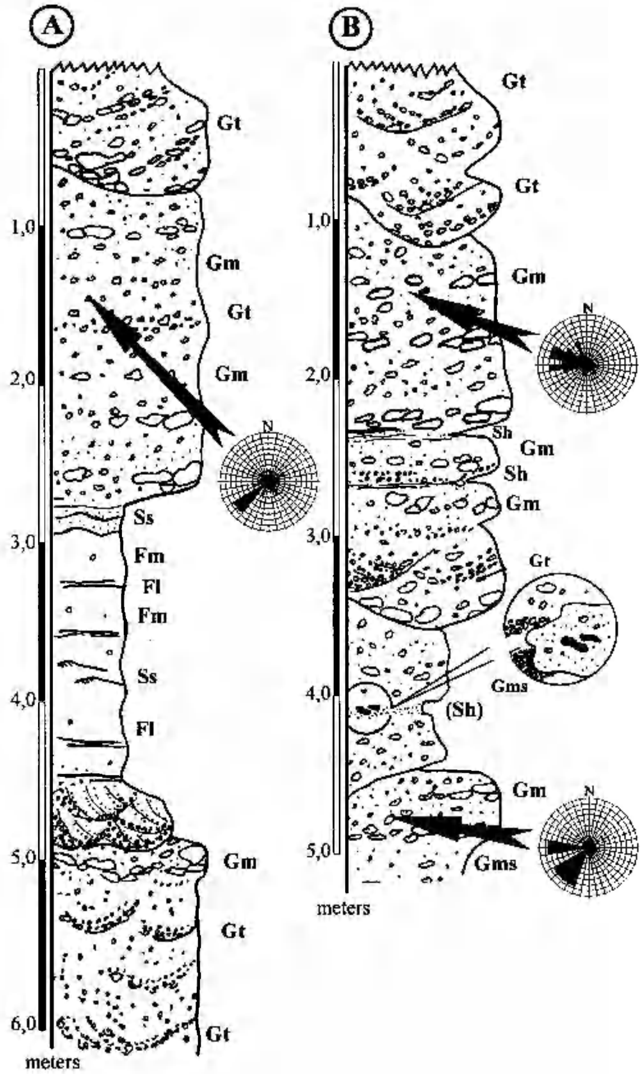

Fig. 6. Sedimentological logs of sections at Lichkov 1 (A) and Lichkov 2 (B). Palaeotransport diagrams show measurements of the a-axes of pebbles.

Lichkov 1

The northern wall of a very large gravel-pit (525 m a.s.l.) located east of the village contains the 10 m thick sequence. However, only the highest 6 m are well exposed. Also, the base of the sequence is not visible. The exposed sequence consists of several units that differ in structure, grain size and colour (Fig. 6A).

The lowermost unit consists of alternating Gm and Gt beds. The light grey gravel is quartz enriched (up to 30% of pebbles). The gneiss pebbles are generally slightly decomposed and clasts of Cretaceous rocks are absent. This unit is eroded, with a sequence of scours filled with 0.5 m thick St unit. The latter is overlain by a sequence of finer sediment, consisting of dark, laminated sand and mud (Fl facies), alternating with thin Fm and Ss facies beds. The next erosional surface is at the top of fine-grained deposits. This is overlain by reddish gravels of the upper unit of the sequence. The Gm and Gt facies that dominate in this unit are interbedded similarly to those in the lowermost part of the sequence. However, quartz content is here very low (< 5%), the gneiss pebbles are not weathered, and the admixture of Cretaceous material is present. Imbricated clasts unequivocally indicate palaeocurrent directions from NE to SW (Fig. 6A).

Lichkov 2

The southern wall of the same gravel-pit contains deposits similar to those of Lichkov 1 (Fig. 6B). At the base of the sequence, a 0.5 m thick Gm unit overlies partly exposed Gms gravel. The palaeocurrent direction of imbricated clasts suggests transport from NE to SW. The quartz pebble content is here about 15%. This unit is correlative to the lower unit of Lichkov 1 and its upper boundary is also erosional. The middle part of the sequence, deposited over a distinct erosional surface, is 1.5 m thick. It consists of Gms gravel containing deformed sand lenses (probably Sh facies) and well-sorted gravel lenses (probably Gt facies), and above, the alternating Gt, Gm and Sh facies beds. The upper unit is gneiss-dominated and amount of quartz is insignificant. Some gneiss clasts are slightly weathered. Clast imbrication indicates transport from E-ESE to W-WNW, which differs from that of the lower part of sequence.

LITHOSTRATIGRAPHY

Three sedimentary series may be distinguished based on lithofacies assemblages, textural features and distinct differences in petrographic composition (Fig. 7).

Boboszów series

This series is represented by the sediments at Boboszów 1, in the upper part of the sequence at Boboszów 2, and in the upper parts of the sequences at Lichkov 1 and 2. It is up to 4 meters thick and the base of the sequence lies from 530 m a.s.l. at Boboszów to 520 m a.s.l. at Lichkov.

The Boboszów series consists exclusively of gravel and sandy gravel deposits. In all investigated profiles only alternating beds of Gt and Gm facies are present. The series is gneiss-dominated with rare quartz (Tab. 2). Gneiss pebbles do not display chemical decomposition. In the coarse sand (1–2 mm), the quartz content is relatively low (<40%) (Tab. 3).

Lichkov series

This series is represented by the lower units at Lichkov, the Kraliký sequence and probably also the lower part of the sequence at Boboszów 2. The maximum exposed thickness of this series is about 4 meters, and the position of its base varies from 585 m a.s.l. at Kraliký to 515 m a.s.l. at Lichkov.

The Lichkov series contains various lithofacies. Besides the Gm-Gt gravel sets, thick layers of massive, matrix-supported Gms gravel are common. Also, a large spectrum of sandy deposit accumulated in different flow regimes is present, such as facies St, Ss, Se and Sh, and they are locally interbedded with fine-grained lithofacies (Fl, Fm). All these facies form distinct, fining-upward facies associations: St-Fl, Ss-Fl-Fm, Gm-Gt-Sh, Gm-Se, Gt-Se. Gneiss pebbles predominate in the series although quartz pebbles are significant, reaching up to 23% (Tab. 2). Cretaceous material is absent or occurs only directly at the base of the series. In the coarse sand fraction, quartz usually exceeds 50% (Tab. 3).

Červeny Potok series

This series only occurs in the two outcrops at Červeny Potok and it lies at 605 m a.s.l.. The lithofacies assemblages in the Červeny Potok series are similar to those of Lichkov series. There is Gm gravel and thick Gms gravel and alternating sandy (Ss, Se) and fine-grained (Fl) beds. However, this series differs much from other series in its textural characteristics and petrographic composition. The textural maturity of these sediments is low, their roundness varies from angular to subangular and sorting is very poor. The series is also quartz-dominated, containing more than a 50% quartz content in the pebble fraction, and more than 60% in the sand fraction (Tables 2, 3).The gneiss pebbles are strongly chemically decomposed.

DEPOSITIONAL ENVIRONMENTS

The Boboszów series, consisting of only Gm-Gt facies assemblage, probably represents a poorly developed cycle of a distal gravel-dominated braided river. This assemblage is similar to a Donjek type sequence (Miall, 1978), but enriched in gravel facies and with no fine-grained deposits. The mean gravel content in the sequence is 65–75%, which correlates with the very broad gravel content limits for Donjek type rivers (10–90%, after Miall, 1978). However, the Gm facies dominates in the Boboszów series, which is characteristic rather for proximal braided rivers of Scott type. The alternating finer Gt and coarser Gm gravel beds reflect high energy deposition in the mid-channel zone by downstream migration of transverse crescent dunes in shallow channels between longitudinal bars. The lack of sandy facies may reflect highly episodic sedimentation and very fast current decay at the end of flood episodes. The absence of overbank deposits may also reflect strong erosion during the advancing-stage of floods. Another possible interpretation is that the whole sequence was deposited during a relatively short time which did not allow significant migration of the river tract. Minor or no chemical decomposition of feldspars in the gneiss pebbles and a large discharge of coarse material suggest that during deposition, strong physical weathering occurred and chemical weathering was virtually absent. This may, together with proofs of episodic processes, suggest arid or semi-arid conditions during the deposition of the sequence.

The Lichkov series is represented by an almost full distal gravel-dominated braided river facies assemblage of a Donjek type river. The lower part of the Lichkov 1 sequence may serve as a model succession of this type of alluvium. Trough bedded Gt gravel passes here into Gm gravel, and then into trough bedded sand (St) and fine-graineds sediments upwards (mainly Fl facies, with minor Fm and Ss facies). This succession may be interpreted as a response to a slow shallowing of water as a result of the migration of the active river tract. The St facies was deposited in shallow troughs developed on bars during a low flow regime. The Fl facies formed as a result of the vertical accretion of fine material (silt and finest sand) in an overbank environment or in abandoned channels. During floods, small channels developed there and coarser well-sorted sand was deposited in shallow troughs. In other sequences this succession is not fully developed, but some parts of the model cycle are present. The debris-flow deposits (Gms) are relatively common, which suggests sedimentation on alluvial fans. The possible explanation of the complete sequence is that sediments of a large river flowing from the north are interbedded with deposits developed on small, local alluvial fans associated with tributary

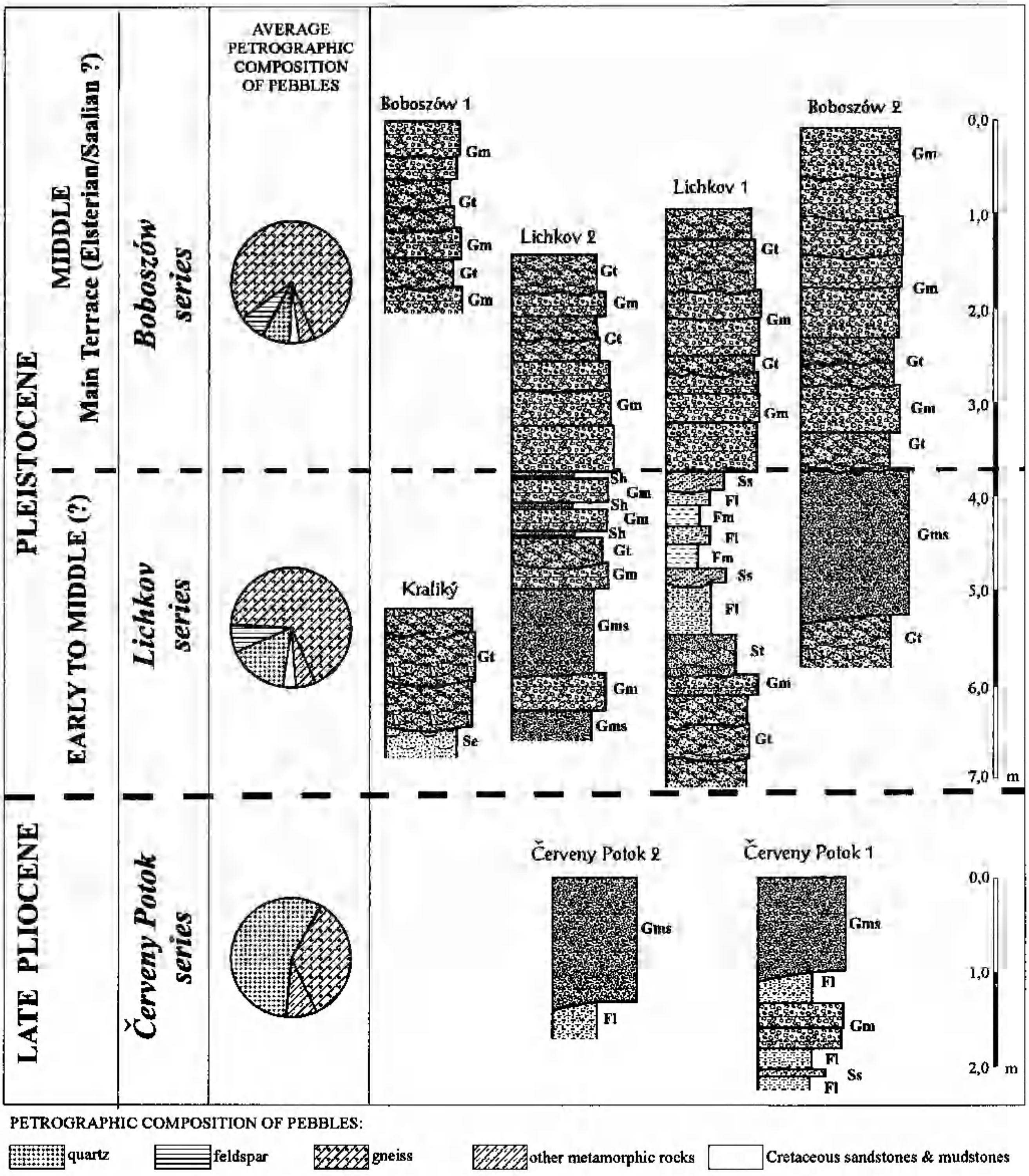

Fig. 7. Lithostratigraphic succession, main lithological characteristics and proposed age of the fluvial series of the Upper Nysa Depression.

rivers. More abundant quartz pebbles and the higher degree of chemical decomposition of gneiss pebbles suggest more intensive chemical weathering in the source area and probably more humid climatic conditions. A more stable sedimentary environment, with permanent deposition and well developed sedimentary cycles, may be taken as another proof of such climatic conditions.

The Červeny Potok series is very poorly exposed, and thus the environmental interpretation is rather limited. In general, the same lithofacies are present as in the Lichkov series. The sedimentary environment was thus probably the same, but the higher topographic position, specific textural features and different petrographic, quartz-dominated, composition clearly show that the Červeny Potok series represents a different stratigraphic unit. The almost total chemical decomposition of the gneissic pebbles suggests that the source area occurred in regions with thick weathering mantle formed under humid condition. The short transport of the material from the north can be deduced from palaeocurrent data and the textural immaturity of the sediment. In turn, the petrographic composition is obviously connected with the source of material rather than with long transport.

AGE OF SEDIMENTS

The three series described above were probably deposited during three different chronostratigraphic stages. The Boboszów series is clearly the youngest and the Lichkov sequence is older as indicated from sediment successions in the Lichkov and Boboszów sections (Fig. 7). The stratigraphic position of the Červeny Potok series is more problematic, as the sequences at Červeny Potok have no direct relation to other series. However, it seems that it may be older than or probably of the same age as the Lichkov series, but is obviously not younger (Fig. 7). An absolute dating of the studied sediments is impossible because of a total lack of organic material or palaeontological findings. The lower age limit is established by the Santonian sandstones in the Štity graben, and the upper age boundary by the Nysa Kłodzka terrace gravel of the Weichselian age in Roztoki (north of Miedzylesie).

The Červeny Potok series is lithologically very similar to coarse-grained preglacial, Late Pliocene, deposits in the northern part of the Kłodzko Basin (Jahn *et al.*, 1984; Krzyszkowski *et al.*, 1998) and in the Sudetic Foreland (Przybylski *et al.*, 1998) and to coarse-grained preglacial deposits in the Upper Moravia Basin, the age of which was so far described as Neogene (Mio-Pliocene according to Řezáč, 1955 or Early to Middle Pleistocene according to Radwański & Sawicki, 1957). The Červeny Potok sequence is most probably age-equivalent to the Late Pliocene White Gravels of Klodzko, Lądek Zdrój and Gorzuchów (Walczak, 1968; Jahn *et al.*, 1984; Krzyszkowski *et al.*, 1998), although it probably represents the nothwesterly part of the preglacial, Late Pliocene to Early Pleistocene, series (up to 250 m thick) of the Upper Moravia Basin (Ru ička, 1987).

The Lichkov and Boboszów series are probably of Quaternary age, which can be deduced from low level of petrographic maturity of the sediments. These series are correlated with the gravels of the river terraces of the Klodzko Basin and the Upper Moravian Basin. The Lichkov and Boboszów series may be correlated with the Main Terrace of the Nysa and Ścinawka rivers and its counterpart – the Grey Gravels of Klodzko. This series is supposed to represent Middle Pleistocene (Holsteinian to Early Saalian). They may also be correlated with the Morava river terrace system which contains three old Pleistocene terraces: the 35 m high, so-called Günz terrace, the Lukovska Terrace and the Brodecka Terrace dated to early and late Mindel, respectively (Ru ička, 1973).

However, it is possible that the Lichkov series is older and represents the younger part of the preglacial series dated back to the Early Pleistocene to the early Middle Pleistocene, whereas the Boboszów series may represent the late Middle Pleistocene (Fig. 7). Another possibility is that the Boboszów series is very young and correlative with the Upper Terrace of the Nysa Kłodzka and the Red Gravels of Klodzko, which represent the postglacial, post-early Saalian, fluvial event, most probaly of late Saalian/ Eemian age. If this is the case, it may also correlate with the Morava river Kralicka (Main) Terrace, the age of which was established to Riss by Ru ička (1973).

PALAEOGEOGRAPHY

The lack of Palaeogene to Miocene deposits in the Upper Nysa Graben suggests low, almost flat or slightly hilly relief during that time and no tectonic activity. Probably only during the Late Miocene tectonic activity was greater, and morphological scarps were formed as a result of the reactivation of older, Late Cretaceous faults. At the same time, the Sudetic Marginal Fault and the faults bounding the Upper Moravia Basin came into existence. Since that time, and especially during the Pliocene, the chemically weathered mantles have been removed from the mountains into the tectonic depressions. The oldest (Pliocene), Červeny Potok, series was probably deposited by a river flowing from N to S (Fig. 8). The river course further south is impossible to reconstruct due to a lack of sediments outcrops, although a southern direction, towards the southern end of the Nysa Graben and a western direction, towards the northern Bohemia Basin are equally probable.

The reactivation of faults during the Early Pleistocene probably resulted in a slight subsidence of the southern part of the Upper Nysa Graben and further uplift of the adjacent mountain ranges. This may explain the lack of Cretaceous material and gneiss-dominated gravel assemblages in the sediments of the Lichkov series The series was deposited by rivers flowing from N or NE (Fig. 8), but as with the older series, further south the drainage direction remains unsolved. The river that accumulated the deposits of the Lichkov series at Lichkov was probably quite long and the main watershed was situated that time about 15 km to the north (Sroka, 1997).

The Middle Pleistocene palaeogeography in the Upper Nysa Depression was highly influenced not only by frequent climatic oscillations, from warm and humid interglacial to cold and arid periglacial conditions, but also by

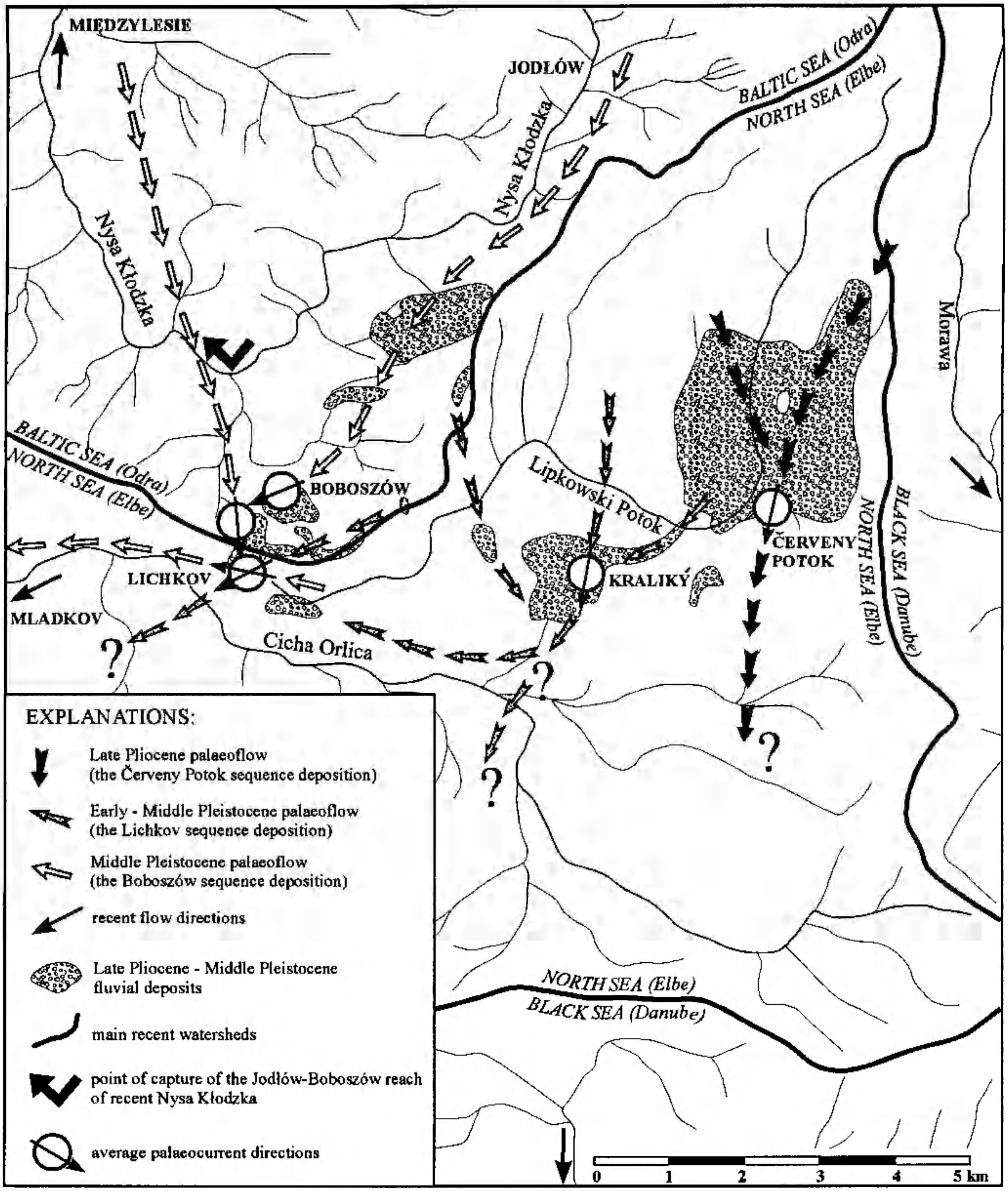

Fig. 8. Reconstruction of drainage pattern during the Late Pliocene to Middle Pleistocene of the southern part of the Upper Nysa Depression based on palaeocurrent indicator measurements and gravel petrography.

the glaciation of the northern part of the Kłodzko Basin. The Scandinavian ice sheet advanced twice, during the early Elsterian and then during the early Saalian, a few kilometres south of Kłodzko, *i.e.* it was about 25 km north of the studied area (Krzyszkowski *et al.*, 1998). In spite of the fact that the source of the material of the Boboszów series remains the same as that of the Lichkov series, as a result of the arid, most probably, periglacial climate during the accumulation, the petrographic composition and texture of the sediments changed slightly. Perhaps river piracy from the north managed to limit the drainage basin area and conditions changed to a more proximal environment. Rivers at that time flowed from N to S, but the drainage was directed into the present Ticha Orlice valley between Lichkov and Mladkov (Fig. 8). It must be stressed that the Boboszów series represents a local fluvial deposit with no admixture of glacial material from the north.

During postglacial time, the upstream erosion of the Nysa Kłodzka enlarged its drainage basin and captured the Jodłów–Boboszów reach of the river. The point of capture is reflected in the rapid change of direction of the Nysa Kłodzka river valley in Boboszów. This capture could have come about during the post-early Saalian glacio-isostatic rebound that created deep erosion in the river valleys of the entire Kłodzko Basin (Krzyszkowski *et al.*, 1998). Weichselian alluvial sediments that fill the valley bottoms display palaeoflow from S to N and contain significant amounts of Cretaceous material and very large admixtures of silty matrix. This reflects the incision of the river into the Cretaceous rocks.

REFERENCES

DON, J., 1996. The Late Cretaceous Nysa Graben: implications for Mesozoic–Cenozoic fault-block of the Sudetes. *Zeitschrift für Geologischen Wissenschaften, Berlin*, 24: 317–324.

GRODZICKI, A., 1989. Metoda denudodezagregacji i jej zastosowanie w badaniach skał okruchowych. *Acta Universitatis Wratislaviensis, 1092, Prace Geologiczno Mineralogiczne*, 16: 1-187 {in Polish only}.

JAHN, A., ŁAŃCUCKA-ŚRODONIOWA, M. & SADOWSKA, A., 1984. Stanowisko utworów plejstoceńskich w Kotlinie Kłodzkiej [The site of Pliocene deposits in the Kłodzko basin, central Sudetes]. *Geologia Sudetica*, 18 (2): 7–43.

JERZYKIEWICZ, T., 1970. The upper Cretaceous turbidite sequence in the Sudetes (south-western Poland). *Buletin of the Polish Academy of Sience, Earth Sciences*, 18: 149–159.

KRZYSZKOWSKI, D., PRZYBYLSKI B. & BADURA, J., 1998. Late Cainozoic evolution of the Nysa Kłodzka river system between Kłodzko and Kamieniec Ząbkowicki, Sudetes Mts, Southwestern Poland, *Geologia Sudetica*, 31: 133–155.

LEPPLA, A., 1900. Geologisch-hydrographische Beschreibung des Niederschlagsgebietes der Glatzer Neisse. *Abhandlungen der Koniglich Preussischen Geologischen Landesanstalt, Neue Folge, Berlin*, 32: 1–75.

MEISSNER, A., 1911. Die Talgeschichte der Stillen Adler in Ostböhmen. *Geogr. Jahrensberichte der Österreich*, 9: 1–117.

MIALL, A. D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In: Miall, A. D. (Ed.), *Fluvial sedimentology, Canadian Society of Petroleum Geologists Memoir*, 5: 597–604.

MIALL, A. D., 1985. Architectural element analysis: A new method of facies analysis applied to fluvial deposits. *Earth-Science Reviews*, 22: 261–308.

PRZYBYSKI, B., BADURA, J., CZERWONKA, J. A., KRZYSZKOWSKI, D., KRAJEWSKA, K. & KUSZELL, T., 1998. Preglacial Nysa Kłodzka fluvial system in the Sudetic Foreland, Southwestern Poland. *Geologia Sudetica*, 31: 171–196.

RADWAŃSKI, S. & SAWICKI, L., 1957. Geologiczna mapa Sudetów 1:25,000, arkusz Międzylesie. *Państwowy Instytut Geologiczny*, Warszawa.

RADWAŃSKI, S., 1975. Kreda Sudetów Środkowych w świetle wyników nowych otworów wiertniczych. *Biuletyn Instytutu Geologicznego*, 287: 5–50.

ŘEZÁČ, B., 1955. Terasy řeky Metuje a tabulova plošina Adršpasskoteplicka. *Rozpravy Česke Akademie Ved*, 65 (7): 11–24.

RUZIČKA, M., 1973. Fluvialni sedimenty řeky Moravy v okoli Olomouce. *Sbornik Geologických Ved.*, A 9: 7–43.

RUZIČKA, M., 1989. Pliocen Hornomoravskeho uvalu a Mohelnicke brazdy. *Sbornik Geologických Věd.*, A 19: 129–151.

SROKA, W., 1997. Ewolucja morfotektoniczna Sudetów w rejonie Kotliny Kłodzkiej w świetle analizy morfometryczno-statystycznej. *Acta Universitatis Wratislavienis, 1939, Prace Geologiczno Mineralogiczne*, 58: 1–97.

SVOBODA, J. & CHALOUPSKÝ, J., 1961. Vysvětlivky k přehledne Geologické Mapě ČSSR 1:200,000, list Nachod, M-33-XVII. *Ústřední Ústav Geologický*, Praha, pp. 1–185.

TIETZE, E., 1901. Die geognostischen Verhältnisse der Gegend von Landskron und Gewitsch. *Jahrbuch der Geologische Reichsanstalt, Wien*, 317–730.