Annales Societatis Geologorum Poloniae (2004), vol. 74: 63–93.

PALAEOGEOGRAPHY OF THE WESTERN SANDOMIERZ BASIN IN LATE NEOGENE AND EARLY QUATERNARY TIMES (CARPATHIAN FOREDEEP, SOUTH POLAND)

Stanisław BRUD

Institute of Geological Sciences, Jagiellonian University, Oleandry 2A, 30-063 Kraków, Poland
e-mail: stbrud@ing.uj.edu.pl

Brud, S., 2004. Palaeogeography of the western Sandomierz Basin in Late Neogene and Early Quaternary times (Carpathian Foredeep, South Poland). *Annales Societatis Geologorum Poloniae*, 74: 63–93.

Abstract: The sub-Quaternary topography of the western Sandomierz Basin has been compared to variable thicknesses of Quaternary sediments and geomorphology of the area. The lithology and age of the top of Miocene strata have been determined. The Witów Series has been interpreted as a sequence of a braided river that used to flow into the retreating marine basin, forming a fan delta whose age, according to macrofloristic determinations, has been assigned to the Late Miocene. Lower Quaternary gravels cap the remnants of a planated surface situated at 240–250 m a.s.l. The Błonie gravel horizon occurring at a similar altitude was deposited by a river active in Narevian and/or Nidanian glacial stages, and its top underwent reworking during the Sanian-2 stage.

Deposits infilling the fossil sub-Carpathian Furrow have been mapped and dated to the Cromerian *s.l.* interglacial stage. The final alluviation of this segment of the furrow took place during the Sanian-2 stage. Reconstruction of the drainage pattern during the Eopleistocene, South-Polish glaciations, and Masovian interglacial stage has been proposed as well.

Key words: Neogene, Quaternary, Early Pleistocene, sub-Quaternary surface, coarse-clastic fluvial sediments, Witów Series, sub-Carpathian Furrow, Sandomierz Basin, Carpathian Foredeep, South Poland.

Manuscript received 22 January 2004, accepted 27 February 2004

INTRODUCTION

The turn of the Tertiary and Quaternary in the Sandomierz Basin is marked by an hiatus. Different opinions expressed in archival papers dealing with this area have motivated the author to synthesize all the existing geological data and to revise the previously described sites. The aim of this paper is to reconstruct palaeogeographic evolution of the medial part of the Carpathian Foredeep since the Late Miocene, that is, from the time of retreat of the marine Miocene basin, through successive stages of erosion, denudation, and accumulation of coarse-clastic sediments in the Early Quaternary, up to the South-Polish glacial stages.

STUDY AREA

The Sandomierz Basin is a physiographic macroregion (Kondracki, 2001) showing well-preserved morphological boundaries. It is of triangular shape; the base of this triangle being located at the foot of the Carpathians and its apex situated at the Vistula and San rivers' confluence (Fig. 1). The southern boundary is marked by a morphological step of the Outer Carpathians, 40 to 140 m high, which is roughly coincident with the Carpathian frontal thrust. The NW boundary is also well-marked in the topography along the erosional escarpment of the Małopolska Upland, more than 70 m high. On the NE, the Sandomierz Basin is bordered by the Roztocze Ridge. Detailed studies have focused on the western part of the area, up to the 21°15' E meridian on the east (Fig. 1).

METHODS

The basic technique used consisted in detailed geological mapping at the scale of 1:25, 000 of the Tarnów Upland, aided by an analysis of archival data from the western part of the Sandomierz Basin. In addition, geomorphological mapping was performed in the Bochnia Foothills and the Carpathian margin near Brzesko-Okocim, Wojnicz, Strzyżów and Pilzno, as well as south of Niepołomice (Fig. 2). Geological-geomorphological map of the study area has been constructed on the basis of geomorphic sketches prepared for the Detailed Geological Map of Poland, 1:50,000 (DGMP), sheets elaborated by the author, as well as using

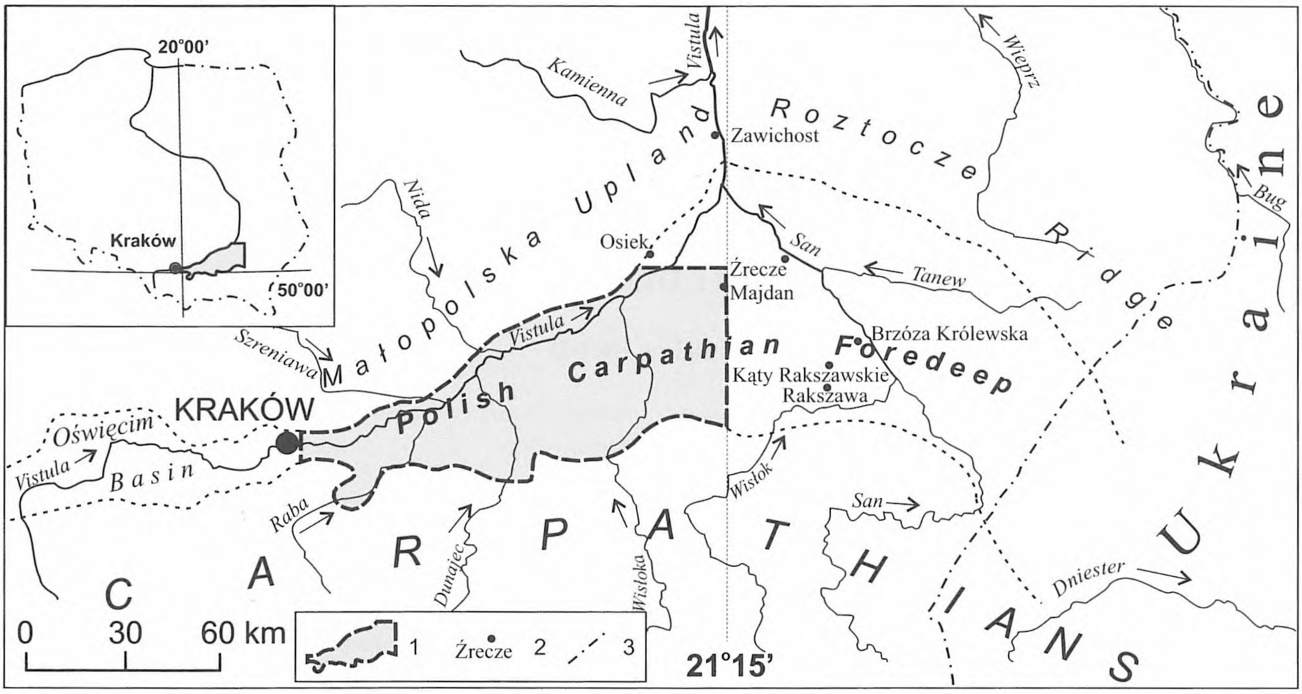

Fig. 1. Location of the study area and main physiographic units in Southern Poland (simplified after Kondracki, 2001). *1* – study area, *2* – location of exposures described in the text and situated outside the study area, *3* – Polish-Ukrainian border

archival data. Maps of the sub-Quaternary surface and the map of thickness of Quaternary sediments have been prepared basing on some 10,000 drillholes and probes, ca. 4,000 of which pierced the top of Miocene strata. The area studied covers some 4, 350 sq. km, what gives on the average 10 observation points per 1 sq. km. Geological cross-sections, drawn using this ample data base, enable one to reconstruct the successive evolutionary phases of the region.

Laboratory methods have included: grain-size analysis, composition of heavy minerals, roundness measures of quartz grains, and petrographic determination of gravel composition. All these techniques are compatible with those used in preparing DGMP sheets, enabling a comparison with archival data. As far as petrographic analyses of coarse-clastic sediments are concerned, a technique introduced by Rutkowski (1995a) has been applied. Subdivisions of the Late Neogene has been assumed after Rögl (1996) for the Central Paratethys (Tab. 1), and after Lindner & Wojtanowicz (1997) for the Quaternary Period (Tab. 2).

GEOLOGICAL SETTING OF THE CARPATHIAN FOREDEEP

The Carpathian Foredeep was formed in front of the Carpathian orogen due to collision of the European Platform with the ALCAPA-Tisza blocks, and belongs to the Paratethys basin, a subprovince within the European Neogene basins (Kovač *et al.*, 1998). The folded and imbricated Cretaceous–Palaeogene flysch sequences of the Outer Carpathians are thrust upon flat-lying Badenian–Sarmatian strata of the foredeep, extending between the foothills of the Holy Cross Mountains and Roztocze Upland. The Sandomierz Basin occupies the medial and eastern parts of the foredeep, being situated east of the so-called "Cracow Ridge" (Ney, 1968).

The area studied is composed of several structural stages. The base of the foredeep is represented by folded and poorly metamorphosed Precambrian–Riphean rocks which are overlain by flat-lying Palaeozoic and Mesozoic strata (Oszczypko *et al.*, 1989). The sub-Miocene surface exposes mostly Jurassic and Cretaceous strata developed in facies similar to those in the Małopolska Upland, and protruding south-eastwards under the overthrust Carpathians.

The Carpathian Foredeep can be subdivided into two parts: the inner and outer ones (Oszczypko, 1997, 2001). The inner foredeep, overthrust by the flysch Carpathian nappes, is at least 50 km wide and extends as far south as the Pieniny Klippen Belt (Oszczypko & Tomaś, 1985; Oszczypko & Ślączka, 1989; Oszczypko, 1997). The foredeep is filled up by the Lower through Middle Miocene terrestrial and marine strata. In the marginal part of the Carpathians, in front of the Carpathian frontal thrust, there occurs a zone of uprooted, strongly folded strata that build the Stebnik (Ney, 1968) and Zgłobice (Kotlarczyk, 1985) Units. These units compose a narrow, steeply south-dipping wedge, sometimes associated with the more outer supra-fault folds that show a minor degree of deformation and are principally composed of fine-clastic marine strata (Krzywiec, 1997, 1998; Brud, 1997a).

The outer foredeep, in turn, extends from a dozen or so kilometers near Cracow to nearly 100 km at the Rzeszów–Tarnobrzeg meridian. The foredeep is filled by mostly Middle through Upper Miocene siliciclastic strata and underlying evaporites (Oszczypko, 1997, 1998, 1999). In the study area, the sub-Quaternary subcrops expose mostly Badenian and Sarmatian (Late Sarmatian?) fine-grained strata (Fig. 3).

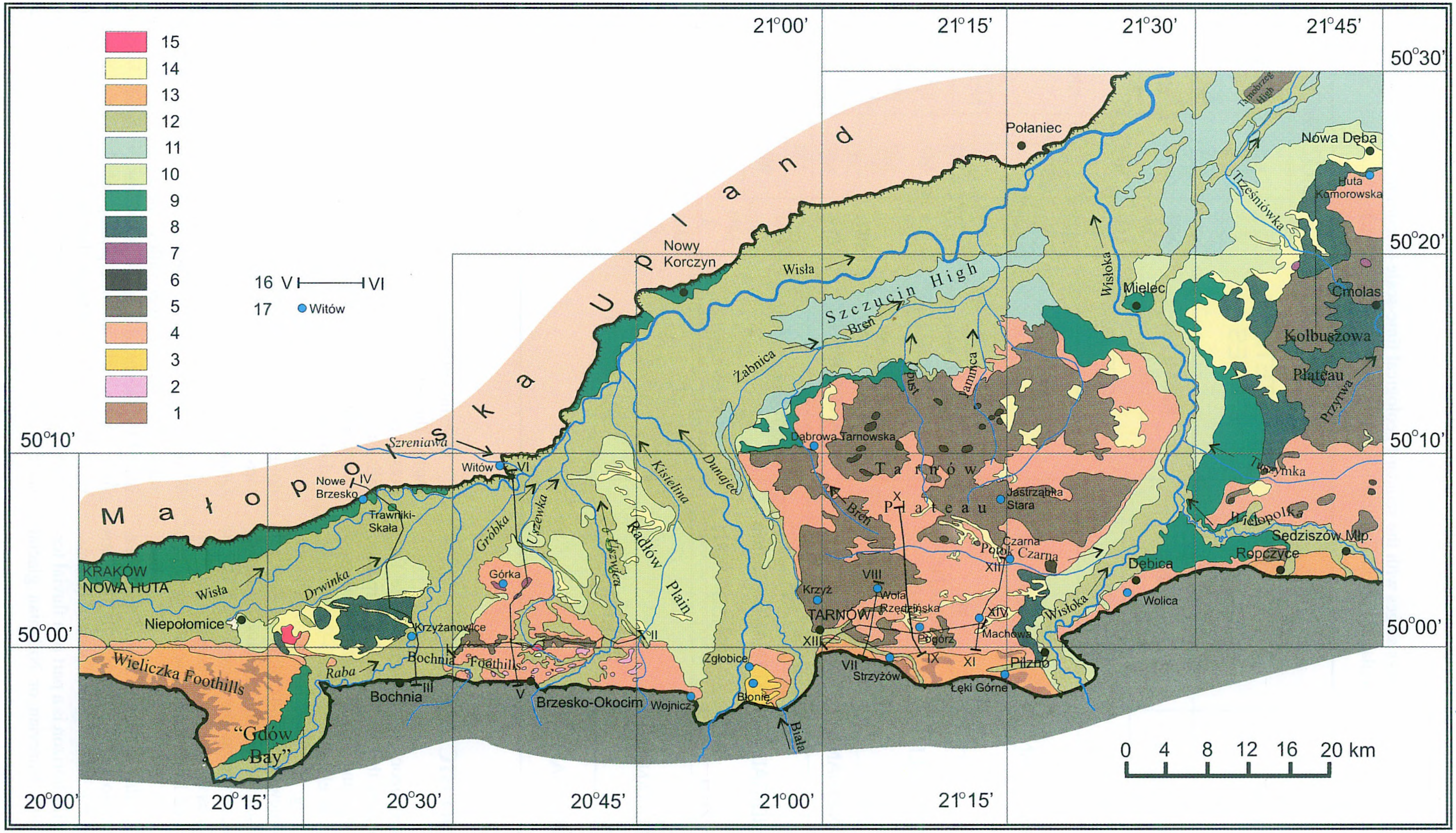

Fig. 2. Geologic-geomorphological sketch map of the Sandomierz Basin. *1* – planation surfaces elevated 280–300 m a.s.l. and 250–270 m a.s.l., *2* – Eopleistocene gravel covers situated at ca. 240–250 m a.s.l., *3* – Błonie gravel horizon situated at 70 m above the Dunajec river bed and 260 m a.s.l. (Narevian or Nidanian glacial stage?); Sanian Glaciation: *4* – fluvioglacial covers, *5* – morainic plateaus, *6* – morainic hills, *7* – kames; Middle-Polish Glaciations: *8* – terraces 13–25 m above river beds; Vistulian Glaciation and Holocene: *9* – accumulational terraces 20–25 m above river beds, *10* – accumulational terraces 8–12 m above river beds, *11* – accumulational terraces 5–7 m above river beds, *12* – floodplains 3–4 m above river beds; *13* – loess and regolith covers upon planated surfaces in the Wieliczka Foothills and Outer Carpathian margin; *14* – wind-blown sands and dune areas; *15* – peat-covered plains; *16* – geological cross-sections; *17* – location of exposures mentioned in the text

Table 1

Late Neogene correlation of Paratethys stages with the standard geological time-scale (according to Rögl, 1996; biozones of calcareous nannoplankton modified according to Andreyeva-Grigorovich *et al.*, 2003)

M.A.	EPOCH	AGE	CENTRAL PARATETHYS STAGES	EASTERN PARATETHYS STAGES	BIOZONES: Mammal Zones	BIOZONES: Planktonic Foraminifera	BIOZONES: Calcareous Nanno-plankton
5	Plio-cene	ZANCLEAN	DACIAN 5.6	KIMMERIAN 5.2	MN 14	PL1	NN13
	5.3						NN12
	Late MIOCENE	MESSINIAN 7.1	PONTIAN	PONTIAN	MN 13	M14	NN11
		TORTONIAN	PANNONIAN	MEOTIAN	MN12	M13 b	
10				10.0	MN11	M13 a	
					MN10		
	11.0		11.5	SAR-MATIAN: Khersonian	MN9	M12	NN9/10
	Middle MIOCENE	SERRAVALLIAN	SARMATIAN 13.0	SAR-MATIAN: Bessarabian	MN 8-7	M11-M8	NN9/8
				SAR-MATIAN: Volhynian			
		14.8	BADENIAN	KONKIAN KARAGANIAN TSHOKRAKIAN	MN 6-5	M7	NN6-7
15	16.4	LANGHIAN		TARKHANIAN		M6; M5	NN5
	Early MIOCENE	BURDIGALIAN	KARPATIAN 17.2	KOTSHAKHURIAN		M4	NN4
			OTTNANGIAN 18.3		MN 4	M3	NN3
20		20.5	EGGENBURGIAN	SAKURALIAN	MN 3	M2	NN2
		AQUITANIAN	EGERIAN	CAUCASIAN	MN 2	M1 b	
		23.8			MN 1	M1 a	NN1
25	OLIGO-CENE	CHATTIAN			MP 28-30; MP 27-24	P22	NP25

GEOMORPHIC SETTING

The oldest preserved geomorphic elements are fragments of planation surfaces that occur on the Carpathian margin. In the "Gdów Bay" and Tarnów–Pilzno areas, there occur two such surfaces at elevations of 280–300 m a.s.l., and 250–270 m a.s.l. (Fig. 2). Their dating is, however, hardly possible (*cf.* Zuchiewicz, 1984a), although they can be correlated with the so-called foothills and riverside levels (Zuchiewicz, 1987), preserved in the Nowy Sącz Basin. These surfaces, similarly as the northern margin of the Sandomierz Basin, are capped by a thick layer of weathering covers and loesses.

At the Dunajec and Biała Dunajcowa rivers' interfluve, a flat surface occurs rising some 70 m above valley bottoms (*ca.* 264 m a.s.l.), called the Błonie gravel horizon (Klimaszewski, 1961; Fig. 3). This horizon is a part of a fluvial terrace correlated with either Narevian or Nidanian glacial stages (Klimek, 1991).

Morainic plateaus and fluvioglacial plains were formed during the Sanian-2 glacial stage. Fluvioglacial sands are preserved east of Cracow at the base of the Wieliczka Foothills only. Farther eastwards, between Raba and Uszwica rivers, a fluvioglacial plain occurs, bearing till-covered monadnocks near Mokrzyska and Szczepanów, and kames near Górka (Fig. 4, 5). This zone extends eastwards towards Biadoliny. Near Brzesko-Okocim, upon flat monadnock hilltops (240 m a.s.l.), tills are accompanied by relict Lower Quaternary fluvial gravels.

The Tarnów Plateau extends between the Dunajec and Wisłoka rivers (Fig. 2). On the west, it slopes steeply towards the Dunajec river valley, the escarpment being dissected by short and deeply-cut streams that erode Miocene strata. A characteristic morphological element of this plateau are planated surfaces that rise at 240–250 m a.s.l., probably representing remnants of the pre-glacial planation surface of the Sandomierz Basin. The plateau is mostly built up of sand-gravelly fluvioglacial sediments and tills, which

Table 2

Correlation of stratigraphic subdividions of the Pleistocene of the South-Polish Uplands and Western Europe (according to Lindner & Wojtanowicz, 1997; slightly modified)

AGE			Magnetostratigraphy		0[ka]	South Polish Uplands – Climatostratigraphic units: Warm stages	Cold stages	Western Europe
QUATERNARY	HOLOCENE			BRUNHES	10	Holocene		Holocene
	PLEISTOCENE	North-Polish Glaciations	Blake		100		Vistulian	Weichselian
						Eemian		Eemian
		Middle-Polish Glaciations	Jamaica				Wartanian	Warthe
					200	Lubavian		
			Chegan		300		Odranian	Saalian
		"Great Interglacial"				Zbójnian		
							Livecian	
					400	Masovian		
		South-Polish Glaciations			500		Sanian-2	Elsterian
						Ferdynandovian		Cromerian
					600		Sanian-1	
						Małopolanian		
					700		Nidanian	
		Eopleistocene		MATUYAMA	800	Podlasian		Bavelian
			Jaramillo		900		Narevian	Menapian
					1000	Celestynovian		Waalian
			Olduvai				Otwockian	Eburonian
					1870	Ponurzycian		Tiglian
			Reunion		2480		Różcian	Pretiglian

cap differentiated topography of the top of Tertiary strata. A similar structure is displayed by the Kolbuszowa Plateau (Fig. 2), upon which denuded glacial plateau culminates at 240–250 m a.s.l. Small hills built up of moraines and/or kames (Szajn, 1993) occur only locally.

The principal landform of the western Sandomierz Basin is a broad valley of the Vistula river which undermines the Małopolska Upland, forming a several tens of meters high escarpment. The Vistula river valley increases its width from some 3 km near Cracow to more than 10 km at the outlet of the Wisłoka river. The valley bottom is occupied by three terrace steps rising, resp., 20–25 m, 8–12 m, and 5–7 m above the river bed. The present-day vast valley bottom is occupied by a 3–4 m-high flood-plain.

The so-called "high" (loess) terrace (205–220 m a.s.l.) forms a shelf up to 2 km wide along the left bank of the Vistula river between Nowa Huta and Nowe Brzesko, and proceeds farther northeastwards in isolated, discontinuous patches (Fig. 2). The relevant remnants on the right bank of the Vistula river are the Trawniki and Skała meander hills (Gębica, 1995; *cf.* Fig. 5).

The lower terrace steps are usually composed of sand and gravel. These "supra-inundational" terraces were formed during the last glacial stage (Vistulian) and the Holocene. The Carpathian tributaries of the Vistula river build at places flat alluvial fans, like those of the Raba river (Gębica, 1995), or Dunajec and Uszwica rivers in the Radłów Plain (Radzki *et al.*, 1992). The fans are commonly capped by extensive aeolian sand covers and dunes (Fig. 2).

SUB-QUATERNARY SURFACE

The first ever outline of the top of the Miocene strata in the Sandomierz Basin was presented by Bożym-Rogalska (1964). The subsequent papers by Laskowska-Wysoczańska (1971), Jonak (1979), Jawor *et al.* (1974, 1982), Sokołowski (1981, 1987), as well as Nowak & Żółkiewski (1989) took into account some parts of the study area only. These sketches are of variable cognitive value, depending on the number of data used and the quality of their interpretation. The use of numerous new data points, together with a

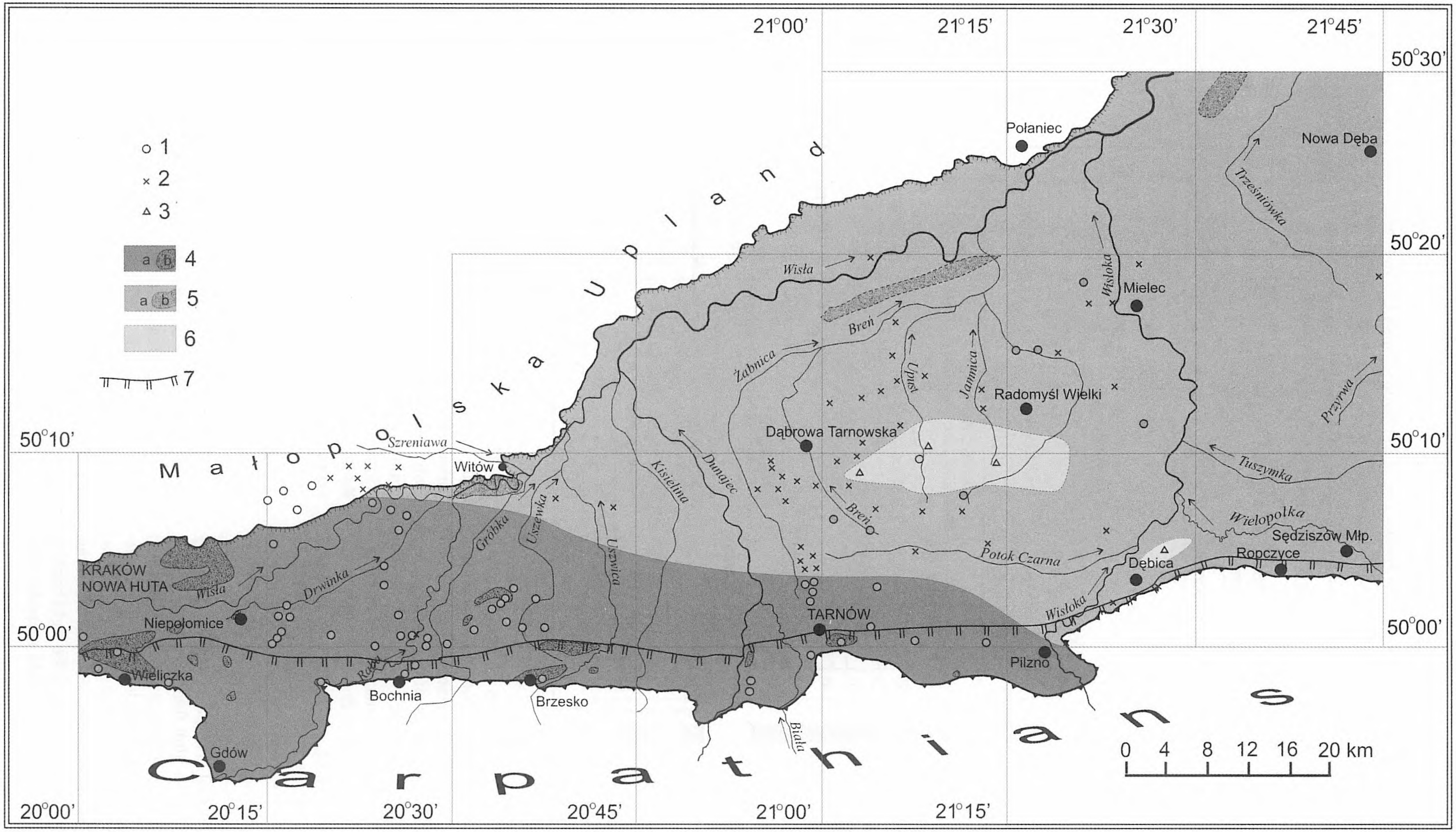

Fig. 3. Distribution of the Middle/Upper Miocene strata on the sub-Quaternary surface in the western part of the Sandomierz Basin, based on microfaunistic and microfloristic data collected from surface exposures and shallow cartographic boreholes (compiled by Brud, 2001). Age: *1* – Badenian, *2* – Sarmatian, *3* – Late Sarmatian. Lithology: *4* – Badenian: *a* – clays and silts, *b* – sands and locally gravels; *5* – Sarmatian: *a* – clays and silts, *b* – sands and silts; *6* – Late Sarmatian: clays and silts; *7* – Zgłobice Unit thrust

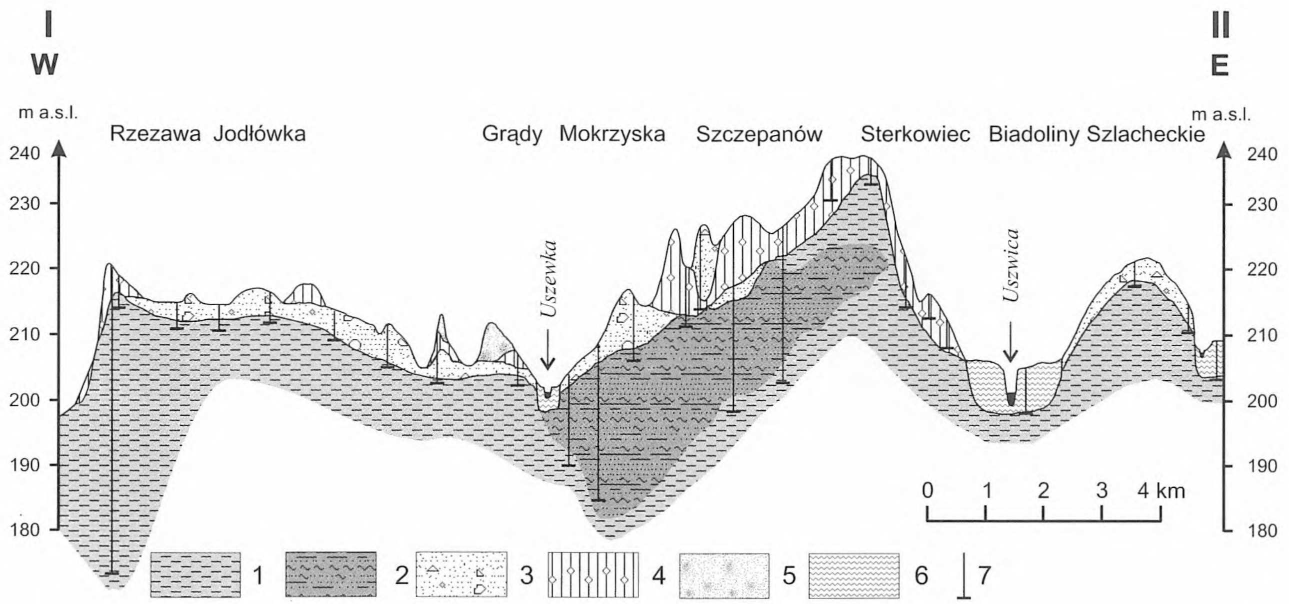

Fig. 4. Geological cross-section I–II. Miocene: 1 – clays, 2 – sands, silty sands; Quaternary: South Polish Glaciation: 3 – fluvioglacial sands and gravels, 4 – tills; Holocene: 5 – aeolian sands and dunes, 6 – young valley infills, 7 – boreholes

critical evaluation of archival sources, has made it possible to revise the hitherto-expressed views on morphology of the top of the Miocene in that part of the Sandomierz Basin (Fig. 7).

The studies conducted by Płonczyński (1992) near Grobla contradicted a view expressed by Połtowicz (1967) on the presence of channels filled by Quaternary gravels. Three cartographic boreholes were drilled at Grobla 5, Grobla 6, and Grobla 32 oil industry borehole sites. The obtained thicknesses of Quaternary sediments were as follows: 7 m (vs. 35 m in the original description of the Grobla 5 borehole), 14.5 m (vs. 48 m at Grobla 6), and 12.5 m (vs. 20 m at Grobla 32 – see Fig. 5). Similar discrepancies have been encountered east of Tarnów, where at Pogórska Wola 3 borehole (Brud, 1997a), the borehole log turned out to be entirely different from that described previously (*i.a.*, the Miocene strata have been drilled down to some 50 m).

These examples show that data coming from uncored oil-industry boreholes cannot be used for the construction of the map showing the top surface of the Miocene. Gravels obtained from drilling fluid could have been derived from intercalations within Miocene clays (see Połtowicz, in Rutkowski, 1987b; as opposed to Połtowicz, 1967).

The top surface of Miocene strata is cut by a submarine erosional furrow marked by linear sand-silty infills within the clays. Such a landform represents a palaeovalley, a few tens of metres deep and up to 1 km wide, which runs shortly south of the present-day Vistula river channel near Szczucin (Fig. 2). The infill was palynologically and microfaunistically dated to the Sarmatian (Płonczyński, 1992). The orientation of this palaeovalley is well constrained by geophysical and borehole data in the DGMP Szczucin sheet only. One can observe a relationship with erosional furrows from the Tarnobrzeg area, where the top of the Krakowiec Clays is dissected by palaeochannels up to a few hundred metres wide, which are filled by laminated Upper Miocene siltstones (Piątkowski, 1973; Mycielska-Dowgiałło, 1978, 1987; Drągowski *et al.* 1979; cf. also Fig. 2).

The presented sketch of the top surface of the Miocene is dominated by erosional landforms, particularly those of the Late Pleistocene age (Fig. 7, 8). Upon the uplands and foothills, however, older denudational, relict landforms are preserved as well. The principal morphological element of the top of the Miocene is a broad erosional channel of the palaeo-Vistula river, showing a graded bottom sloping towards the NE. The gradient of this surface is slightly higher than that of the present-day river, and attains 0.34%. The local relief does not exceed 10 m. Along the northern margin of this palaeoriver, close to Nowy Korczyn only (Fig. 2), there occur remnants of a higher-situated Miocene-built strath which is overlain by the Vistulian alluvia of the Vistula's high terrace. Near the confluence of the Raba and Vistula rivers, a well-visible palaeomeander occurs, being presently obliterated by the Raba river alluvial fan. East of the outlet of Dunajec to Vistula, there occurs a strath rising some 160 m a.s.l. which only in part coincides with the Szczucin High (Starkel, 1972).

This high is not a remnant hill built up of Miocene strata, like, for instance, the Tarnobrzeg High (Fig. 2), but only a part of an older strath covered by the Vistula's alluvia whose sandy sediments have undergone subsequent aeolianisation. That is why this landform is a positive one, although the top of Miocene strata does not show any more prominent relief. South of the Szczucin High (Fig. 7), a vast depression presently drained by the Żabnica and Breń stream occurs, representing a palaeoflow of the Vistula river. Farther eastwards, the erosional surface becomes more differentiated, being dissected by furrows that are cut down as low as 130 m a.s.l., and separated by the Tarnobrzeg High. The present-day depression of the Vistula

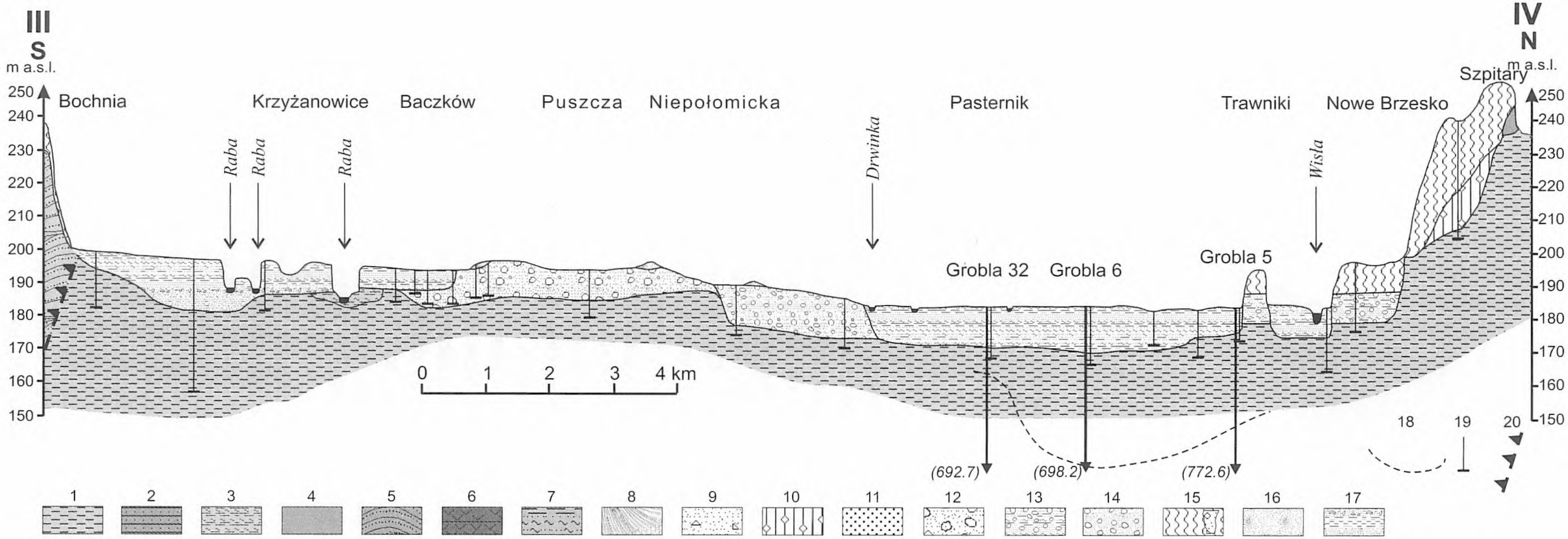

Fig. 5. Geological cross-section III–IV. Miocene: *1* – clays, *2* – sandstones, *3* – clays, silts, *4* – clays, silty sands, pebble mudstones of submarine slumps, *5* – sandstones, sands, sands with intercalations of silts and clays (Zgłobice Unit), *6* – gypsum, *7* – clays, silts, sands (lower part of the Witów series), *8* – sands, gravels (upper part of the Witów series); Quaternary: South-Polish Glaciations: *9* – fluvioglacial sands and gravels, *10* – tills, *11* – sands and silts of kames; Middle-Polish Glaciations: *12* – gravels and sands of the Raba terrace (alluvial fan); Vistulian Glaciation and Holocene: *13* – gravels and sandy gravels of the Vistula upper terrace ("loess terrace"), *14* – sands with gravels of the Vistula high terrace, *15* – loess, loess-like loams, slopewash sediments, and infills of young erosional scours, *16* – aeolian sands and dunes, *17* – gravels, sands, muds of the Vistula and Raba flood plain; *18* – top of Miocene strata based on oil-industry borehole data, *19* – cartographic boreholes, *20* – Carpathian frontal thrust

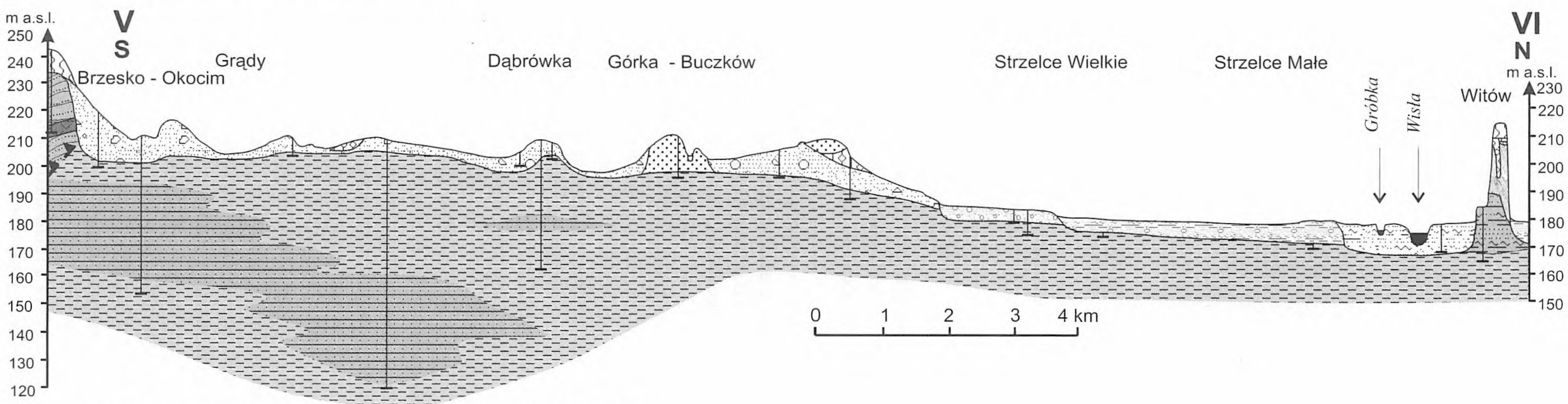

Fig. 6. Geological cross-section V–VI. For explanations – see Figs. 4, 5.

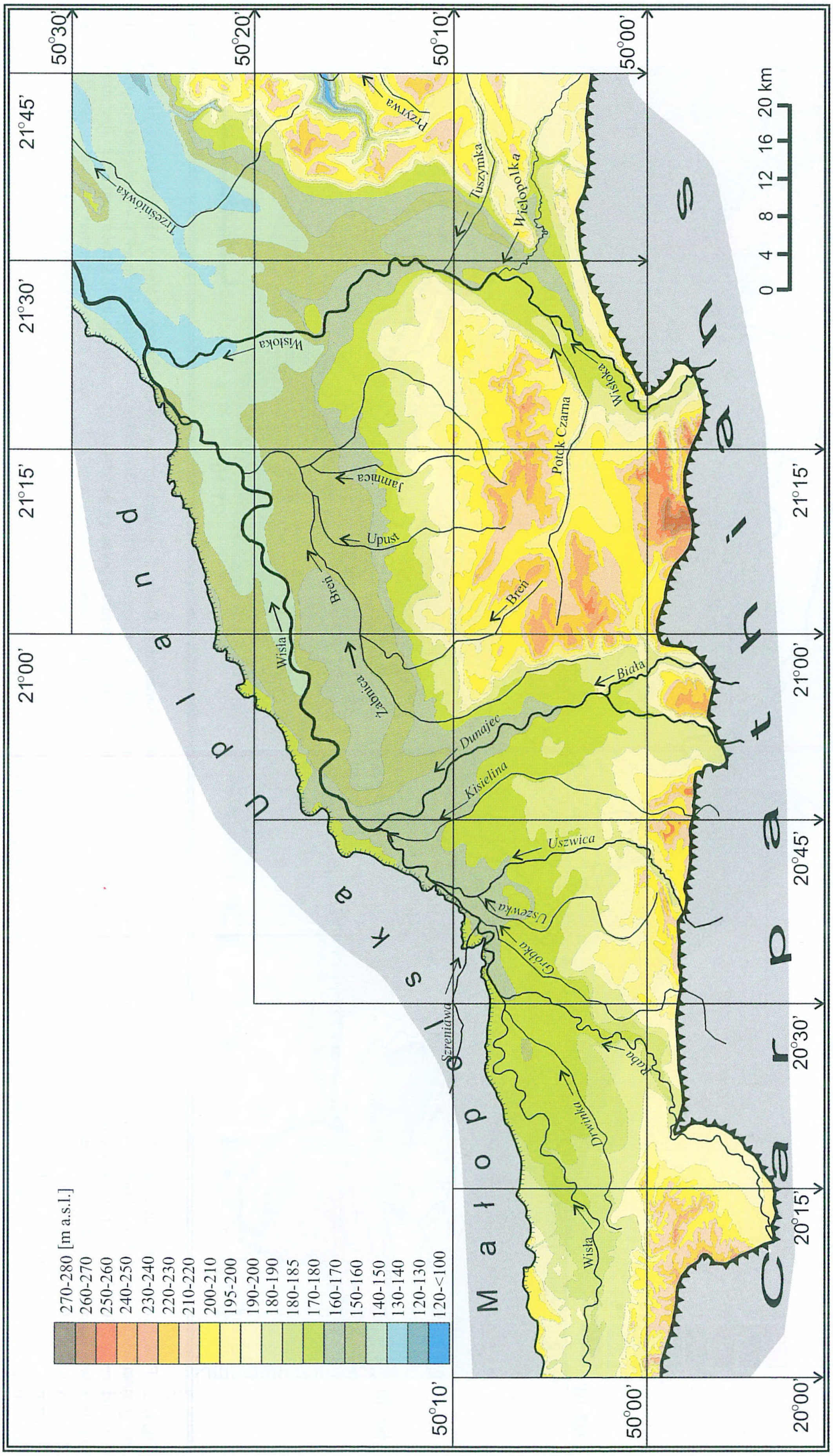

Fig. 7. Morphology of the top of the Miocene (sub-Quaternary surface) in the western part of the Sandomierz Basin (middle part of the Polish Carpathian Foredeep)

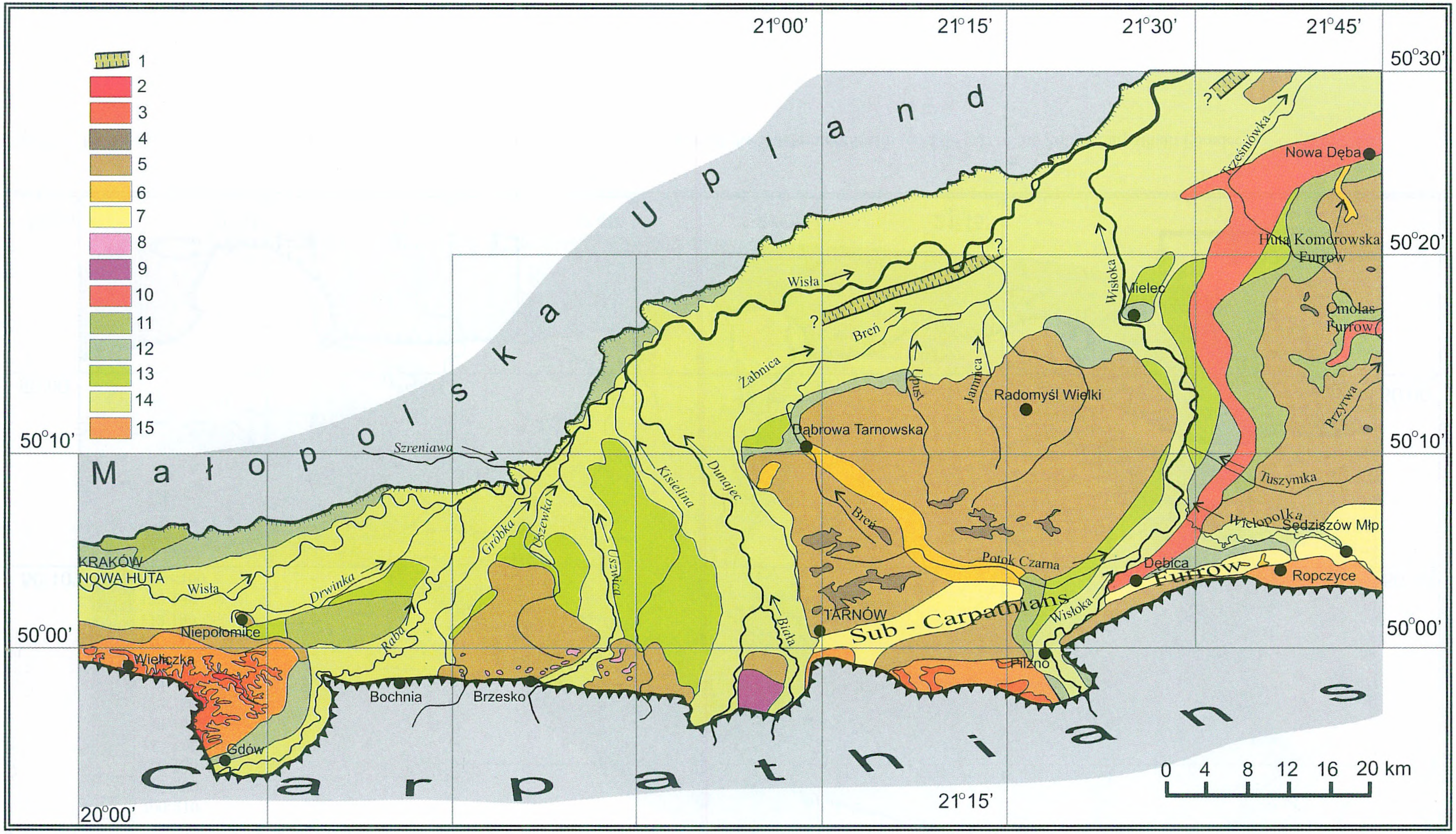

Fig. 8. Palaeogeomorphological sketch of the sub-Quaternary surface of the western part of the Sandomierz Basin. *1* – palaeofurrows cut into the top of clayey Miocene strata, filled by silts and fine-grained sands; denudational landforms: *2* – planation surface at 280–300 m a.s.l. ("Foothills level"), *3* – planation surface at 250–260 m a.s.l. ("riverside level"), *4* – relics of pre-glacial planation surfaces at 240–250 m a.s.l. preserved below glacial sediments; glacial and fluvioglacial landforms: *5* – morainic plateaus, proglacial fans, morainic hills, kames (Sanian-2 Glaciation), *6* – glacial furrows; fluvial landforms: *7* – strath in the Sub-Carpathian Furrow situated at 220–195 m a.s.l. (Cromerian Interglacial?), *8* – relics of gravel-covered surface at 240–250 m a.s.l. (Eopleistocene?), *9* – strath of the Błonie gravel horizon at 260 m a.s.l. (Narevian/Nidanian? Glaciation), *10* – valley bottoms formed in the Masovian (Holsteinian) Interglacial (?), *11* – straths of 13–25 m terraces (Middle-Polish Glaciations), *12* – straths of supraflood terraces 20–25 m above river beds (Vistulian), *13* – straths of supraflood terraces 8–12 m above river beds (Vistulian–Holocene), *14* – straths of floodplains and supra-flood terraces (Holocene), *15* – foothills covered by weathering covers and loess showing young erosional scours

river valley is not the deepest one. Going eastwards towards the San river valley, there occurs a deeper palaeodepression obliterated by alluvia of the higher Vistula terrace, and filled by fluvial sediments which have been interpreted by Szajn (1987, 1991) as the Eemian ones.

The Wisłoka river does not use its original valley, either. Frequent avulsions have resulted in differentiated morphology of the top of Miocene strata. Close to the margin of the Kolbuszowa Plateau, there occur fragments of an erosional-accumulational terrace of the Middle-Polish glacial age that rise at *ca.* 170 m a.s.l. (Fig. 7). These terraces slope westwards, towards a level cut during the "Great Interglacial" time (Mądry, 1997) at *ca.* 160 m a.s.l. These straths are now covered by alluvium of the uppermost terrace (20–25 m above the Wisłoka river bed), whose origin is assigned to the Middle-Polish glacial stages (Mądry, 1997; Fig. 2). West of Dębica, up to a region situated east of Mielec (Fig. 7, 8), one can detect the deepest incision of the Wisłoka river formed during the Great (Eemian?) Interglacial times, being filled by the Vistulian alluvia (Boratyn & Brud, 1996b; Mądry, 1997, *cf.* Figs 7, 8).

In the Vistulian Late Glacial, the Wisłoka river shaped a strath north of Dębica, along the western margin of the Tarnów Plateau, rising at *ca.* 178 m a.s.l., and separating a Miocene remnant hill (185 m a.s.l. – Fig. 7). All these landforms are now covered by the Vistulian Late Glacial and Holocene alluvia of the Wisłoka river (Fig.2). Farther northwards, the recent Wisłoka river turns towards the NW, abandoning its previous valley that runs east of Mielec, undermining Miocene strata. The Mielec Hill, rising some 10 m above the surrounding erosional plain, is a remnant of an erosional-accumulational North-Polish upper terrace (Kurek & Preidl, 1997), well visible in the present-day topography (Fig. 2).

Similar changes in the channel pattern can also be observed in the Dunajec river valley, close to the confluence of the Biała and Dunajec rivers. There occurs a buried fragment of an higher strath, rising at some 190 m a.s.l., like near Radłów, where a meander hill (186 m a.s.l.) has been cut off (Fig 7). These two palaeohighs are covered by the Vistulian alluvia of the Dunajec river. No correlation between the higher Dunajec terrace (10–12 m above river bed) and morphology of the Miocene top surface has been found. This confirms an hypothesis about polygenetic character of the Radłów Plain. A flat surface rising at 190–200 m a.s.l. that extends at the foot of the Górka kames and Mokrzyska moraines, through the southern part of the Radłów Plain, until a flat hilltop situated at the Biała and Dunajec rivers' interfluve, together with the above-mentioned buried hill and flattened spur in the western part of Tarnów, were probably shaped during the Middle-Polish glaciations (Fig. 7).

The Bochnia Foothills near Brzesko-Okocim display relict gravel covers that mantle flat-topped hills. These flattenings rise at 240–250 m a.s.l., coinciding in elevation with the Błonie strath in the Dunajec and Biała rivers' interfluve, as well as with flattened hilltops of the Tarnów and Kolbuszowa Plateaus (Fig. 2).

The Tarnów Plateau (Fig. 2) is a key element for the recognition of Early Quaternary processes that shaped the Sandomierz Basin. The sub-Quaternary surface in this plateau rises at 240–250 m a.s.l., like hills in the Brzesko-Okocim area and the Błonie gravel horizon (Fig.7). The plateau is dissected in its southern part by a few kilometres wide erosional furrow, sloping towards the east. Its bottom near Tarnów occurs at 216 m a.s.l. and gradually descends to some 205 m a.s.l. near Czarna (Fig. 7). This depression overpasses the present-day Wisłoka river valley and continues eastwards where, near Dębica, is preserved as a bench along the Carpathian margin at an elevation of 192–195 m a.s.l. (Boratyn & Brud, 1997b, Fig. 8). It is the westernmost segment of the "sub-Carpathian Furrow" (Laskowska-Wysoczańska, 1971; Starkel, 1972). This furrow is a fossil landform, since the present-day morphology shows clear inversion. Right above the deepest part of the furrow there occur hills rising up to 250 m a.s.l., and the thickness of Quaternary sediments increases up to 35 m (Fig. 9). The topography of this furrow (broad, flat valley showing insignificant gradient) points to its fluvial origin, although more detailed analysis reveals its polygenetic character. The southern margin of the "sub-Carpathian Furrow" is marked by the Łęki Górne step, where the top of the Miocene strata rises up to 250 m a.s.l., and between Skrzyszów and Łęki Górne forms a flattening rising at 270 m a.s.l. The furrow has probably been supplied from two directions: immediately from the Dunajec river valley, turning eastwards near the southern part of Tarnów (Pulit, 1975), as well as from the south, from the Biała river valley (Figs 7, 8). The latter palaeoflow, represented by some thirty metres-thick series of sands and gravels, is now buried under Vistulian loesses (Figs 2, 9).

Another important morphological element of the sub-Quaternary surface is a palaeodepression along the Dąbrowa Tarnowska–Żukowice–Czarna line, which shows properties typical of a subglacial furrow formed during the Sanian-2 glacial stage (Figs 8–12). This furrow is probably associated with an erosional level at 208–210 m a.s.l. that occurs near Fiuk-Sieradza, SW of Dąbrowa Tarnowska (Nitychoruk, 1991). These two palaeogeomorphic phenomena are also marked as zones of increased thickness of Quaternary sediments (Fig. 13). The youngest feature of the sub-Quaternary surface in the Tarnów Plateau are incisions of the Chotowski, Czarna, and Wątok streams that slope below a level of 190 m a.s.l., and were formed at the end of the Pleistocene (Brud & Mamakowa, 2001, Figs 9, 12).

The sub-Carpathian Furrow continues farther eastwards near Ropczyce, Sędziszów Małopolski and Rzeszów (Figs 7, 8), being utilised by the present-day Wisłok river valley. The palaeomorphology of this segment is also characterized by an eastward gradient: from 205 m a.s.l. to 195 m a.s.l. This relatively flat surface is dissected by a few tens of metres deep depressions. A dense network of boreholes has made it possible to map these depressions, which are usually closed ones. Their bottoms reach 157 m a.s.l. and 170 m a.s.l. (Fig. 7). These features could represent subglacial furrows or even erosional kettles that were formed at the glacial margin, close to the Carpathian frontal thrust. The lack of lithological studies does not enable one to subdivide the pre-glacial and fluvioglacial gravel series. The youngest Wielopolka and Tuszymka river valleys which truncate the strath of the sub-Carpathian Furrow in this region appear to

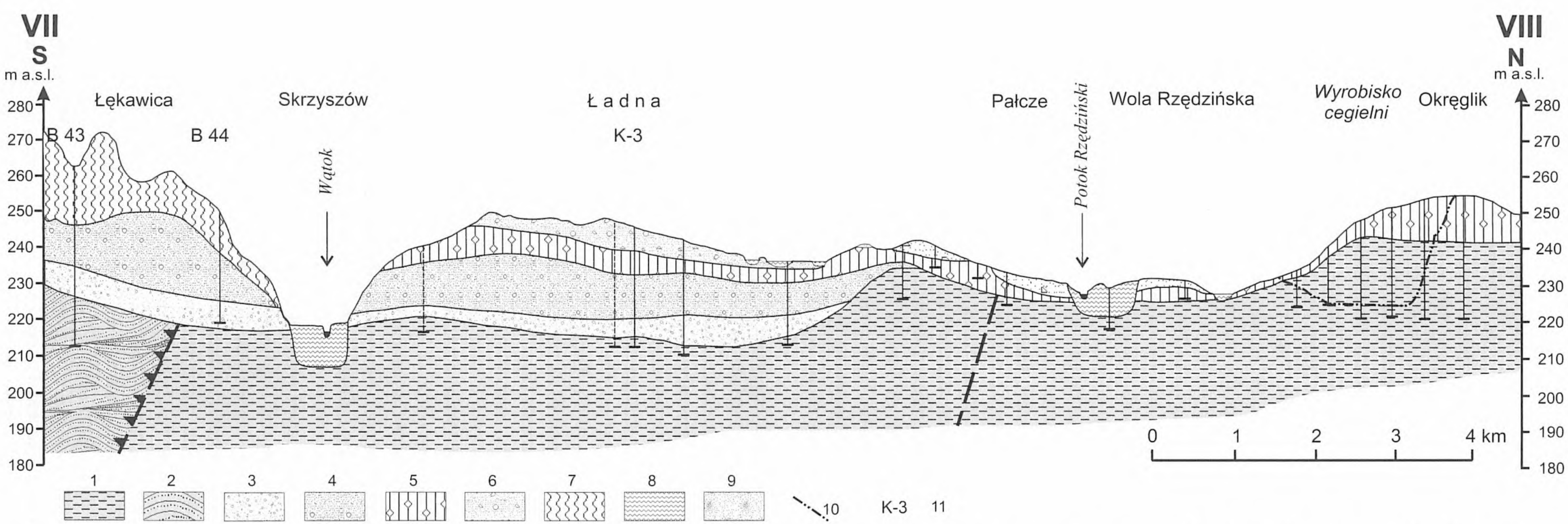

Fig. 9. Geological cross-section VII–VIII. Miocene: *1* – clays, *2* – folded siltstones, sandstones with intercalations of silts and clays; Quaternary–Preglacial: *3* – gravels, sands with gravels; South Polish Glaciations: *4* – lower fluvioglacial sands and gravels, *5* – tills, *6* – upper fluvioglacial sands and gravels; Vistulian Glaciation and Holocene: *7* – loess, loess-like loams, slopewash sediments, *8* – aeolian sands and dunes, *9* – sands and silts infilling young erosional scours, *10* – depth of the excavation of the Wola Rzędzińska brickyard, *11* – cartographic boreholes mentioned in the text

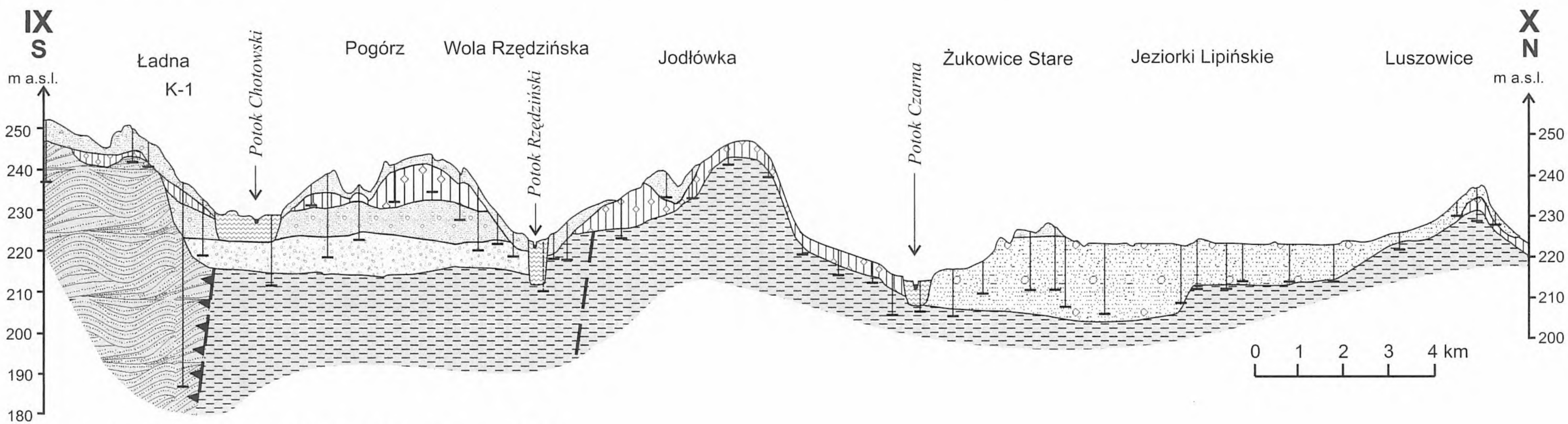

Fig. 10. Geological cross-section IX–X. For explanations – see Fig. 9

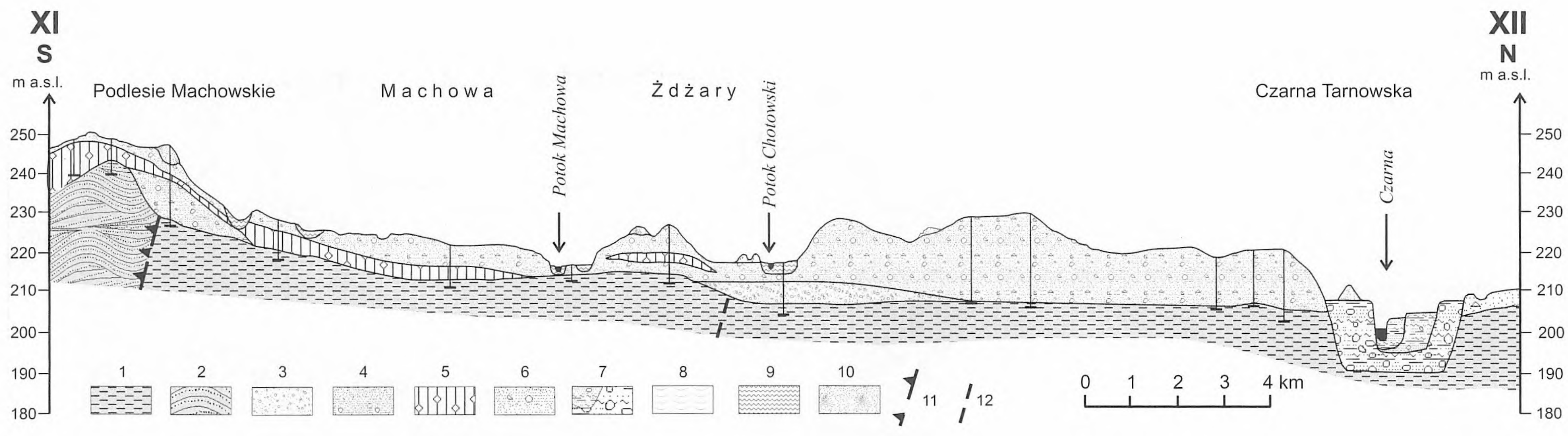

Fig. 11. Geological cross-section XI–XII. Miocene: *1* – clays, *2* – folded siltstones, sandstones with intercalations of silts and clays; Quaternary–Preglacial: *3* – gravels, sands with gravels; South Polish Glaciations: *4* – lower fluvioglacial sands and gravels, *5* – tills, *6* – lower and upper fluvioglacial sands and gravels (undivided); Vistulian Glaciation and Holocene: *7* sands, gravels and muds of the Czarna River terraces, *8* – slopewash sediments, *9* – sands and silts infilling young erosional scours, *10* – aeolian sands and dunes; *11* – Carpathian frontal thrust, *12* – faults

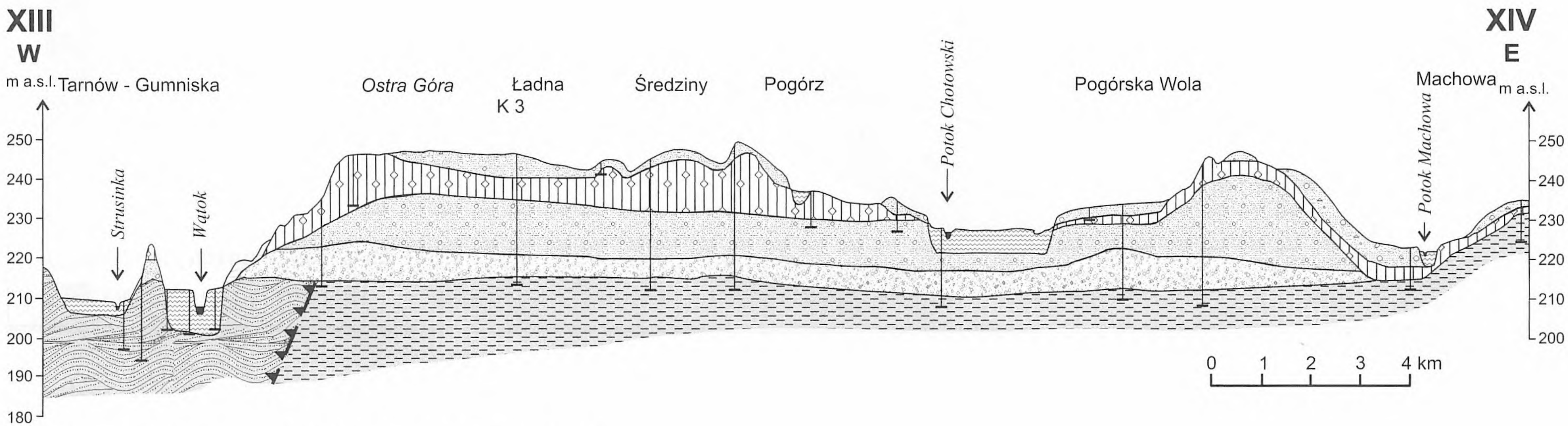

Fig. 12. Geological cross-section XII–XIV. For explanations – see Fig. 11

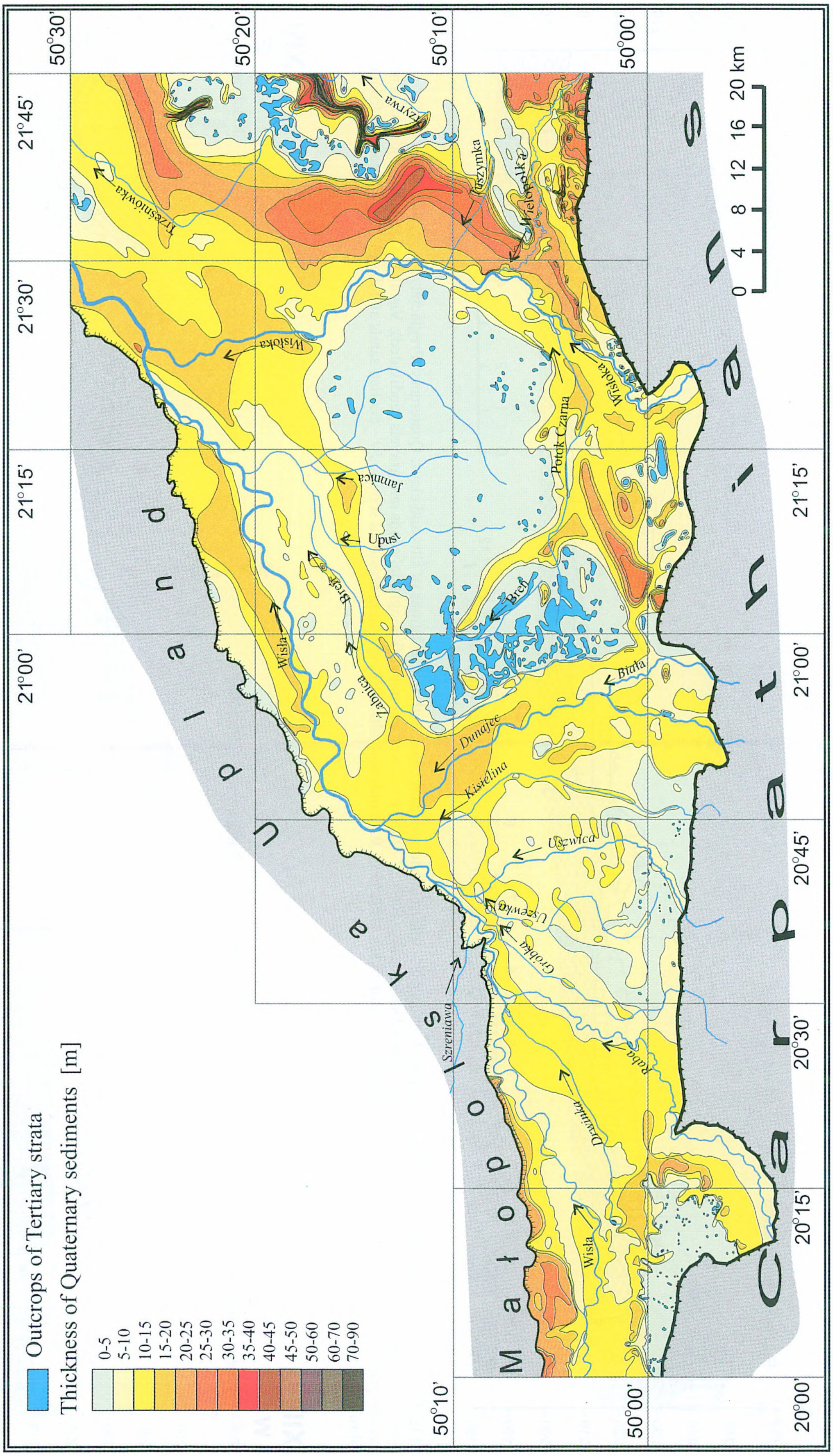

Fig. 13. Thickness of Quaternary sediments in the western part of the Sandomierz Basin

be considerably younger, and associated with the Vistulian glacial stage. The primary outflow of Wielopolka towards the Wisłoka river valley during the Eemian times cannot be excluded.

The eastern part of the Kolbuszowa Plateau is slightly lower than the Tarnów Plateau: hilltop flattenings occur here at 230–240 m a.s.l., and show Miocene strata exposed at the groundsurface. Quaternary sediments have been eroded away. A characteristic morphological element here are deeply-cut and winding furrows, like that sloping down to <119 m a.s.l. near Dąbrówka/Cmolas in the Przyrwa river valley, or even to 90 m a.s.l., judging from geophysical surveys (Mądry, 1997, *cf.* Figs 7, 8).

It is a source area of a larger structure that continues northeastwards into the DGMP Kolbuszowa (Kwapisz, 1996) and Stany (Kwapisz, 1992) sheets. Its bottom occurs at 117 m a.s.l. north of Kolbuszowa, and at 135.5 m a.s.l. in the southern part of the DGMP Stany sheet. This valley probably formed a tributary of a parallel segment of the Nowa Dęba depression (Fig. 7). The landform is from a few hundred metres to some 2 km wide, and it is filled by muds, sands, and fluvial gravels which are up to 100 m thick (Mądry, 1997). The origin of such landforms is associated with the Masovian interglacial stage, during which fluvial valleys became developed within subsiding troughs (Mądry, 1997). Another deep incision into the Miocene strata is the Huta Komorowska furrow, SW of Nowa Dęba (Figs. 7, 8), which erodes the northern margin of the Kolbuszowa Plateau down to 133.5 m a.s.l. (Kwapisz & Szajn, 1987; Szajn, 1993). The valley is filled by typical glacial sediments: tills and varved clays at the bottom, and the Masovian interglacial fluvial sediments at the top (Szajn, 1993).

All these furrows, usually described as fluvial valleys, display polygenetic origin and probably represent subglacial furrows, similarly to those described from the Silesian-Cracow region by Lewandowski (1996).

Morphological differentiation of the top surface of the Miocene strata before the advance of the Sanian-2 icesheet is documented by the position of tills. In the northern part of the study area, along the Wisłoka river valley, the tills occur at 180–190 m a.s.l. (Walczowski, 1970, 1979). Near the Tarnobrzeg High, the till slopes down to some 145 m a.s.l. (Mycielska-Dowgiałło, 1978), whereas in the western part of the northern slope of the Kolbuszowa Plateau the till extends between 180 and 220 m a.s.l. at morphological culminations (Kwapisz, 1992, 1996). Moreover, there also occur deep subglacial furrows, wherein tills reach a level of 130 m a.s.l. (Huta Komorowska region; *cf.* Kwapisz & Szajn, 1987). In the Dunajec river valley, the tills occur at some 195 m a.s.l. (Purchla, 1991). The base of glaciofluvial sediments south of Dąbrowa Tarnowska and near Fiuk-Sieradza attains a level of 200 m a.s.l. (Nitychoruk, 1991). In the Nowe Brzesko region the tills are preserved in the northern area only, occurring at *ca.* 220 m a.s.l. (Płonczyński, 1992). East of the Raba river valley (DGMP sheet Borzęcin), the base of tills occurs at 180 m a.s.l. (Radzki *et al.*, 1992). In the Wisłoka river valley, in turn, these tills are situated below 200 m a.s.l. (Boratyn & Brud, 1996b). On the northern slope of the Tarnów Plateau, the tills in question occur at 190–200 m a.s.l. (Płonczyński, 1997; Kurek & Preidl, 1997), whereas in central parts of the plateau the tills cap flattened hilltops at some 240–250 m a.s.l. (Brud, 1997a; Mądry, 1997; *cf.* also Fig. 2, 7, 8 and 9).

EXTENT, FACIES DEVELOPMENT, AND THICKNESS OF QUATERNARY SEDIMENTS

The thickness differentiation of Quaternary sediments is closely associated with the topography of the sub-Quaternary surface. The greatest thicknesses have been encountered within palaeovalleys and upon high terraces (*cf.* Fig. 2, 7, 13).

Quaternary sediments in the study area are mostly of fluvial origin. There occur numerous, vast river valleys bearing a well-developed system of erosional-accumulational terraces (Fig. 2). Morainic plateaus, in turn, are characterized by greater facies and thickness differentiation of Quaternary sediments; the exposures of pre-Quaternary strata being also quite common. Relatively thick Quaternary sediments east of Cracow include, *i.a.*, a dozen or so metres thick loesses overlying the Pleistocene alluvia of the Vistula and Raba rivers. In the Vistula river valley, the alluvia are up to 20 m thick, the thickness increasing downstream of the outlet of the pre-Wisłoka valley to some 30 m near Nowa Dęba. A zone of increased thickness of fluvial sediments occurs also SE of Połaniec, where a narrow bench built up of Vistulian Late Glacial and Holocene alluvia does occur (Sokołowski, 1987). Another zone of thick alluvium is an area situated south of Żabnica and Breń, marking an ancient flow of the Dunajec and Vistula (?) rivers, probably during the Vistulian Late Glacial (Sokołowski, 1987). The intervening Szczucin Hill is covered by relatively thin (5–10 m) young alluvium of the Vistula river. The dune-covered areas do also show increased thicknesses (>20 m) of Quaternary sediments (Fig. 13).

In the Dunajec river valley, the zone of maximal thickness of Quaternary strata occurs in its lower course, as well as near the eastern margin of the Radłów Plain, marking a palaeoflow trace of this river. A hill undermined by the Dunajec river, well visible on the map of the sub-Quaternary surface, is not marked in the present-day morphology, but shows a reduced thickness of Quaternary sediments. Upon a smooth surface of the Radłów Plain, there occurs a monotonous series of sand-gravelly sediments, up to 10 m thick, which was deposited by the Dunajec and Uszwica rivers, and in the northern part also by the Vistula river, probably in Vistulian times (Sokołowski, 1987). Only in younger valley fills associated with the Kisielina and Uszwica rivers the thickness of alluvium does exceed 10 m.

All the above-mentioned rivers were active in Late Quaternary times, principally during the Vistulian. The Wisłoka river valley shows a more complicated pattern of fluvial infills, which is also noticeable in increased thicknesses of alluvia. The zone of maximal thicknesses (>40 m) is associated with the palaeo-Wisłoka furrow which is filled by fluvial sediments of the Masovian (?) and Eemian interglacial age (Mądry, 1997; Fig. 13). The base of this palaeovalley is filled by gravels drilled by two cartographic boreholes in the area of DGMP Dębica sheet, including the K-2 borehole (Boratyn & Brud, 1996b). These are coarse-grained gravels and cobbles that show a minor admixture of sand, and display a stable petrographic composition which is different from that of all the other gravel series marked in the Dębica sheet. The gravels are dominated by Carpathian flysch-derived sandstones, supplemented by crystalline rocks of both glacial and exotic provenance, Palaeozoic sandstones, quartz, flintstones, and cherts. As far as heavy mineral composition is concerned, siderites are predominant, the remaining minerals including micas, chlorites, opaque minerals, garnets, and zircons. The sand grains are angular and poorly rounded, showing half-polished surface. Such a characteristic indicates a fluvial origin of the material, pointing as well to poor reworking, short transport, and abundant supply of the local Carpathian rocks; the influx of glacial-derived material being of minor importance. These sediments used to be associated with the Eemian interglacial stage (Boratyn & Brud, 1996b; Mądry, 1997). The author concludes, however, that they could have been deposited during the Masovian interglacial stage, when erosion was proceeding more vigorously after the retreat of the Sanian-2 icesheet and related glacioisostatic rebound (Laskowska-Wysoczańska, 1971). The problem requires further studies, though.

The westward migration of the Wisłoka river resulted in reduction of the thickness of Quaternary strata to a few metres near Mielec and SW of Dębica. At some places, the Miocene strata become exposed at the groundsurface like, for instance, west of Mielec. Similar incisions into the Miocene rocks in the Sandomierz Basin can only be observed at Krzyżanowice on the Raba river, and at Zgłobice on the Dunajec river (Fig. 2, 13).

Increased thicknesses of Quaternary sediments are very well noticeable at the base of the Carpathian frontal thrust between Tarnów and Sędziszów Małopolski (Fig. 13). These sediments fill a preglacial erosional furrow that forms the westernmost continuation of the sub-Carpathian Furrow (Fig. 8). West of the Dunajec river valley, the Quaternary cover becomes considerably thinner and does not indicate a preglacial flow along the Carpathian margin. Sediments infilling the sub-Carpathian Furrow are overlain by glacial sediments of the Sanian-2 icesheet, being represented by tills and fluvioglacial sands and gravels. Therefore, the total thickness of Quaternary strata exceeds 35 m. One can also take notice of an increased thickness of fluvioglacial sediments that fill a furrow dissecting the Tarnów Plateau, from Dąbrowa Tarnowska towards the SE (Brud, 1997b).

Still thicker Quaternary sediments occur in deep erosional dissections of the subglacial furrow-type at Huta Komorowska near Nowa Dęba (Fig. 8; Kwapisz & Szajn, 1987; Szajn, 1987, 1991, 1993), Cmolas (Mądry, 1997), and within eversion kettles near Ropczyce where relevant thicknesses exceed 90 m (*cf.* Fig. 7 and 13).

The Huta Komorowska furrow is filled by at least 64 m-thick Quaternary sediments, including three till beds. The lowermost till is interpreted as having been deposited during the Sanian-1 glacial stage, judging from the lack of Carpathian flysch-derived material. The upper beds, associated with the Sanian-2 glacial stage, do contain Carpathian material (Szajn, 1991, 1993). The topmost silt-sandy strata were deposited during the "Great Interglacial" time (Kwapisz & Szajn, 1987).

An analysis of sediments infilling a deep furrow near Cmolas points to their bipartition: the base is composed of sand-gravelly series, whereas the upper series represents silts. Petrographic composition of gravels shows the presence of Carpathian sandstones, as well as quartz, red and grey granitoids, and Cretaceous marls, indicating a Pleistocene age and a supply from the Małopolska Upland. This conclusion is confirmed by the results of heavy mineral studies, whose spectra are dominated by garnets and amphiboles. Grain-size analyses, sorting indices, and grain roundness studies point to a fluvioglacial origin (*cf.* Kwapisz, 1996; Mądry, 1997). The cited authors interpret the above sediments as resulting from reworking of the glacial material by a river existing at the beginning of the Masovian interglacial stage. The overlying silt-sandy series with floristic remains could have represent the middle and upper parts of the Masovian interglacial.

According to the present author, the lower series is – following the results of lithological studies – of fluvioglacial origin and had been deposited in a subglacial furrow. It is evidenced by uneven longitudinal profile of the valley bottom: the base of the headwater stretch should be placed lower (*ca.* 117 m a.s.l.) than the outlet to the principal valley (*ca.* 130 m a.s.l.; see Kwapisz, 1992). Only the upper series was indeed deposited during the Masovian interglacial time, forming a typical fluvial series. Taking into account the lack of unequivocal pieces of evidence, however, the age of this landform has been accepted following the idea of Mądry (1997), the author of the DGMP Cmolas sheet.

The morainic plateaus and foothill areas are covered by not so thick Quaternary sediments. The "Gdów Bay" area is overlain by loess-like loams of variable thickness, usually not exceeding 5 m. Exposures of older strata are present as well, developed either in the Bogucice sandstone or clayey-silty facies with intercalations of bentonites (Fig. 13; Burtan, 1954). In the Raba and Dunajec river valleys' interfluve, upon monadnock hills built up of sandy Miocene strata, the Quaternary cover is up to 5 m thick.

The typical morainic Tarnów and Kolbuszowa Plateaus are usually capped by a relatively thin layer of tills and glaciofluvial (kame) sands, except for the Czarna stream area (Fig. 13), where tills are more than 20 m thick. The sediments composing kame hills north of Brzesko-Okocim exceed at places 10 m in thickness (Fig. 6).

In those plateau areas where the substratum is composed of clayey sediments, it is sometimes difficult to discriminate between tills and weathered clays. The average thickness of till layers is usually a few metres, rarely attaining 15 m. Such increased thicknesses have been encountered at the Wola Rzędzińska brickyard, where the top of sedimentary log is composed of brown-grey, sandy, and strongly calcareous tills (Fig. 9). The tills are underlain by a few metres thick layer of clayey, grey, calcareous till that bears isolated clasts of Scandinavian-derived granitoids and even boulders, up to 0.5 m in diameter. Such sediments have been described in archival records as "reworked Miocene deposits". Similarly developed sediments have been drilled at a plateau near Jastrząbka Stara, Pogórz, and Machowa, close to the Carpathian margin (Fig. 9, 10; Brud, 1997b). In well-log descriptions one can also find traces of "sub-till silts" or "fines", probably representing ice-dammed lake sediments. These observations point to a strong glacial scouring of the bedrock, and indicate incorporation of Miocene sediments into the tills. A well-mapped area of the occurrence of such sediments extends between headwaters of the Breń and Czarna streams (Fig. 13).

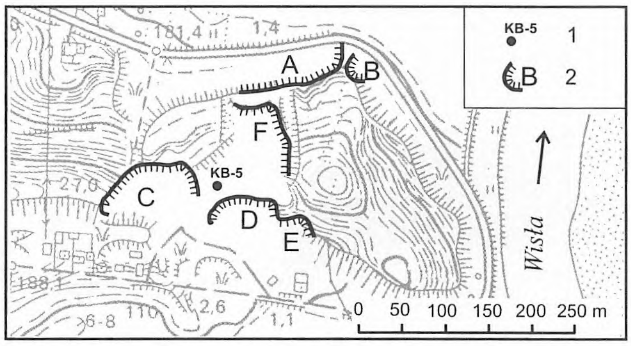

Fig. 14. Location of the sites and cartographic borehole at the Witów exposure. *1* – location of the cartographic borehole KB-5, *2* – present course of escarpment at the Witów outcrop. Letters denote successive sites

POSITION OF THE WITÓW SERIES IN THE LIGHT OF NEW DATA

The sandy-gravel sediments described by Łyczewska (1948) as the "Witów Series" are exposed at the interfluve of the Vistula and Szreniawa rivers, between Nowe Brzesko on the west and Witów on the east (Fig. 2, 6). These are poorly cemented sandstones, sands, gravels, and silts which cap Miocene clays and are overlain by differentiated Quaternary sediments. The hitherto-conducted studies have resulted in contrasting opinions about the age and origin of this series, starting from a concept of marine Miocene strata (Łyczewska, 1948; Kucia-Lubelska, 1966; Tyczyńska, 1978), through the Eopleistocene (Dżułyński *et al.*, 1968; Rutkowski, 1987a, b, 1995b; Nawrocki & Wójcik, 1988; Radzki *et al.*, 1993; Zuchiewicz, 1995a), Narevian (Lindner & Siennicka-Chmielewska, 1995, 1998; Lindner & Nowakowski, 1996), and South-Polish (Sanian) glacial stages (Gradziński & Unrug, 1959), up to the Masovian interglacial times (Drzewicka-Kozłowska, 1963). These strongly differentiated views have motivated the author to a new exploration of the classical Witów exposure that has resulted in findings of abundant macrofloristic remains (Brud & Worobiec, 2003). An analysis of the latter enable one to contradict the previous opinions.

GEOLOGICAL SETTING

Detailed studies have focused on the Witów exposures only, labelled as: Witów A, B, C, D, E, and F (Fig. 14).They are situated on a spur undermined by the Vistula and Szreniawa rivers. Artificial exposures make it possible to examine best the sand-gravel series and overlying loesses at the site Witów C. In the 1980s, the KB-5 borehole was drilled (Radzki *et al.*, 1992) during preparation of the DGMP Borzęcin sheet, enabling for a reconstruction of the Witów Series log (Fig. 15).

In 2001, close to this borehole the basal part of Witów D log became exposed, together with the entire near-surface part of the Witów Series. There occurred horizontally-laminated silty sands and silts bearing plant detritus and charcoal remains (Fig. 15). The exposed series was dissected by a few metres wide channels filled by sands. There also occurred small lenses of coarse-clastic material, including gravels, a few metres thick. Within poorly-lithified sandstone beds, numerous intercalations of plant detritus and macrofloristic remains have been found. The sedimentary log continues up to the exposure Witów C, where, at the base, silts with macrofloristic remains occur as well. The lower part of the log includes a more than 2 m-thick layer of poorly lithified sandstone bearing infrequent clay balls of grey, clayey shales, and isolated pebbles. The sandy material contains abundant detritus of crushed, indeterminable, thin-shelled calcareous fauna, most probably small molluscs. From among larger fragments, the *Lemintina arenaria* (Linnaeus), and *Gyrineum (Aspa) marginatum* (Martini) gastropods have been identified. The layer in question displays as well small-scale erosional scours and amalgamated surfaces. The amount of silts with plant detritus and macrofloristic remains increases up the section.

The sand-silty series is dissected by an erosional scour filled by coarse-clastic gravels which bear two specimens of gastropods, represented by corroded shells of Clavatula sp. and Turritella sp. A subsequent sandy-gravel complex, 5 to 8 m-thick, is separated from the two previous complexes by a distinct erosional surface, and shows cross stratification at the bottom and subhorizontal stratification at the top. The uppermost complex exposed at this site is represented by another gravel-sandy series with numerous erosional scours and lenses of coarse-clastic gravels, clearly dominating over sands. There also occur infrequent intercalations of silts and clays that bear macrofloristic remains.

At the top of the gravel series at Witów A and C exposures, there occur bluish silts with sandy intercalations, resembling rhythmites. At the Witów C exposure, they are now not exposed. Typical glaciofluvial gravels of the Sanian-2 glacial stage, up to 1.5 m thick, are only exposed at Witów A and F sites. They contain numerous gravels of rocks of Scandinavian provenance, pointing to a glacial origin of the deposit, as has been confirmed as well by petrographic analyses made by Rutkowski (1987b). These sediments are locally overlain by a till bed and ice-dammed silts (Figs 6, 15). In the main Witów C exposure, these sediments are not preserved; immediately upon sands and gravels of the Witów Series and lacustrine silts, there occur greenish loess-like silts of the subaqueous-loess type, bearing abundant malacofauna with, *i.a.*, *Pupilla muscorum*. The origin of these silts should be related to the Pleni-Vistulian. Higher up the section, there come typical massive loesses with *Vallonia pulchella*, *Vallonia costata*, and *Perforatella vicina*,

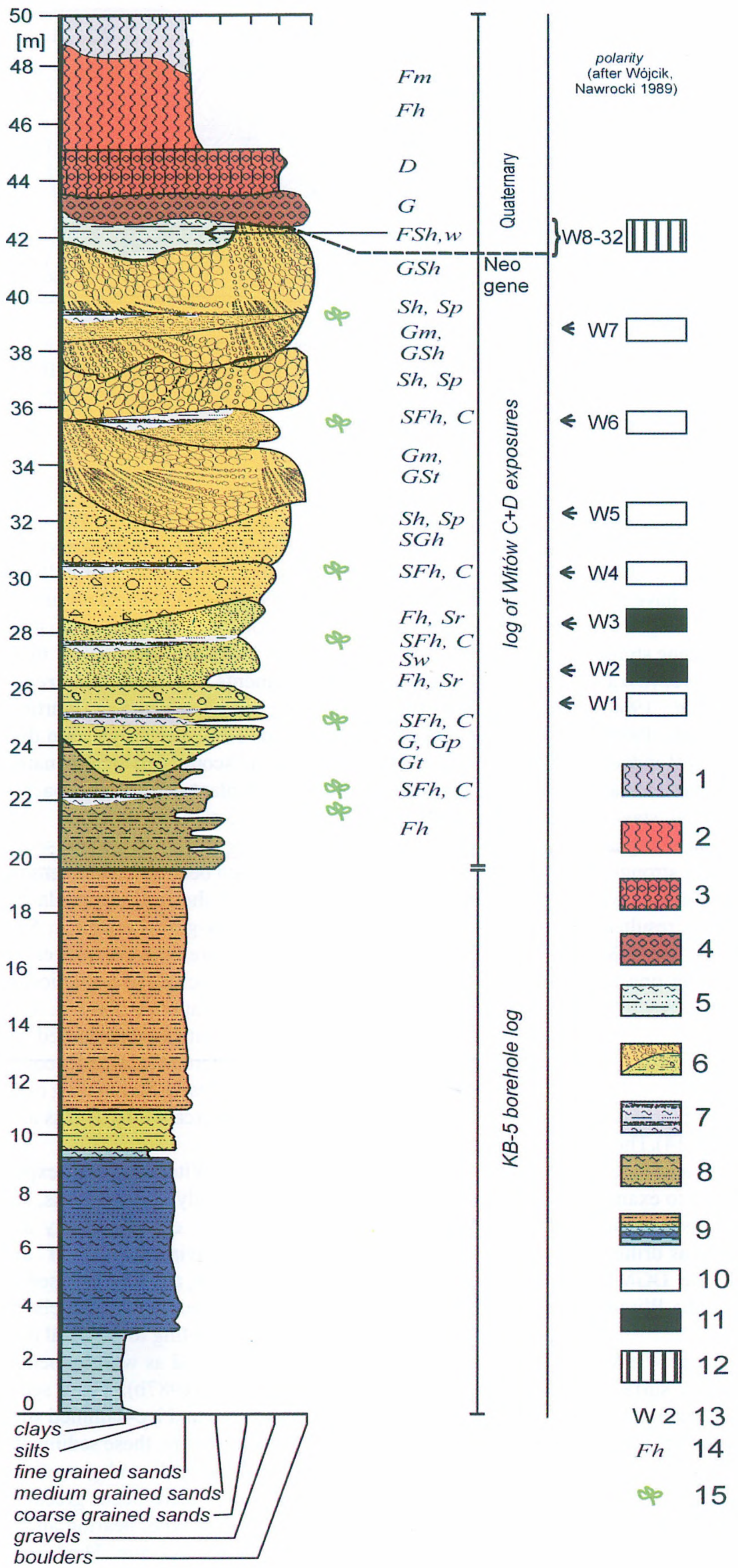

Fig. 15. Synthetic log of the Witów Series compiled from sections of the Witów exposures and borehole KB-5. *1* – archaeological layer, *2* – loess, *3* – tills, *4* – fluvioglacial gravels, *5* – sandy silts, *6* – fluvial gravels and sands, *7* – silts and clays with plant remains, *8* – sandy silts with plant debris, *9* – silts, clays, silty sands, *10* – reverse polarity, *11* – normal polarity, *12* – mixed polarity, *13* – sampling sites, *14* – symbols of lithofacies (see Table 3), *15* – plant macroremains

pointing to either Vistulian or Holocene times. The topmost brown and black-greyish cultural horizons are of Holocene age. These include numerous bones of both domestic and wild animals, such as: cows, horses, goats, and boars. The human settlement in this area has been proceeding for a long time: since the younger Stone Age, through the Bronze Age, up to the Roman period (Marciniak, 1963). Traces of human activity are very important due to a possibility of contamination of older sediments by the younger ones, that can lead to erroneous age estimations.

PETROGRAPHIC COMPOSITION OF WITÓW GRAVELS

The petrographic composition of gravels in the Witów Series shows predominance of Carpathian-derived sandstones, whose amount increases towards the larger fractions. These sandstones originated from the most resistant lithological flysch members; *i.e.*, the Lgota and Godula beds, and – less frequently – Grodziszcze beds of the Silesian Nappe (*cf.* Dżułyński *et al.*, 1968; Rutkowski, 1987b). These gravels are very well rounded and usually ellipsoidal in shape. Examples of exfoliation weathering and Fe-Mn coatings of black-brownish colour are quite common. A characteristic feature of the Witów Series is the lack of Jurassic and Cretaceous flintstones coming from the Małopolska Upland. However, gravels of crystalline rocks are relatively common. These have originally been interpreted as derived from glacial erratics (Gradziński & Unrug, 1959), then as Carpathian flysch-derived exotic rocks (Kucia-Lubelska, 1966; Dżułyński *et al.*, 1968, 1974; Lindner & Nowakowski, 1996). Apart from red granitoids (Dżułyński *et al.*, 1968; Lindner & Nowakowski, 1996), mostly composed of quartz, potassium feldspars, plagioclases, biotite and chlorite, other magmatic rocks can also be found, including: grey granitoids, medium- to coarse-grained biotitic gneisses, porphyries, and melaphyres. All these rock types have been derived from the Carpathians and represent exotic rocks originating, probably, from the Istebna beds (Kucia-Lubelska, 1966). A conglomeratic clast found at Witów C contains rounded fragments of Carpathian flysch sandstones, quartz, and red granitoids. Therefore, the crystalline material must have been repeatedly recycled in the Carpathian flysch basin, from which it has finally been supplied to the Witów Series.

In addition to crystalline rocks, there also occur lidytes, grey organodetritic limestones with recrystallised faunistic remains similar to those of the Cracow region, pelitic limestones of the Štramberk-type, as well as banded Mikuszowice flintstones, and brown menilitic cherts. A conspicuous component are pink or pinkish-purple quartzitic sandstones (two specimens only) that are macroscopically similar to both the Werfenian (Seis) quartzites from the Tatras, and Scandinavian-derived rocks (Jotnian sandstones), as well as Cambrian and/or Devonian quartzites derived from the Holy Cross Mts. Infrequent specimens of Lithotamnium limestones bearing indeterminable small molluscs should also be mentioned.

The author's opinion is that the entire gravel-size material was derived from the flysch Carpathians, being enriched in a small admixture of Miocene rocks (Lithotamnium limestones, mollusc shells, clay balls) derived from the southern margin of the Carpathian Foredeep. No traces of flints, Jurassic limestones, or quartzites derived from the northern margin of the foredeep have been found. Diagrams portraying petrographic composition of the gravel fraction (*cf.* Brud, 2002) show a close resemblance to those of the Sośnicowice Pliocene gravels (see Smoleńska, 1975; in Rutkowski, 1995b).

Table 3

Symbols of lithofacies used in this study (according to Zieliński, 1995, 1998)

SYMBOL	GRAIN SIZE	STRUCTURE
Gm	gravels	massive structure
Gt	gravels	trough cross-stratification
Gp	gravels	planar cross-stratification
GSh	gravelly sands	horizontal stratification
GSt	gravelly sands	trough cross-stratification
SGh	sandy gravels	horizontal stratification
Sp	sands	planar cross-stratification
Sh	sands	horizontal stratification
Sr	sands	ripple cross-lamination
Sw	sands	wavelamination
SFh	silty sands	horizontal stratification
Fm	silts or clays	massive structure
Fh	silts or clays	horizontal lamination
Fv	silts or clays	varved
C	carbonaceous detritus	horizontal stratification
D	diamicton	massive structure

LITHOFACIES AND SEDIMENTARY ENVIRONMENT

The Witów Series shows a great lateral and vertical variability. The existing exposures provide evidence for the presence of a whole spectrum of depositional environments of variable energy: from those devoid of flow to supracritical flow ones (*cf.* Fig. 15 and Table 3).

Clays and horizontally, lense-like and wavy laminated silts, representing a lithofacies of a flat bottom, suspended load depositional-type, occur mainly at the base of the Witów Series. Higher up the section, such sediments form only thin lenses within coarse-clastic sediments. Facies associated with the lower flow regime (the subcritical one) are exposed best at Witów F. Small furrows filled by gravel-sandy material are here overlain by sands showing wavy and lense-like lamination. There also occur ripplemarks, usually of the B-type, which are underlined by thin laminae of plant detritus upon lee-side slopes. At the Witów C exposure, a very well visible transverse bar showing tabular and wedge-like cross-lamination occurs, showing a characteristic increase in gravel material deposited at its margins. This structure is underlain by an erosional scour filled by cross-bedded gravels and sands, and pointing to high energy of the palaeoflow. The gravel diameters attain here 0.7 m (Łyczewska, 1948). The author has found in this zone gravel lags composed of boulders up to 0.5 m in diameter. Very rapid palaeoflow is testified to by sediments observed at Witów B: there occur horizontally laminated sands with gravels, deposited from a near-bottom part of the suspended load.

According to the author, such lithofacies assemblage is characteristic of a braided river entering a fan-delta shed into the retreating marine Miocene basin. A general tendency towards coarsening-upwards, similarly as in the top part of the Krakowiec Clays near Tarnobrzeg, can be seen, testifying to shallowing of the marine basin (Mycielska-Dowgiałło, 1978). A sequence of sediments showing a normal grain-size gradation, pierced by the KB-5 borehole, represents accretion of the delta front upon prodeltaic sediments. The channels, already observed at Witów D, are filled by sands and – higher-up – gravels, and probably represent distributary channels. The gravel-dominated series represents, in turn, high-energetic braided river environment. The river was flowing from the Carpathians, accumulating Carpathian-derived material alongside with that scoured from the Miocene strata of the foredeep (clay balls, fauna, plant detritus). Therefore, mature and resistant gravel material must have originated from a relatively far transport on the order of a few tens of kilometres, whereas poorly-resistant material was derived from the immediate surroundings of the series.

MACROSCOPIC PLANT REMAINS OF THE WITÓW SERIES

During exploration of successive exposures of the Witów Series, numerous plant remains have been found, in addition to indeterminable detritus that was already mentioned by Dżułyński *et al.* (1968). All the available exposures bear silts and poorly-lithified sandstones with plant detritus, leaves, shoots, branches, fruits, cones, and bark fragments. The most frequent are leaves. It should be underlined that the above-mentioned inventory has been identified throughout the exposed log of the Witów Series; from its bottom (Witów D) to the top (Witów C; Fig. 15). One should also take notice of the fact that fossil leaves are always coeval with the host sediment, since they cannot survive redeposition.

In the analysed part of the Witów Series, macroscopic remains of conifers and angiosperm (Brud & Worobiec, 2003) plants have been found. From among determined specimens, a very important one is *Zelkova zelkovifolia* (Unger) BůŹek et Kotlaba from the Ulmaceae family. Another important taxon is *Pinus* cf. *palaeostrobus* (Ettingshausen) Heer, from the *Haploxylon* Koehne sub-genus. The preserved imprints of shoots, bearing fascicles joining five, up to 10 cm long needles, show a close resemblance to the recent *Pinus strobus* L., *i.e.*, eastern white pine, known from the North American continent. This species is also similar to that described from Pliocene strata, *i.e.*, the Rumelian pine (Brud & Worobiec, 2003).

Apart from leaves, the series contains as well remains of cones of coniferous trees, and a nut which is very similar to *Juglans regia* L., *i.e.*, walnut tree. The most exotic species found in Witów is *Spirematospermum wetzleri* (Heer) Chandler, an extinct plant belonging to the Zingibiraceae family (Ginger Family).

The state of preservation of many of the specimens excludes a possibility of their determination up to the species level, although the inventory of determined genera enables one to conclude about the character of vegetation existing during the deposition of the Witów Series. A few specimens belonging to the *Zelkova* and *Fagus* genera, as well as Juglandaceae family have been determined that points to the presence of mesophile forests growing in temperate or warm temperate climate. The most characteristic feature, however, is the presence of coriaceous, entire margined leaves with stout vein probably belonging to Laurophyllous evergreen plants. It is worth to note that such specimens have been found in the uppermost part of the Witów C log.

From among plant remains found in the Witów Series, apart from *Spirematospermum wetzleri*, no taxa typical of mire vegetation have been encountered. The *Juglans* and *Populus* genera indicate the presence of riparian forests, occupying river banks and their floodplains. On the other hand, the leaves of *Fagus* and *Zelkova* represent communities growing on higher-elevated river terraces or highs rising above the floodplain. The presence of pine remains and leaves of the *Leguminosae* sensu Berger type indicates the presence of small patches of vegetation, preferring more dry habitats, including xerophytic communities. Such a floristic composition testifies to a climate that must have been much more warmer than the present one, showing as well higher precipitation totals (*cf.* Brud & Worobiec, 2003).

AGE IMPLICATIONS

As it has already been mentioned, the Witów Series has been assigned to different time-spans, from the Miocene (Łyczewska, 1948) up to the Masovian interglacial (Drzewicka-Kozłowska, 1963). Trying to supplement macrofloristic studies from the base of Witów D exposure, samples have been collected for both palynological and microfaunistic analyses (Brud, 2002). Foraminifers have not been found, and recycled calcareous nannoplankton points to an Eocene age. The palynofacies, however, is dominated by terrestrial elements. Infrequent, although well-preserved dinocysts represent Palaeogene forms. Łyczewska (1948) and Gradziński & Unrug (1959) found Miocene microfauna and considered it to be redeposited. Palynological determinations documented the presence of Tertiary taxa (Sobolewska, 1963; Oszast, in Dżułyński *et al.*, 1968), alongside with infrequent Quaternary ones. The Tertiary pollen were interpreted as redeposited from older strata, the key sample being represented by a lump of clay embedded inbetween sands bearing small charcoals. The pollen spectrum of this sample pointed to a cold and forest-less period, typical for the Early Quaternary (Dżułyński *et al.*, 1968). According to the author, two options can be considered: either the analysed clays had recorded a colder episode during the Pliocene (*cf.* Stuchlik, 1980), or older sediments became contaminated by the younger ones.

The preserved plant remains, such as fruits of *Juglans* genus or leaves of *Zelkova* genus, are only known from Neogene strata, and have not been found in Quaternary sediments in Poland. *Spirematospermum wetzleri* used to occur in Europe between the Eocene and Pliocene. This plant is considered a palaeotropical element within Tertiary floras of Europe, and its present-day counterparts occupy habitats located upon banks of water reservoirs in Indochina. The *Fagus* and *Populus* genera have been described from both Tertiary and Quaternary strata (Brud & Worobiec, 2003).

The above-presented arguments do not solve the problem of dating of the Witów Series. According to the author, the Narevian age (suggested by Lindner & Siennicka, 1994; Lindner & Siennicka-Chmielewska, 1995, 1998; Lindner & Nowakowski, 1996) should certainly be rejected. The results of palaeomagnetic determinations, relating the Witów Series to a time-span between the Jaramillo event and Brunhes/Matuyama boundary (Nawrocki & Wójcik, 1989), should also be reinterpreted.

Basing on taxonomic composition and the state of preservation of macroflora which excludes redeposition, one can conclude about a Late Miocene–Pliocene age of the series (Brud, 2002; Brud & Worobiec, 2003). However, lithofacies analysis of deposits of a braided river encroaching upon a fan-delta related to a retreating marine basin at Witów, can narrow the age of that part of the Witów series to the Late Sarmatian–Meotian.

LOWER QUATERNARY GRAVEL-SANDY SEDIMENTS AT THE CARPATHIAN MARGIN

BRZESKO-OKOCIM AREA

East of Brzesko-Okocim, there occurs a narrow strip of hills orientated SW–NE, showing planated culminations at 241–243 m a.s.l., and rising some 35 m above the present-day Uszwica river bed. These hills represent monadnocks built up of sands with gravels and armoured clay-balls, sandstones, and clays of the Chodenice and Grabowiec beds (Figs 3, 4) The Miocene strata are unconformably overlain by relict gravel series, called sometimes "the mixed-gravel series" (Skoczylas-Ciszewska, 1954; Klimaszewski, 1961).

Basing on analyses performed at four exposures near Żabia Góra and Jadowniki near Brzesko-Okocim, one can conclude that the overlying gravel-sandy sediments have been deposited during the Quaternary, their top being reworked under periglacial conditions. The base of these gravels is an erosional one. The gravels are massive or show poorly marked horizontal or cross-lamination. Even the stratified gravels do show very poor sorting measures (σ_I – 2.85–3.94; Sk_I – 0.18–0.23; K_G – 0.76–0.81). The maximum gravel diameter is 20 cm. There occur both well-rounded and angular clasts, composed of very resistant rocks and soft Carpathian shales. The transport route must have been very short.

The petrographic composition of gravels occurring in Tertiary sands that build a strath points to two alimentary areas of the clastic material: the main body of gravels is composed of very poorly-rounded and angular clasts of poorly-cemented Carpathian flysch sandstones; whereas very well rounded, resistant clasts of quartz, lidyte, and Menilitic cherts derived from a more distant source form a subsidiary group. Moreover, there also occur gaizes and opokas, represented by noncalcareous, porous, light-brown clasts of decalcified opokas that intercalate the Menilite-type cherts. Carbonates are absent from the series. Gravels are poorly rounded; subrounded sandstone clasts do predominate, whereas quartz grains are well rounded.

Quaternary gravels show a marked enrichment in resistant material. A characteristic feature is the presence of dark manganese coatings and traces of chemical weathering in the form of dissolution of less resistant parts of the rocks. Apart from the dominating Carpathian flysch sandstones, there occur quartz grains which are more numerous, as compared to the Tertiary sands. Lidytes and opokas constitute a minor admixture. Moreover, one can also find silicified rocks, fragments of ferrugineous coatings, quartzites, and leucocratic granites, similar to those of the Tatras. Neither Scandinavian, nor Małopolska Upland-derived material has been found.

A study of the degree of roundness and frosting of quartz grain surfaces show differentiated textural types. The highest share is occupied by very well rounded grains, typical of beach environment which show traces of chemical weathering consisting in both dissolution and grain coating. A SEM-conducted chemical analysis of these coatings has revealed that both sand grains and sandstone gravel coatings are mainly composed of iron oxides. Only one sample has revealed a minor amount of aluminium oxide. These results are not helpful in reconstruction of climatic conditions, neither in age estimation of the coatings. There also occur angular grains pointing to a short transport from weathered sandstone strata. All the analysed samples contain a relatively large amount (*ca.* 20%) of fractured grains that can indicate either periglacial processes or very intensive flow conditions.

Comparative analyses of gravels occurring upon slopes of the discussed monadnocks undoubtedly testify to their fluvioglacial origin. There occur Scandinavian-derived red, weathered granitoids, flintstones coming from the Małopolska Upland, Tatra-derived Werfenian quartzites, as well as Cambrian quartzites supplied from the Holy Cross Mts. Poorly rounded, weathered, and weakly-cemented Carpathian flysch sandstones are present as well.

The Lower Quaternary gravels in all analysed exposures rest upon erosional surfaces, and their sedimentary structures and grain-size of the material indicate the upper subcritical flow conditions. Moreover, poor sorting and roundness measures, together with the presence of clasts showing weak resistance to mechanical corrosion, indicate a short transport route. The material must have been derived from at least two source areas. Very well rounded quartz and lidyte grains were probably transported from a more distant source, whereas the sandstone clasts were of local origin. The petrographic composition indicates that these sediments are pre-glacial ones, and associated with a geomorphic level of 240–250 m a.s.l. (Fig. 2, 8) The origin of this series could have, then, be related to local rivers associated with the Błonie gravel horizon (260 m a.s.l.), or with fluvial gravels that build the Dunajec river 40–65 m-high terrace, distinguished here by Kozikowski (1963). Advanced chemical weathering, including both dissolution and mineral coating formation, points to a prolonged period of weathering. Perhaps, these are traces of degraded weathering covers of Pliocene age, presently occurring in the Roztocze area only, on the northern margin of the Carpathian Foredeep (Maruszczak, 1996, 2001). The sediments in question could have represent a relict preglacial cover that has survived upon monadnocks, like in Scandinavia (Migoń, 1996).

THE BŁONIE LEVEL GRAVEL SERIES

The coarse-clastic sediments occurring upon the interfluve between the Dunajec and Biała river valleys near Tarnów (Fig. 2) build two main geomorphic levels. Close to Błonie and Zgłobice, a gravel series occurs, rising at 250–265 m a.s.l., *i.e.*, >70 m above the Dunajec river bed (Figs 2, 8), and forming the Błonie gravel horizon (Klimaszewski, 1961). The gravels mantle an erosional surface cut into the Miocene clays, and their thickness does not exceed 5–6 m. Gravels exposed at a stretch nearly 150-m-long near Błonie and up to 3 m thick, cap a flat surface cutting the Miocene strata which slopes at *ca.* 5° towards the NE. The second, lower gravel horizon of Zbylitowska Góra, occurring at some 230 m a.s.l. (40 m above the Dunajec river bed; Fig. 2, 8), appears to have been associated with the activity of fluvioglacial waters during the anaglacial phase of the Sanian-2 glaciation (Klimaszewski, 1961, 1967; Dżułyński *et al.*, 1968).

The gravels exposed at Błonie at *ca.* 250 m a.s.l. cap sandy-clayey Badenian sediments (Brud, 2002). These are sandy gravels bearing boulders up to 15 cm in diameter, including as well lenses of vari-grained sands. Thicker sand intercalations, up to a dozen or so metres long and 20–30 cm thick, usually display low-angle cross-stratification. The sands are well sorted (σ_1 – 0.74), as compared to poorly-sorted gravels (σ_1 – 2.76). The gravels show imbrication, are indistinctly horizontally stratified, and very well rounded. Measurements of cross-stratification indicates a supply from the western sector, *i.e.*, from the present-day Dunajec river valley.

Gravels of the Błonie level do reveal a very characteristic petrographic composition, consisting of a large amount of Lower Triassic (Werfenian) quartzites derived from the Tatric Series, particularly in coarser fractions; whereas white, leucocratic Tatra granites increase their share within finer fractions, what can be a result of their disintegration. The Scandinavia- and Małopolska Upland-derived material is lacking, whereas lidytes, Menilite cherts, and decalcified Carpathian gaizes constitute a minor admixture (up to a few per cent). Similar results have been obtained by Klimek (1991) who, however, noted a much more higher amount of the Tatra-derived quartzites within coarser fractions; as confirmed by analyses performed at Zbylitowska Góra and Błonie by Magiera & Sokołowski (1987) and Sokołowski (1997).

The occurrence of lithofacies assemblages dominated by GS, GSm, GSt, and Sl facies points to the upper flow regime of a braided river, bearing gravel lags of the gravel-sandy bar-type. The palaeodirections of supply of the material link their deposition with the Dunajec valley, although the share of the Biała river cannot be excluded in the formation of the Błonie horizon, as indicated by the presence of banded Menilite cherts, typical for rivers of the eastern part of the Carpathians, starting from the Biała Dunajcowa river (Magiera & Sokołowski, 1987). According to Klimek (1981), the Dunajec and Biała river's interfluve used to be a proximal part of the alluvial fan deposited by a braided (pre-Dunajec) river at the Carpathian margin.

Textural properties of the sandy facies point to a short reworking of the material supplied from the Tertiary weathering covers, as angular grains do predominate here. Fractured clasts are abundant, pointing to severe climatic conditions and a transport by a high-energetic river where larger clasts are destroyed due to collisions of grains transported by saltation and traction. Such conditions must have been provided by a braided river active during a glacial stage.

The Błonie gravel horizon (Klimaszewski, 1967) used to be assigned – basing on an admixture of Scandinavian-derived material – to the Sanian-2 recessional phase. A similar (up to a few per cent) admixture of glacial material at the top of the series is also quoted by Sokołowski (1997), who suggested that the fluvioglacial washing did not reach the basal part of the series, originated before the Sanian-2 stage (Magiera & Sokołowski, 1987). The Błonie localities, exposing the gravel series overlying the Miocene strata, must have, then, represent older sediments which had not been washed-out by fluvioglacial waters.

In a broader context, the stratigraphic position of this horizon, as compared to a pattern of terraces of the Nowy Sącz segment of the Dunajec river valley (Zuchiewicz, 1984b, 1995b, 1998), is linked with either the Narevian or Nidanian glacial stages (Klimek, 1991). The Łazy Brzyńskie site (Zuchiewicz, 1991; Rutkowski & Zuchiewicz, 1992) description leads the author to accept a view of an older than Sanian-2 age of this series.

COARSE-CLASTIC SEDIMENTS OF THE SUB-CARPATHIAN FURROW

Sediments infilling the sub-Carpathian Furrow are exposed at the surface in the Tarnów-Gumniska area only, as well as south of Dębica. SE of Tarnów, a right-hand tributary of the Biała river, the Wątok stream, dissects the Carpathian margin, reaching up to the Miocene strata (Figs 9, 12). The erosion has reached here down to the basal sediments which infill the incipient stretch of the sub-Carpathian Furrow. Preglacial gravels are overlain by a thin layer of wash-out sediments and occur at a level of 220 m a.s.l. (Fig. 12). These sediments are exposed at artificial and episodic exposures only. The exposed coarse-clastic sediments attain some 3 m in thickness, whereas their maximal clast diameter does not exceed 20 cm. Their petrographic composition clearly reflects that of the Dunajec alluvia, including a large share of the Tatra-derived material. Strongly calcareous sands of the substratum are clearly disturbed and tilted northwards at ca. 30°, containing – apart from crushed fragments of thin-shelled fauna – specimens of the *Heterostegina costata* foraminifer, which suggests an Early Badenian age (Skawina beds; Fig.3).

The gravel-sandy series extends north-eastwards, following the trend of the sub-Carpathian Furrow (Fig. 8). When elaborating the DGMP sheet Wola Rzędzińska, two cartographic boreholes have been drilled through Quaternary sediments of the sub-Carpathian Furrow, and are labelled as Pogórska Wola K1, and Ładna K3 (Brud, 1997a, b; Figs 9, 10, 12).

The Ładna K-3 borehole log shows a preglacial sandy-gravel series occurring at depths of 20.5–30.6 m (Figs 9, 12). The Miocene strata are overlain by 3.5 m-thick gravels, passing into coarse-grained sands at the bottom and fine-grained sands at the top. This series probably represents a fluvial cycle. Morphoscopic parameters of quartz grains and the degree of their roundness do not differ much from the overlying fluvioglacial sands; the composition of heavy minerals also fits to the spectrum typical for glacial sediments proper (Brud, 1997b). A characteristic feature is the lack of Scandinavian-derived material; whereas flysch Carpathian sandstones and the Tatra-derived rocks (light granites, quartzites) are quite frequent.

A very similar composition is shown by gravels drilled at Pogórska Wola (borehole K-1; Fig.10), on the southern margin of the sub-Carpathian Furrow. The sandy series is there 8 m thick and it is developed in the form of a sedimentary cycle beginning with coarse-grained sands with gravels at the bottom, to fine-grained sands, overlain by clayey silts at the top (Brud, 1997b). The gravel-sandy material of the sub-Carpathian Furrow is covered by tills and glaciofluvial sands with gravels of the Sanian-2 glacial stage. In all archival logs coming from this area, one can take notice of a bipartition of the sub-till series (Fig. 12). At the base, there occur coarse-clastic sediments which I relate to the "preglacial', intepreted as the Cromerian interglacial *s.l.* The sand-dominated sediments, like the above Pogórska Wola K3 ones, should be linked to the anaglacial phase of the Sanian-2 glacial stage. A comparison of petrographic composition of gravels occurring above tills of the Tarnów Plateau, points to their entirely different glacial "petrographic province", represented by the Machowa, Krzyż, Żabia Góra near Brzesko, or gravels infilling the Dąbrowa Tarnowska–Potok–Czarna furrow (Fig 8, 10, 11).

The Tatra-type material (granites, Werfenian quartzites) transported by the Dunajec river into the Sandomierz Basin underwent repeated recycling and occurs far to the east of the present-day Dunajec river valley (Laskowska-Wysoczańska, 1971, 1979, 1987; Szajn, 1993). In early Quaternary times, the Tarnów-Gumniska region was the area where the ancient Dunajec river did transport its material towards the Wisłoka river, and then to the Wisłok.

An exposure of the sub-Carpathian Furrow sediments occurs SW of Dębica, in an active brickyard Wolica (Fig. 8). The two exploitation levels expose clayey Sarmatian sediments (Garecka & Jugowiec, 1999), covered by coarse-clastic Quaternary sediments (Boratyn & Brud, 1996a). The sandy-gravel sediments form a small, oval hill, orientated N–S and up to 6 m tall (232 m a.s.l.). The top part of clayey sediments at the contact with the Quaternary is weathered, colourless, and contains small carbonate concretions. In the NE part, the coarse-clastic sediments immediately mantle the erosionally cut Miocene clays. In a section on the SE wall, under gravel-sandy sediments, there occurs a lense of sandy-clayey sediments. It tapers out towards the east, and its maximal thickness of 2.3 m is attained in the western part of the exposure. These are, predominantly, a few metres-thick sandy silts, horizontally and wavy laminated, bearing thin clayey intercalations. Higher up, there occurs a few metres-thick gravel-sandy series with sand interlayers. The gravels are dominated by horizontal and cross-layering. In the top part, massive structure is sometimes present, resulting probably from periglacial processes, as testified to by pseudomorphoses after ice-wedge casts.

In the petrographic composition of the Wolica gravels, local Carpathian sandstones of the Ropianka Formation dominate. A relatively high is the amount of carbonate rocks (5–17%) of the marly limestones type and marls coming from various members of the Carpathian flysch: fucoid marls, Węgierka marls, and carbonate interlayers within the Ropianka Formation (Boratyn & Brud, 1996b). The share of Tatra-derived quartzite, particularly in coarser fractions, is noticeable. From among magmatic rocks, there occur infrequent Tatra-type leucocratic granites, and red exotic porphyries. The Scandinavia- and Małopolska Upland-derived material is lacking. Textural properties of the sediments testify to their maturity: within heavy minerals there dominate garnets, tourmalines, and zircons, whereas less resistant minerals, like amphiboles are lacking. Micas and chlorites compose, in turn, 25% of the material. The sandy fraction contains 90% of grains of very well rounded quartz grains showing semi-lightening and lightening surfaces. All these properties indicate that the sediment has been laid down by a preglacial river flowing along the Carpathian margin. The palaeocurrent directions, reconstructed on the basis of cross-bedding and clast imbrication generally point to a westerly source. Relatively high elevation of these sediments (230 m a.s.l.) does not correlate with the erosional level of the sub-Carpathian Furrow, neither in the Tarnów Plateau, nor in Ropczyce–Sędziszów area. The proximity to the Carpathian frontal thrust, strong deformations of Miocene strata, and minor tectonic structures observed within Quaternary sediments, interpreted by the author as compressive ones, can testify to neotectonic uplift of the area in front of the Carpathian orogen (Brud, 2002).

RECONSTRUCTION OF RELIEF DEVELOPMENT AND DRAINAGE PATTERN IN THE STUDY AREA AS COMPARED TO THE NEIGHBOURING REGIONS

LATE MIOCENE–PLIOCENE (11.5–2.5 Ma)

In the Late Sarmatian and Early Pannonian (Bessarabian), according to Rögl's (1996; Table 1) stratigraphic subdivision for the Central Paratethys, accepted in this paper, the remnant marine Miocene basin started to retreat towards the east (Fig. 16A). The extent of this basin was limited to the Tarnobrzeg region that was linked with the western Ukrainian basin of the Eastern Paratethys still in Bessarabian times (Paruch-Kulczycka, 1999). This conclusion is confirmed by determination of molluscs from the Źrecz area (east of Tarnobrzeg), wherefrom Bessarabian taxa have been identified (Studencka, 1999). The basin was becoming gradually shallower and fed by clastic material derived originally from the north (Gaździcka, 1994). The last stage of the basin evolution was the encroachment of deltaic sediments (Karnkowski, 1989). Foraminiferal assemblages typical of near-shore and deltaic environments, enrichment in plant detritus, and an increase in the amount of mica flakes within the sediments, all appear to support this hypothesis (Czepiec & Kotarba, 1998). Moreover, as opposed to the lower parts of Neogene strata near Tarnobrzeg, where dinocysts derived from the Polish Lowland do predominate, the upper parts of the Neogene log displays redeposited dinocysts of Palaeogene age, derived from the eroded Carpathians (Gedl, 1999). Studies conducted in the eastern part of the Carpathian Foredeep confirm the occurrence of vast delta-like fans shed from the NW, and point to basin shallowing in Sarmatian times (Dziadzio, 2000). Results of recent studies of calcareous nannoplankton from the youngest sediments infilling the Polish segment of the Carpathian Foredeep (Olszewska, 1999) are compatible with those reported from Romania (Marunteanu 1999). Laskowska-Wysoczańska (1993, 1995), when quoting from unpublished papers by Głazek *et al.* (1986–1990), points to a possibility of marine sedimentation within the foredeep still in the Late Meotian and Early Pontian (NN 10, 11). These statements need, however, to be confirmed.

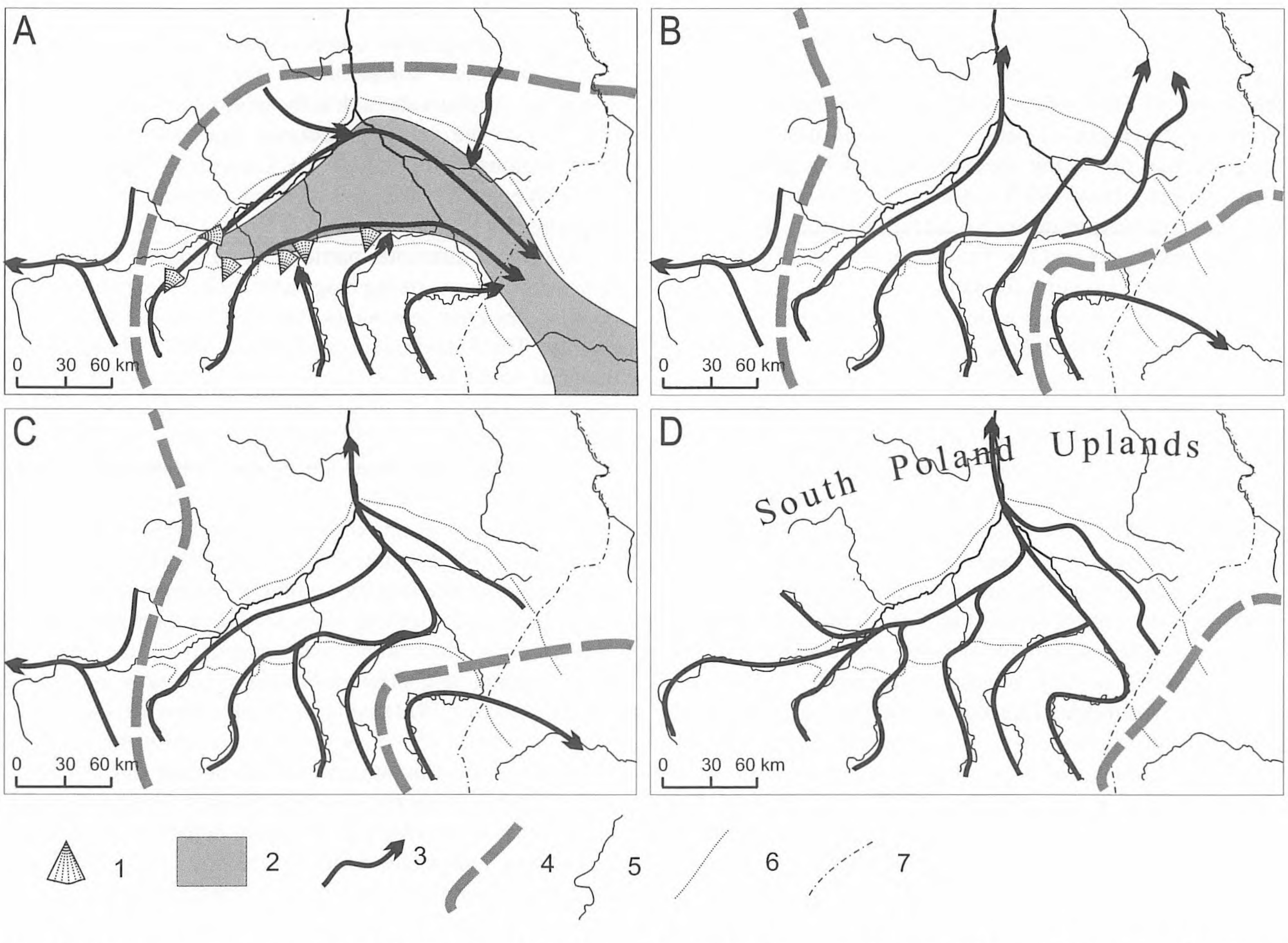

Fig. 16. Drainage pattern changes in the Sandomierz Basin during: **A** – the Late Sarmatian (Meotian), **B** – Late Pliocene and Eopleistocene, **C** – South-Polish Glaciations, **D** – "Great" (Holsteinian) Interglacial (author's reinterpretation of data presented by: Wojtanowicz, 1977/78; Laskowska-Wysoczańska, 1971, 1993, 1995; Szajn, 1993; Kwapisz & Popielski, 1999; and Brzezińska-Wójcik & Kociuba, 2001). *1* – fan-deltas shed into the retreating marine basin, *2* – inferred extent of the marine basin during Late Sarmatian–Pannonian times, *3* – palaeoflow directions, *4* – watershed zones, *5* – contemporary drainage pattern, *6* – boundaries of the Sandomierz Basin, *7* – state boundary

The drainage pattern of the NW margin of the relict marine basin was poorly developed, as shown by a very low amount of Jurassic and Triassic rocks within Miocene strata of the Cracow-Silesian region (Radwański, 1968), or by complete lack of the Małopolska Upland-derived rocks within the Witów Series (Rutkowski, 1987a, b, 1998; Brud, 2002). Buried valleys of the pre-Soła, pre-Vistula (upper reach), and pre-Odra rivers were drained westwards through the Kędzierzyn Graben, whereas the Cracow area represented a watershed region (Lewandowski, 1996). There occur gravel series bearing completely decalcified material, dominated by quartz, cherts, and silicified limestones, alongside with decalcified opokas and Carpathian sandstones (Rutkowski, 1987a).

The Sandomierz Basin was dominated by fluviolacustrine sedimentation within shallow reservoirs supplied by sand-silty sediments which infill channels/depressions cut into clayey sediments (Fig. 8). The relevant examples are palaeofurrows described from the Szczucin and Tarnobrzeg areas. Deposition near Szczucin was proceeding within minor freshwater basins, showing periodical marine ingressions in the Late Miocene (L. Stuchlik; in: Płonczyński, 1997). Palynological pilot determinations and analyses of heavy mineral composition of sediments infilling similar basins near Tarnobrzeg, also indicate a Late Miocene age (Piątkowski, 1973; Drągowski *et al.*, 1979). Erosional dissections in the top of the Krakowiec Clays have also been noted from the northern part of the Tarnobrzeg Plateau, documenting drainage directed towards the Black Sea basin (Fig. 16A; Mycielska-Dowgiałło, 1978).

The Carpathian rivers, at least from the Early Pliocene onwards, show stabilised outflow towards the north (Zuchiewicz, 1987), turning farther towards the east, according to the then originating easterly drainage (Laskowska-Wysoczańska, 1971; Wojtanowicz, 1977–78). The "foothills planation surface" originated in the Carpathians during Late Pliocene times which, in the study area, is preserved in the "Gdów Bay" and near Tarnów–Pilzno (Fig. 8). In the Sandomierz Basin, a planated surface situated at 250 m a.s.l. was formed. According to Różycki (1972), the Vistula river shaped its gorge near Zawichost already in the Late Pliocene (Fig. 16B), whereas the Wieprz river used to flow northwards, carrying Carpathian material towards the Middle-Polish Basin (Brzezińska-Wójcik & Kociuba, 2001; Maruszczak, 2001). Other authors claim that during the Pliocene, another, easterly drainage was predominant, and that the Vistula gorge near Zawichost was formed either in the Tiglian (Wojtanowicz, 1977–78), or Cromerian interglacial (Laskowska-Wysoczańska, 1971), or after the retreat of the Odranian glaciation (Laskowska-Wysoczańska, 1983, 1993, 1995). The presence of Tatra-derived material is an important palaeogeographic indicator. This material appears for the first time within sediments exposed near Mizerna in Podhale region in Pliocene times (Birkenmajer, 1979). The Tatra-derived gravels do not occur in sediments of the northern Sandomierz Basin (Osiek, Połaniec, Huta Komorowska gravels), but can be found in the eastern part (Rakszawa, Kąty Rakszawskie, Brzoza Królewska; Fig. 1). This indicates that the ancient Dunajec was not flowing northwards, but preferred to utilise the Carpathian margin. The pre-Vistula river valley, without its upper reach, was then of minor importance, carrying only the pre-Raba river waters (Fig. 16B).

EOPLEISTOCENE (2.5–0.8 Ma)

During the Eopleistocene, the 240–250 m a.s.l. planated level within the Sandomierz Basin underwent dissection, and today it is represented by isolated monadnock hills near Brzesko-Okocim and flat-topped culminations in the Tarnów and Kolbuszowa Plateaus (Fig. 8). Flat hilltops near Brzesko-Okocim are covered by remnant pre-Pleistocene gravel series, showing traces of prolonged chemical weathering proceeding both in Pliocene, and Eopleistocene interglacial stages. These covers have been preserved despite subsequent advance of the Sanian-2 icesheet. The Dunajec river was supplying Tatra-derived material towards the Sandomierz Basin at a level of *ca.* 250 m a.s.l., then was turning eastwards. The Pliocene–Eopleistocene uplift of the eastern part of the Sandomierz Basin led to changes in the drainage pattern already at the beginning of the Eopleistocene. The pre-Wisłoka and pre-Wisłok rivers became to direct their courses to the NE, depositing gravels with Tatra material near Rakszawa–Brzóza Królewska at a level of 230–245 m a.s.l. (Laskowska-Wysoczańska, 1971, 1993). Then, these rivers dissected the Roztocze Ridge, joining the ancient Wieprz river course (Fig. 16B; Wojtanowicz, 1977–78; Kwa- pisz & Popielski, 1999; Brzezińska-Wójcik & Kociuba, 2001). In the Outer Carpathians, a system of strath and cut-and fill terraces, controlled by both climatic and tectonic factors, did originate (Zuchiewicz, 1984b, 1995b, 1998). The Carpathian segment of the San river directed its waters towards the Dniester river valley (Fig. 16B), marking this flow by terrace covers preserved now at 40 to 70 metres above river beds. In Eopleistocene times, the meandering Dniester river formed a vast alluvial plain, fed by Carpathian-derived material (Maruszczak, 2001). The pattern of the oldest Dniester terraces has not been fully reconstructed and is a matter of debate (*cf.* Rudjuk, 2000; Maruszczak, 2001; Łanczont *et al.*, 2002), what makes correlation with the San river valley terraces impossible and renders age estimation of piracy of the San river by the Vistula river. Data gathered in the Vistula river gorge near Zawichost point to a northerly drainage from the Sandomierz Basin in "preglacial" times, at a level 10–15 m higher than the present one (Pożaryski *et al.*, 1994).

SOUTH-POLISH GLACIATIONS (0.8–0.45 Ma)

Reconstruction of the incipient segment of the sub-Carpathian Furrow in the southern part of the Tarnów Plateau, now buried under glacial sediments of the Sanian-2 stage, has enabled to constrain its age. This furrow could not have been active in the anaglacial part of this glaciation only. An erosional landform, clearly visible on the map of sub-Quaternary surface (Fig. 7), must have originated earlier. The sub-Carpathian Furrow played a leading role in the regional drainage system, both during the Podlasian and Małopolanian interglacials, gathering waters of the ancient Dunajec, Wisłoka, and Wisłok rivers, and carrying them farther along the lower San river valley towards the Zawichost gorge (Fig. 16C). The San river was then the principal river in the Sandomierz Basin, whereas pre-Vistula used to be its minor tributary (Pożaryski *et al.*, 1994). The upper reaches of the pre-Vistula were drained towards the Odra basin (Kotlicka, 1982; Lewandowski & Kaziuk, 1982; Lewandowski, 1993, 1996).

The Sanian-2 icesheet radically changed the drainage pattern. The icesheet encroached upon morphologically diversified surface with a developed valley network. Since the northerly outflow became blocked by ice, the sub-Carpathian Furrow played initially a role of a marginal streamway, carrying waters towards the east. Later, this segment became buried under glacial sediments up to a level of 230–250 m a.s.l. During this glaciation, deep subglacial furrows were cut near Huta Komorowska (Kwapisz & Szajn, 1987; Kwapisz, 1992), and near Ropczyce closed depressions resembling evorsion kettles were shaped. Close to the northern margin of the Kolbuszowa Plateau, the Majdan and Huta Komorowska gravel series were deposited (Szajn, 1993). During recession of the Sanian-2 icesheet, the Tarnów Plateau became dissected by the Dąbrowa Tarnowska–Czarna furrow which marked an outflow of fluvioglacial waters towards the Wisłoka river valley (Fig. 8).

MASOVIAN INTERGLACIAL AND SUBSEQUENT QUATERNARY STAGES (<0.45 Ma)

After the retreat of the Sanian-2 icesheet, another reorganisation of the drainage pattern took place (Fig 16D). A lowering of the erosional base-level and glacioisostatic rebound resulted in strong erosion and formation of deeply-cut river valleys. The Dunajec and Wisłoka rivers became directed immediately northwards, towards the Vistula river valley. Only the Wisłok river, utilising a segment of the old sub-Carpathian Furrow, did flow eastwards towards the San river valley. The deepest incision took place in the Wisłoka river valley which used to flow east of its present-day course. The Vistula river also followed another trace, flowing shortly south of the Tarnobrzeg Plateau. During subsequent evolution of the drainage network, after the retreat of the Odranian icesheet, the upper stretch of the Vistula river became captured from the Oświęcim Basin towards the Sandomierz Basin (Kotlicka, 1982). Later on, intensive erosional and accumulational processes were active within river valleys, whereas plateau areas underwent denudation, leading to the present-day topography of the area.

CONCLUSIONS

1. Basing on sedimentological studies, macro- and microfaunistic and palynological analyses, as well as petrographic research, the Witów Series has been interpreted as a succession of a braided river shed into a retreating marine basin. Petrographic analyses and faunistic studies indicated that the source area for the Witów Series was located in the Outer Carpathians. No traces of material supply from the Małopolska Upland have been found. Age estimations of floristic remains point to the Late Miocene–Pliocene.

2. The topography of the top-Miocene surface is much less diversified as compared to previous studies. The enclosed hypsometric map clearly indicates landforms associated with the present-day morphology, as well as buried landforms, unrelated to the present surface.

3. Flat hilltops rising at 240–250 m a.s.l. represent remnants of a planated surface formed during Late Pliocene–Eopleistocene times. Near Brzesko-Okocim, this surface is overlain by strongly weathered, relict gravel series that was deposited in the Eopleistocene.

4. Fluvial origin of the Błonie gravel horizon has been confirmed. The level was formed during the Narevian and/or Nidanian stages, whereas its top part became washed during the Sanian-2 glaciation.

5. The trace of the buried sub-Carpathian Furrow between Tarnów and Sędziszów Małopolski has been reconstructed. Longitudinal profile of this furrow clearly points to the eastward-directed outflow, whereas petrographic composition of infilling gravels bearing an admixture of the Tatra-derived material, as well as burial under typical glacial sediments indicate that the furrow represents a palaeo-Dunajec river valley, active mainly during the Cromerian *sensu lato* interglacial stage.

Acknowledgements

This paper is an abridged version of the author's Ph.D. thesis, prepared under the supervision of Prof. Dr. Witold Zuchiewicz, whom the author would like sincerely thank for his support, patience, and valuable hints. Heartful thanks are also due to valuable critical remarks offered by Prof. Dr. Elżbieta Mycielska-Dowgiałło and Prof. Dr. Nestor Oszczypko, who have peer-reviewed the manuscript.

I would also like to thank Prof. Dr. W. Bałuk, Prof. Dr. J. Małecki, and Dr. W. P. Alexandrowicz for determination of Tertiary and Quaternary malacofauna; Dr. G. Worobiec for determination of macrofloristic remains; Assoc. Prof. Dr. E. Stworzewicz, Prof. Dr. A. Nadachowski, and Dr. P. Wojtal for their determination of mammal bones and molluscs from the Witów site; Dr. B. Woronko for her analyses of quartz roundness and surface scan-microscopic characteristics; Dr. M. Paszkowski and Dr. M. Kusiak, for analyses of heavy mineral composition; Assoc. Prof. Dr. B. Olszewska for microfaunistic studies, as well as Dr. P. Gedl for dinocyst determinations.

This work was financially supported through a Committee for Scientific Research (KBN) grant no. 6 PO4D 069 19 (to. W. Zuchiewicz).

REFERENCES

Andreyeva-Grigorovich, A. S., Oszczypko, N., Savitskaya, N.A., Ślączka, A. & Trofimovich N.A., 2003. Correlation of the Late Badenian salts of the Wieliczka, Bochnia and Kalush Areas (Polish and Ukrainian Carpathian Foredeep). *Annales Societatis Geologorum Poloniae*, 73, 2: 67–89.

Birkenmajer, K., 1979. Przewodnik geologiczny po pienińskim pasie skałkowym. (In Polish). Wydawnictwa Geologiczne, Warszawa, pp. 3–238.

Bożym-Rogalska, A., 1964. The Sub-Quaternary relief of the Sandomierz Basin. (In Polish, English summary). *Zeszyty Naukowe Uniwersytetu Jagiellońskiego, Prace Geograficzne*, 87, 10: 7–10.

Boratyn, J. & Brud, S., 1996a. *Szczegółowa mapa geologiczna Polski w skali 1:50 000, arkusz Dębica.* (In Polish). Centralne Archiwum Geologiczne, Warszawa.

Boratyn, J. & Brud, S., 1996b. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Dębica.* (In Polish). Centralne Archiwum Geologiczne, Warszawa: 1–45.

Brud, S., 1997a. *Szczegółowa mapa geologiczna Polski w skali 1:50 000, arkusz Wola Rzędzińska.* (In Polish). Centralne Archiwum Geologiczne, Warszawa.

Brud, S., 1997b. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Wola Rzędzińska.* (In Polish). Centralne Archiwum Geologiczne, Warszawa: 1–33.

Brud, S., 2002. *Ewolucja paleogeograficzna zachodniej części Kotliny Sandomierskiej w późnym neogenie i wczesnym czwartorzędzie.* (In Polish). Unpublished Ph.D. thesis, Institute of Geological Sciences, Jagiellonian University, Kraków, 97 ms. pp.

Brud, S. & Mamakowa, K., 2001. Late Glacial–Holocene evolution of the Wątok valley stream in Tarnów Gumniska site, South Poland. *Studia Geomorphologica Carpatho-Balcanica*, 25: 81–88.

Brud, S. & Worobiec G., 2003. Results of investigations on plant macroremains found in deposits of the Witów Series (South Poland). (In Polish, English summary). *Przegląd Geologiczny*, 51, 5: 392–401.

Brzezińska-Wójcik, T. & Kociuba, W., 2001. Transformation of the Roztocze segment of the Wieprz River Valley (SE Polad) in the Pleistocene. (In Polish, English summary). *Przegląd Geologiczny*, 49 (3): 257–266.

Burtan, J., 1954. *Szczegółowa mapa geologiczna Polski w skali 1:50 000, arkusz Wieliczka.* (In Polish). Wydawnictwa Geologiczne, Warszawa.

Czepiec, I. & Kotarba, M. J., 1998. Palaeoecology and organic matter in the Late Badenian and Early Sarmatian marine basin of the Polish part of the Carpathian Foredeep. *Przegląd Geologiczny*, 46 (8/2): 732–736.

Doktor, M., 1977. Sandy gravels of Miocene age from Łęki Górne. (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 47: 419–449.

Doktor, M., 1983. Sedimentation of Miocene gravel deposits in the Carpathian Foredeep. (In Polish, English summary). *Studia Geologica Polonica*, 78: 6–107.

Doktor, M., 1987. Mioceńskie żwiry w rejonie Gdowa. (In Polish). In: Rutkowski J. (ed.), *Trzecio- i staroczwartorzędowe żwiry Kotliny Sandomierskiej. Materiały Sympozjum Komisji Badań Czwartorzędu Polskiej Akademii Nauk.* Kraków 22-24 czerwca, Akademia Górniczo-Hutnicza, Kraków: 26–29.

Drągowski, A., Kaczyński, R. & Pinińska, J., 1979. The influence of erosional furrow on the conditions of sulphur mining in the Tarnobrzeg area. (In Polish, English summary). *Przegląd Geologiczny*, 28 (3): 164–171.

Drzewicka-Kozłowska, I., 1963. Uwagi wstępne dotyczące geologii i morfologii okolic stanowiska archeologicznego w Witowie, pow. Kazimierza Wlk. (In Polish). *Sprawozdania z Posiedzeń Komisji Oddziału Polskiej Akademii Nauk w Krakowie*: 377–384.

Dziadzio, P., 2000. Depositional sequences in Badenian and Sarmatian deposits in the SE parts of the Carpathian Foredeep (SE Poland). (In Polish, English summary). *Przegląd Geologiczny*, 48 (12): 1124–1138.

Dżułyński, S., Krysowska-Iwaszkiewicz, M., Oszast, J. & Starkel, L., 1968. On Lower Quaternary gravels in the Sandomierz Basin. (In Polish, English summary). *Studia Geomorphologica Carpatho-Balcanica*, 2: 63–74.

Dżułyński, S., Rutkowski, J. & Shideler, G.L., 1974. An evaluation of flysch-derived fluvial gravels as provenance indicators. *Rocznik Polskiego Towarzystwa Geologicznego*, 44: 171–179.

Garecka M. & Jugowiec M., 1999. Results of biostratigraphic study of Miocene in the Carpathian Foredeep in the light of the new micropaleontological data. (In Polish, English summary). *Prace Państwowego Instytutu Geologicznego*, 168: 9–28.

Gaździcka, E., 1994. Nannoplankton stratigraphy of the Miocene deposits in Tarnobrzeg area (north-eastern part of Carpathian Foredeep). *Geological Quarterly*, 38: 553–570.

Gedl, P., 1999. Palaeoenvironmental and sedimentological interpretations of the palynological analysis of the Miocene deposits from the Jamnica S-119 borehole (Carpathian Foredeep, Poland). *Geological Quarterly*, 43: 479–492.

Gębica, P., 1995. Evolution of the Vistula River valley between Nowe Brzesko and Opatowiec in the Vistulian and Holocene. (In Polish, English summary). *Dokumentacja Geograficzna*, 2: 5–89.

Głazek, J., Buchvarova, V., Gaździcka, E., Król, E., Łuczkowska, E., Stępisiewicz, M., Wyrwicki, R. & Ziembińska-Tworzydło, M., 1990. *Ustalenie granicy między trzeciorzędem a czwartorzędem we wschodniej części Kotliny Sandomierskiej.* (In Polish). Unpublished manuscript. Institute of Geological Sciences, Polish Academy of Sciences, Warsaw, 144 pp.

Głazek, J. & Szynkiewicz, A., 1987. Stratigraphy of the Late Tertiary and Early Quaternary karst deposits in Poland and their paleogeographic implications. (In Polish). In: Jahn, A. & Dyjor, S. (eds), *Problemy młodszego neogenu i eoplejstocenu w Polsce.* Ossolineum, Wrocław: 113–128.

Gradziński, R. & Unrug, R., 1959. Origin and age of the "Witów series" near Cracow. (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 29: 181–195.

Jawor, E., Jucha, S., Kruczek, J., Sas-Korczyński, S., Wdowiarz, S. & Witek, K., 1982. On the development of upper part of Miocene and Quaternary deposits in the Carpathian Foredeep between Cracow and Tarnów. (In Polish, English summary). *Kwartalnik Geologiczny*, 26: 647–661.

Jonak, Z., 1979. Sub-Quaternary Relief of Niepołomnicka Wilderness Area. (In Polish, English summary). *Zeszyty Naukowe Akademii Górniczo-Hutniczej, Geologia*, 5 (3): 13–23.

Karnkowski, P., 1989. Deltaic deposits of the Carpathians Foreland. (In Polish, English summary). *Przegląd Geologiczny*, 37 (1): 28–32.

Klimaszewski, M., 1961. *South Poland. Guide-book of Excursion, From the Baltic to the Tatras*, III, INQUA VI Congress, Łódź: 1–218.

Klimaszewski, M., 1967. Polskie Karpaty zachodnie w okresie czwartorzędowym. (In Polish). In: Galon, R. & Dylik, J., (eds), *Czwartorzęd Polski.* Wyd. Geol., Warszawa: 431–497.

Klimek, R., 1991. *Utwory czwartorzędowe doliny Dunajca między Biskupicami Melsztyńskim a Zgłobicami.* (In Polish). Unpublished MSc. thesis, Institute of Geological Sciences, Jagiellonian University, Kraków, 49 ms. pp.

Kondracki, J., 2001. *Geografia regionalna Polski.* (In Polish).Wydawnictwo Naukowe PWN, Warszawa, 441 pp.

Kotlarczyk, J., 1985. Evolution of the Carpathian tectogene in the Miocene. W: Geotraverse Kraków – Baranów – Rzeszów – Ustrzyki Dolne – Komańcza – Dukla. *Guide to Excursion 4. Carpatho-Balkan Geological Association, 13th Congress.* Geol. Inst., Kraków: 21–32.

Kotlicka, G. N., 1982. Związek górnej Odry ze zlewnią Morza Czarnego w czasie zlodowacenia środkowopolskiego. (In Polish, English summary). *Kwartalnik Geologiczny*, 27: 427.

Kováč, M., Nagymarosy, A., Oszczypko, N., Csontos, L., Ślączka, A, Marunteanu, M., Matenco, L. & Márton, E., 1998. Palinspastic reconstruction of the Carpathian–Pannonian region during the Miocene. In: Rakús, A. (ed.), *Geodynamic development of the Western Carpathians*. Slovak Geological Survey, Bratislava: 189–217.

Kozikowski, K., 1963. Quaternary sediments of the Carpathian foreland between Brzeźnica and Dunajec river. (In Polish, English summary). *Przegląd Geologiczny*, 11 (9): 414–418.

Krzywiec, P., 1997, Large-scale tectono-sedimentary Middle Miocene history of the central and eastern Polish Carpathian Foredeep Basin – results of seismic data interpretation. *Przegląd Geologiczny*, 45 (10/2): 1039–1053.

Krzywiec, P., 1998. Badeńska historia centralnej (Kraków – Tarnów) części zapadliska przedkarpackiego na podstawie danych sejsmicznych. (In Polish, English summary). In: Zuchiewicz, W. (ed.), *Materiały XIX Konferencji Terenowej Sekcji Tektonicznej PTG Magura '98 "Rozwój strukturalny płaszczowiny magurskiej na tle tektoniki Karpat Zewnętrznych"*, Szymbark 15-17.10.1998. PTG. ING PAN, Kraków: 22–23.

Kucia-Lubelska, M., 1966. The age of the Witów series based on the heavy mineral assemblages. (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 36: 303–311.

Kurek, S. & Preidl, M., 1997. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Mielec*. (In Polish). Centralne Archiwum Geologiczne, Warszawa: 1–36.

Kwapisz, B., 1992. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Stany*. (In Polish). Państwowy Instytut Geologiczny, Warszawa: 1–56.

Kwapisz, B., 1996. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Kolbuszowa*. (In Polish). Państwowy Instytut Geologiczny, Warszawa: 1–29.

Kwapisz, B. & Popielski, W., 1999. Próba rekonstrukcji paleogeografii sieci dolinnej na terenie Płaskowyżu Tarnogrodzkiego i Równiny Biłgorajskiej na tle rzeźby stropu miocenu. (In Polish). *Materiały VI Konferencji stratygrafii plejstocenu Polski*, Czudec, 31.08-4.09 1999. Państwowy Instytut Geologiczny, Kraków: 31–37.

Kwapisz, B. & Szajn, J., 1987. Nowe dane na temat pozycji stratygraficznej żwirów z północnego skłonu Płaskowyżu Kolbuszowskiego. (In Polish). In: Rutkowski, J. (ed.), *Trzecio- i staroczwartorzędowe żwiry Kotliny Sandomierskiej. Materiały Sympozjum Komisji Badań Czwartorzędu Polskiej Akademii Nauk*, Kraków, 22-24 czerwca. Akademia Górniczo-Hutnicza, Kraków: 58–62.

Laskowska-Wysoczańska, W., 1971. Quaternary stratigraphy and palaeogeomorphology of the Sandomierz Lowland and the foreland of the middle Carpathians, Poland. (In Polish, English summary). *Studia Geologica Polonica*, 34: 1–109.

Laskowska-Wysoczańska, W., 1973. Resistance selection in the glacial, fluvioglacial and fluvial formations of the Sandomierz Lowland. *Bulletin of the Polish Academy of Sciences, Earth Sciences*, 22: 51–63.

Laskowska-Wysoczańska, W., 1979. Quaternary vertical movements of marginal zone of the Carpathian Foredeep in front of the Roztocze. *Przegląd Geologiczny*, 23 (6): 318–321.

Laskowska-Wysoczańska, W., 1983. Czwartorzędowe ruchy pionowe środkowej i wschodniej części Kotliny Sandomierskiej. (In Polish). In: Jahn, A. & Dyjor, S. (eds), *Problemy młodszego neogenu i eoplejstocenu w Polsce*. Ossolineum, Wrocław: 207–221.

Laskowska-Wysoczańska, W., 1987. Przedplejstoceńskie serie żwirowe w środkowej i wschodniej części Kotliny Sandomierskiej. (In Polish). In: Rutkowski J. (ed.), *Trzecio- i staroczwartorzędowe żwiry Kotliny Sandomierskiej. Materiały Sympozjum Komisji Badań Czwartorzędu Polskiej Akademii Nauk, Kraków, 22-24 czerwca*. Akademia Górniczo-Hutnicza, Kraków: 50–58.

Laskowska-Wysoczańska, W., 1993. Neotectonic and glacial control of morphostructural evolution of the boundary zone between the Carpathians and the Carpathian Foredeep. (In Polish, English summary). *Annales Societatis Geologorum Poloniae*, 63: 119–151.

Laskowska-Wysoczańska, W., 1995. Neotectonic and glacial control on geomorphic development of middle and eastern parts of the Sandomierz Basin and the Carpathian margin. *Folia Quaternaria*, 66: 105–122.

Lewandowski, J., 1993. Sub-Quaternary morphology of the Silesian-Cracow Region, South Poland, and its morphogenetic evolution. *Folia Quaternaria*, 64: 101–120.

Lewandowski, J., 1996. The main factors of Neogene and Quaternary morphogenetic evolution of the Silesian-Cracow Region (S Poland). (In Polish, English summary). *Acta Geographica Lodzensia*, 71: 131–146.

Lewandowski, J. & Kaziuk, H., 1982. Ancient, Early Pleistocene valleys in the Silesian-Cracow region. (In Polish, English summary). *Kwartalnik Geologiczny*, 26: 177–190.

Lindner, L. & Nowakowski, A., 1996. Origin of granite pebbles in the Witów Series deposits (Southern Poland), as indicated by petrographic studies. (In Polish, English summary). *Przegląd Geologiczny*, 44 (9): 950–952.

Lindner, L. & Siennicka, A. E., 1994. Quaternary deposits in the northern zone of the Vistula River edge east of Brzesko Nowe (Miechów Upland, southern Poland). (In Polish, English summary). *Przegląd Geologiczny*, 42 (2): 105–112.

Lindner, L. & Siennicka-Chmielewska, A. E., 1995. Loesses and their bedrocks in the Southeastern part of the Miechów Upland (S Poland). *Annales Universitas Mariae Curie-Skłodowska, Lublin – Polonia, sectio B*, 50: 75–89.

Lindner L. & Siennicka-Chmielewska, A. E., 1998. The Witów series and the problem of the Tertiary/Quaternary boundary in South-Eastern Poland. *Mededelingen Nederlands Instituut voor Toegepaste Geowetenschappen TNO*, 60: 287–292.

Lindner, L. & Wojtanowicz, J., 1997. Outline of correlation of stratigraphical subdividions of the Pleistocene in the South Polish Uplands. *Przegląd Geologiczny*, 45 (1): 76–80.

Liszkowski, J., 1996. The succession of climates and energetics of erosion processes during the Tertiary based on studies of palaeoalterite formations from the South Polish Uplands. (In Polish, English summary). *Acta Geographica Lodziensia*, 71: 165–178.

Łanczont, M., Boguckyj, A., Kravčuk, J. & Yacyšyn, A., 2002. Geological structure and natural environment of the Halyč Prydnistrov'ja region. (In Polish, English summary). In: Madeyska, T., (ed.), Loess and Palaeolithic of the Dniester River Basin, Halyč region (Ukraine). *Studia Geologica Polonica*, 119: 17–26.

Łyczewska J., 1948. Geological investigation in the Brzesko Nowe Region. (In Polish, English summary). *Biuletyn Państwowego Instytutu Geologicznego*, 42: 47–71.

Magiera, J. & Sokołowski, T., 1987. Ocena możliwości dokumentowania złóż kruszyw naturalnych w obrębie wysokich teras rzecznych na wschód od Dunajca. (In Polish). Część II. Unpublished manuscript. Instytut Geologii i Surowców Mineralnych Akademii Górniczo-Hutniczej, Kraków: 1–73.

Marciniak, J., 1963. Stanowisko w Witowie nad Wisłą w świetle badań archeologicznych. (In Polish). *Sprawozdania z Posiedzeń Komisji Oddziału Polskiej Akademii Nauk w Krakowie*: 373–377.

Marunteanu, M., 1999. Litho- and biostratigraphy (calcareous nannoplankton) of the Miocene deposits from the Outer Moldavides. *Geologica Carpathica*, 50: 313–324.

Maruszczak, H., 1996. Naskorupienia cementacyjne z polewami pustynnymi na wychodniach piaskowców albskich w Rachowie. (In Polish). *Materiały Konferencji Naukowej 50 lat Zakładu Geologii Uniwersytetu Marii Curie-Skłodowskiej 1946-1996*, Lublin: 49–50.

Maruszczak., 2001. Relief development in the eastern part of the Meta-Carpathian Uplands during the post-Sarmatian period. (In Polish, English summary). *Przegląd Geograficzny*, 73: 253–280.

Mądry, S., 1997. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Cmolas.* (In Polish). Państwowy Instytut Geologiczny, Warszawa: 1–25.

Migoń, P., 1996. Survival of Tertiary relief in highly glaciated areas of Northern Europe. (In Polish, English summary). *Czasopismo Geograficzne*, 68: 285–301.

Mycielska-Dowgiałło, E., 1978, Rozwój rzeźby fluwialnej północnej części Kotliny Sandomierskiej w świetle badań sedymentologicznych. (In Polish, English summary). *Rozprawy Uniwersytetu Warszawskiego*, 120: 7–155.

Mycielska-Dowgiałło, E., 1987. Żwiry trzecio- i czwartorzędowe okolicy Tarnobrzega i Machowa. In: Rutkowski, J. (ed.), *Trzecio- i staroczwartorzędowe żwiry Kotliny Sandomierskiej. Materiały Sympozjum Komisji Badań Czwartorzędu Polskiej Akademii Nauk, Kraków, 22-24 czerwca.* Akademia Górniczo-Hutnicza, Kraków: 46–50.

Nawrocki, J. & Wójcik, A., 1990. On age of the "Witów series" in the light of palaeomagnetic studies. *Studia Geomorphologica Carpatho-Balcanica*, 24: 3–9.

Ney, R., 1968. The role of the "Cracow bolt" in the geological history of the Carpathian Fore-deep and its distribution of oil and gas deposits. (In Polish, English summary). *Prace Komisji Nauk Geologicznych Polskiej Akademii Nauk, Oddział w Krakowie*, 45: 1–82.

Nitychoruk, J., 1991. Glacial deposits in the Tarnów Plateau (S Poland) and the problem of Dunajec outflow during the San 2 (=Elsterian 2) Glaciation. *Annales Universitas Mariae Curie-Skłodowska, Lublin - Polonia, sectio B*, 46: 187–200.

Nowak, A. W., Żółkiewski, M., 1989. Fossil relief of the Miocene roof under the Vistula valley within the Oświęcim and Sandomierz Basin. (In Polish, English summary). *Studia Ośrodka Dokumentacji Fizjograficznej PAN*, 26: 55–86.

Olszewska, B., 1999. Biostratigraphy of Neogene in the Carpathian Foredeep in the light of new mocropaleontological data. (In Polish, English summary). *Prace Państwowego Instytutu Geologicznego*, 168: 9–21.

Oszczypko, N., 1997. The Early-Middle Miocene Carpathian peripheral foreland basin (Western Carpathians, Poland). *Przegląd Geologiczny*, 45 (10/2): 1054–1063.

Oszczypko, N., 1998. The western Carpathian Foredeep – development of the foreland basin in front of the accretionary wedge and its burial history (Poland). *Geologica Carpathica* 49: 415–431.

Oszczypko, N., 1999. The Miocene subsidence of the Polish Carpathian Foredeep. (In Polish, English summary). *Prace Państwowego Instytutu Geologicznego*, 168: 209–230.

Oszczypko, N., 2001. The Miocene development of the Polish Carpathians Foredeep (southern Poland). *Przegląd Geologiczny*, 49 (8): 717–723.

Oszczypko, N. & Ślączka, A., 1989. The evolution of the Miocene basin in the Polish Outer Carpathians and their foreland. *Geologica Carpathica*, 40: 23–36.

Oszczypko, N. & Tomaś, A., 1985. Tectonic evolution of marginal part of the Polish Flysh Carpathians in the Middle Miocene. *Kwartalnik Geologiczny*, 29: 109–128.

Oszczypko, N., Zając, R., Garlicka, I., Menčik, E., Dvořák, J., Matejovska, O., 1989. Geological map of the substratum of the Tertiary of the Western Outer Carpathians and their foreland. In: Poprawa D. & Nemčok J., (eds), *Geological atlas of the Western Outer Carpathians and their foreland.* Państwowy Instytut Geologiczny, Warszawa.

Paruch-Kulczycka, J., 1999. Genus *Silicoplacentina* (Class Amoebina) from the Miocene Machów Formation (Krakowiec Clays) of the northern Carpathian Foredeep. *Geological Quarterly*, 43: 499–508.

Piątkowski, T. 1973. Uwagi o genezie osadów piaszczystoilastych wypełniających zagłębienia w stropie iłów sarmatu i osadów badenu okolic Tarnobrzega. (In Polish). *Sprawozdania z posiedzeń naukowych Instytutu Geologicznego, Kwartalnik Geologiczny*, 17: 890–891.

Płonczyński, J., 1992. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Nowe Brzesko.* (In Polish). Wydawnictwa Geologiczne, Warszawa: 1–44.

Płonczyński, J., 1997. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1: 50 000, arkusz Szczucin.* (In Polish). Centralne Archiwum Geologiczne, Warszawa: 1–42.

Połtowicz, S., 1967. Young tectonic movements in the Carpathians Foreland, vicinities of Cracow, and their influence upon the evolution of the Vistula and Raba Rivers. (In Polish, English Summary). *Kwartalnik Geologiczny*, 11: 699–704.

Połtowicz, S., 1974. Tectonic structure of the Carpathian border in the Tarnów and Pilzno area (Polish middle Carpathians). (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 44: 491–511.

Pożaryski, W., Maruszczak, H. & Lindner, L., 1994. Development of the Pleistocene valley of the Middle Vistula River, considering especially its gap in the South Polish Uplands. *Przegląd Geologiczny*, 42 (7): 523–531.

Pulit, F., 1975. The palaeomorphology and palaeohydrography of the Sub-Carpathian pradolina near Tarnów. (In Polish, English summary). *Przegląd Geograficzny*, 47: 345–358.

Purchla, J., 1992. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Tarnów.* (In Polish). Wydawnictwa Geologiczne, Warszawa: 1–30.

Radwański, A., 1968. Lower Tortonian transgression onto the southern slopes of the Holy Cross Mts. (In Polish, English summary). *Acta Geologica Polonica*, 18: 384–445.

Radzki, P., Łopusiński, L. & Widz, D., 1992. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Borzęcin.* (In Polish). Wydawnictwa Geologiczne, Warszawa: 1–33.

Rögl, F., 1996. Stratigraphic correlation of the Paratethys Oligocene and Miocene. *Mitteilungen der Gesellschaft Bergbaustudenten Österreich*, 41: 65–73, Wien.

Różycki, S. Z., 1972. Plejstocen Polski środkowej. (In Polish). *Państwowe Wydawnictwo Naukowe*, 2 Ed., Warszawa: 3–315.

Rudjuk, B.B., 2000. Genus *Bogatschevia* in terrace sediments of Dniester River. *(In Ukrainian). Geological Journal, National Academy of Sciences of Ukraine*, 2: 101–108.

Rutkowski, J., 1987a. O niektórych trzecio- i czwartorzędowych żwirach rejonu Krakowa. (In Polish). In: Rutkowski, J., (ed.), *Trzecio- i staroczwartorzędowe żwiry Kotliny Sandomierskiej. Materiały Sympozjum Komisji Badań Czwartorzędu Polskiej Akademii Nauk, Kraków, 22-24 czerwca 1987.* AGH, Kraków: 24–26.

Rutkowski, J., 1987b. Uwagi o żwirach witowskich. (In Polish). In: Rutkowski, J. (ed.), *Trzecio- i staroczwartorzędowe żwiry Kotliny Sandomierskiej. Materiały Sympozjum Komisji Badań*

Czwartorzędu PAN, Kraków, 22-24 czerwca 1987. AGH, Kraków: 33–39.

Rutkowski, J., 1995a. Petrographic researches of the gravels. (In Polish, English summary). In: Mycielska-Dowgiałło, E. & Rutkowski, J. (eds), *Researches of Quaternary Sediments. Some methods and interpretation of the results*. Faculty of Geography and Regional Studies, University of Warsaw, Warszawa: 133–150.

Rutkowski, J., 1995b. Petrographic composition of the Quaternary gravels of the Carpathians and their foreland. *Studia Geomorphologica Carpatho-Balcanica*, 29: 77–88.

Rutkowski, J., 1998. O staroczwartorzędowych żwirach z Witowa. (In Polish). *Materiały Konferencji "Współczesne procesy morfologiczne i ewolucja rzeźby progu Karpat i ich przedpola"*. Warsztaty Geomorfologiczne w Łazach k/Bochni, wrzesień 1998, Kraków: 90–97.

Rutkowski, J. & Zuchiewicz, W., 1992. Czwartorzędowe osady rzeczne doliny Dunajca na Pogórzu Łącko-Podegrodzkim. (In Polish). In: Zuchiewicz, W. & Oszczypko, N. (eds), *Przewodnik 63 Zjazdu Polskiego Towarzystwa Geologicznego, Koninki, 17-19 września 1992*. ING PAN, Kraków: 154–157.

Sobolewska, M., 1963. Opracowanie paleobotaniczne prób z Witowa, pow. Kazimierza Wlk. (In Polish). *Sprawozdania z Posiedzeń Komisji Oddziału Polskiej Akademii Nauk w Krakowie*: 384–386.

Sokołowski, T., 1981. Remarks on the terraces of Dunajec valley near Tarnów (Southern Poland). (In Polish, English summary). *Annales Societatis Geologorum Poloniae*, 51: 579–594.

Sokołowski, T., 1987. Vistula valley between the outlets of Dunajec and Breń rivers. In: Starkel, L. (ed.), *Evolution of the Vistula river valley during the last 15 000 years, part II, Geographical Studies, Special Issue*, 4: 95–114.

Sokołowski, T., 1997. Remarks on petrographic composition of Quaternary gravels of Tarnów, South Poland. (In Polish, English summary). *Zeszyty Naukowe Akademii Górniczo-Hutniczej, Geologia*, 23 (4): 407–427.

Skoczylas-Ciszewska, K., 1954. *Szczegółowa mapa geologiczna Polski w skali 1: 50 000, arkusz Brzesko*. (In Polish). Wydawnictwa Geologiczne, Warszawa.

Starkel, L., 1972. Kotlina Sandomierska. (In Polish). In: Klimaszewski, M. (ed.), *Geomorfologia Polski, część I, Góry i wyżyny*. Państwowe Wydawnictwo Naukowe, Warszawa: 138–166.

Stuchlik, L., 1980. Chronostratigraphy of the Neogene in southern Poland (northern part of the Central Paratethys) on the basis of paleobotanical studies. *Przegląd Geologiczny*, 28 (8): 443–448.

Studencka, B., 1999. Remarks on Miocene Bivalve zonation in the Polish part of the Carpathian Foredeep. *Geological Quarterly*, 43: 467–477.

Szajn, J., 1987. *Szczegółowa mapa geologiczna Polski w skali 1:50 000, arkusz Baranów Sandomierski*. (In Polish). Wydawnictwa Geologiczne, Warszawa.

Szajn, J., 1991. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1:50 000, arkusz Baranów Sandomierski*. (In Polish). Wydawnictwa Geologiczne, Warszawa: 1–81.

Szajn, J., 1993. *Pozycja stratygraficzna żwirów kolbuszowskich, a rozwój rzeźby północnej części Płaskowyżu Kolbuszowskiego w czwartorzędzie w świetle badań sedymentologicznych*. (In Polish). Unpublished Ph.D. thesis. Wydział Geografii i Studiów Regionalnych UW, Warszawa, 145 ms. pp.

Tyczyńska, M., 1978. The fossil deltas in the Sandomierz Basin. (In Polish, English summary). *Folia Geographica, Series geographica-physica*, 11: 33–50.

Walczowski, A., 1970. *Szczegółowa mapa geologiczna Polski w skali 1: 50 000, arkusz Połaniec*. (In Polish). Wydawnictwa Geologiczne, Warszawa.

Walczowski, A., 1979. *Objaśnienia do Szczegółowej mapy geologicznej Polski w skali 1: 50 000, arkusz Bejsce*. (In Polish). Wydawnictwa Geologiczne, Warszawa: 1–46.

Wojtanowicz, J., 1977/78. Quaternary Changes of the River System of the Sandomierz Lowland. *Annales Universitatis Mariae Curie-Skłodowska, Lublin - Polonia*, sectio B, 32/33: 237–258.

Zieliński, T., 1995. Lithofacies and genetic codes: construction and application (In Polish, English summary). In: Mycielska-Dowgiałło, E. & Rutkowski, J. (eds), *Researches of Quaternary Sediments. Some methods and interpretation of the results*. Wydział Geografii i Studiów Regionalnych UW, Warszawa: 220–234.

Zieliński, T., 1998. Lithofacial identification of alluvial sediments (In Polish, English summary). In: Mycielska-Dowgiałło, E. (ed.), *Sedimentological and postsedimentological structures in Quaternary sediments and their value for interpretation*. Wydział Geografii i Studiów Regionalnych UW, Warszawa: 195–253.

Zuchiewicz, W., 1984a. Evolution of views on origin and age of Carpathian planation surfaces. (In Polish, English summary). *Przegląd Geologiczny*, 32 (8-9): 468–477.

Zuchiewicz, W., 1984b. The Late Neogene–Quaternary tectonic mobility of the Polish West Carpathians. A case study of the Dunajec drainage basin. *Annales Societatis Geologorum Poloniae*, 54: 133–189.

Zuchiewicz, W., 1987. Late Neogene–Early Quaternary evolution and structural control of the Carpathian drainage pattern. (In Polish, English summary). In: Jahn, A. & Dyjor, S. (eds), *Problemy młodszego neogenu i eoplejstocenu w Polsce*. Ossolineum, Wrocław: 211–225.

Zuchiewicz, W., 1991. On different approaches to neotectonics: A Polish Carpathians example. *Episodes*, 14: 116–124.

Zuchiewicz, W., 1995a. Selected aspects of neotectonics of the Polish Carpathians. *Folia Quaternaria*, 66: 145–204.

Zuchiewicz, W., 1995b. Lower Quaternary fluvial deposits in the Polish Outer Carpathians: a state-of-the-art review. *Studia Geomorphologica Carpatho-Balcanica*, 29, 91–97.

Zuchiewicz, W., 1998. Quaternary tectonics of the Outer West Carpathians, Poland. *Tectonophysics*, 297: 121–132.

Streszczenie

PALEOGEOGRAFIA ZACHODNIEJ CZĘŚCI KOTLINY SANDOMIERSKIEJ W PÓŹNYM NEOGENIE I WCZESNYM CZWARTORZĘDZIE (ZAPADLISKO PRZEDKARPACKIE, POLSKA POŁUDNIOWA)

Badania objęły trójkątny obszar zachodniej części Kotliny Sandomierskiej, ograniczony od południa linią głównego nasunięcia Karpat na przedpole i krawędzią morfologiczną Wyżyny Małopolskiej opadającą ku dolinie Wisły na północy. Granica wschodnia wyznaczona została arbitralnie wzdłuż linii południka 21°15' długości geograficznej wschodniej (Fig. 1). Dla obszaru badań, na podstawie szczegółowego zdjęcia geologicznego i geomorfologicznego wykonanego przez autora pracy oraz materiałów archiwalnych z poszczególnych arkuszy *Szczegółowej mapy geologicznej Polski* wykonano szkic geomorfologiczny (Fig. 2). Na podstawie zweryfikowanych danych pochodzących z otworów wiertniczych i sond kartograficznych w ilości sięgających ponad dziesięć tysięcy oraz danych biostratygraficznych sporządzono szkic geologiczny stropowej części utworów miocenu. (Fig. 3). Dane te pozwoliły również na sporządzenie szkicu morfologicznego powierzchni podczwartorzędowej (Fig. 7) oraz szkicu miąższości utworów czwartorzędowych (Fig. 13). Szereg przekrojów geologicznych (Fig. 4–6 i 9–12), opartych na danych z wierceń kartograficznych pozwoliło na zrewidowanie wcześniejszych poglądów na ukształtowanie i genezę powierzchni podczwartorzędowej tego rejonu. Kompleksowa analiza wszystkich zebranych danych pozwoliła na sporządzenie szkicu paleomorfologicznego i określenie genezy oraz wieku powstania poszczególnych elementów paleorzeźby (Fig. 8).

Najstarszymi jej elementami na badanym obszarze są fragmentarycznie rozpoznane paleorynny wycięte w ilastych utworach miocenu wypełnione drobnoklastycznymi osadami tego samego wieku występujące w rejonie Szczucina i Tarnobrzega. Przy brzegu nasunięcia karpackiego na Pogórzu Wielickim i na wschód od Tarnowa zachowały się powierzchnie zrównań na wysokościach 280–300 m n.p.m. i 250–270 m n.p.m., które można wiązać odpowiednio z poziomem pogórskim i przydolinnym. W rejonie Brzeska–Okocimia na ostańcowych wzgórzach z wierzchowinami na poziomie 240–250 m n.p.m. zachowały się reliktowe pokrywy preglacjalnych żwirów. Pozostałości przedglacjalnej powierzchni planacji na obszarze zachodniej części Kotliny Sandomierskiej zachowały się też szczątkowo na obszarze Wysoczyzny Tarnowskiej i Kolbuszowskiej, tworząc płaskie wierzchowiny przykryte osadami glacjalnymi na wysokościach 240–250 m n.p.m. W międzyrzeczu Dunajca i Białej występuje najwyższy i najstarszy poziom terasowy Dunajca (70 m n.p.rz.) – "poziom żwirowy Błoń" wzniesiony na wysokość 260 m n.p.m. i datowany na zlodowacenie narwi i/lub nidy. Charakterystycznym elementem kopalnej rzeźby badanego obszaru jest przebiegająca od Tarnowa ku wschodowi rynna podkarpacka wypełniona dwoma seriami piaszczysto-żwirowymi. Dolna seria, bardziej gruboklastyczna, zawierająca znaczny odsetek charakterystycznego materiału tatrzańskiego (granity i kwarcyty werfeńskie) powstała najprawdopodobniej podczas interglacjału kromerskiego *sensu lato*, górna to fluwioglacjalne żwiry i piaski zlodowacenia sanu 2 (Fig. 9–12). W późniejszych fazach zlodowacenia sanu 2 osadzone zostały gliny zwałowe oraz wycięte i zasypane młodsze rynny subglacjalne, przemodelowywane następnie przez rzeki (rynna Dąbrowa Tarnowska – Czarna, rynna Huty Komorowskiej i rynna w dolinie Przywry koło Cmolasu; Fig. 8). Podczas kolejnych zlodowaceń powstawały poziomy erozyjno-akumulacyjne terasowe, dobrze widoczne zarówno w kopalnej (por. Fig. 7), jak i w dzisiejszej rzeźbie (Fig. 2).

Dla rozpoznania historii geologicznej tego obszaru kluczowe znaczenie miało rozpoznanie genezy i wieku starych pokryw żwirowych w rejonie północnego brzegu terenu badań (żwiry serii witowskiej) oraz południowego – pokryw żwirowych rejonu Brzeska Okocimia i kopalnej rynny podkarpackiej.

W świetle nowych badań pozycja serii witowskiej, sytuowanej wiekowo przez różnych autorów w przedziale miocen–środkowy plejstocen, została określona na późny miocen. Litofacje i środowisko depozycji oraz skład materiału klastycznego odsłonięć w Witowie wskazują na środowisko rzeki roztokowej wkraczającej na deltę stożkową, zasypującą ustępujący zbiornik morski. Dojrzały i odporny na wietrzenie fizyczne materiał żwirowy pochodził z rejonu karpackiego, natomiast słabo odporne szczątki fauny mięczaków mioceńskich, detrytus roślinny oraz toczeńce ilaste wskazują na udział erozji bocznej rzeki i dostawę materiału z bliskiego sąsiedztwa omawianej serii. Podstawowe znaczenie dla określenia wieku serii witowskiej miały znalezione makroszczątki roślinne w postaci liści (nie ulegających redepozycji!), owoców, szyszek i pędów. Obecność gatunków ciepłolubnych, takich jak brzostownica *Zelkova zelkovifolia* (Unger) BůŽek et Kotlaba z rodziny Ulmaceae (wiązowatych) i rodzaju *Juglans*, a nawet paleotropikalnych *Spirematospermum wetzleri* (Heer), notowanych dotychczas tylko w neogenie Europy, świadczy o późnomioceńskim i nie wyklucza plioceńskiego wieku osadów tej serii. Analiza litofacjalna stanowiska w Witowie wskazuje raczej na późny sarmat–meot, jako okres zakończenia sedymentacji morskiej w tej części Paratetydy.

Osady położone przy brzegu karpackim w rejonie Brzeska-Okocimia na spłaszczeniach przedglacjalnej powierzchni zrównania na wysokości 240–250 m n.p.m. wykazują charakterystyczne cechy pozwalające zaliczyć je do osadów powstałych we wczesnym plejstocenie. Żwiry te o strukturze masywnej lub słabo widocznym warstwowaniu poziomym i przekątnym, leżą na wyraźnej powierzchni erozyjnej. Obecność materiału zarówno bardzo odpornego, bardzo dobrze obtoczonego, jak i ostrokrawędzistych okruchów i miękkich łupków wskazuje na bardzo krótki transport i dwa różne źródła jego pochodzenia. Główną masę żwirów stanowi materiał lokalnego pochodzenia z podłoża klastycznych osadów miocenu. Materiał bardziej odporny pochodzi z Karpat. Brak jest skał węglanowych, a opoki i gezy są całkowicie odwapnione. Powierzchnia otoczaków nosi ślady wietrzenia chemicznego w postaci wytrawiania mniej odpornych składników skały. Liczne są polewy manganowe na powierzchniach otoczaków i okruchów oraz różnego typu sylifikacje i naskorupienia żelaziste. Wyraźny wpływ wietrzenia chemicznego (wytrawienia, oskorupienia) obserwować też można na analizowanych powierzchniach ziaren kwarcu. Brak jest zupełnie materiału skandynawskiego, czy też pochodzącego z Wyżyny Małopolskiej. Mogą to być więc relikty eoplejstoceńskich osadów fluwialnych związanych z Karpatami.

Żwiry poziomu Błoń, tworzące wyraźny poziom na wysokości 250–260 m n.p.m. charakteryzują się obecnością materiału tatrzańskiego – kwarcytów werfenu i leukokratycznych granitów. Brak jest w nich materiału skandynawskiego, notowanego tylko incydentalnie w stropie serii. Skład petrograficzny, zespoły litofacjalne i kierunki paleoprzepływów świadczą, iż jest to poziom terasowy Dunajca, który wiązać można ze zlodowaceniami narwi i/lub nidy.

Gruboklastyczne osady spągowej części kopalnej rynny podkarpackiej na odcinku Tarnów–Dębica charakteryzują się również obecnością materiału tatrzańskiego, co przy braku skandynawskiego, wskazuje na jej powstanie podczas szeroko rozumianego interglacjału kromerskiego. Ten fragment rynny podkarpackiej jest dziś przykryty miąższymi seriami glacjalnymi zlodowacenia sanu 2, jednak w świetle badań w sztucznych wkopach i otworach wykonanych w południowej części Wysoczyzny Tarnowskiej i rejonie Dębicy, staje się zrozumiała obecność materiału tatrzańskiego daleko na wschodzie, na północ Rzeszowa.

Reasumując ewolucję geologiczną tej części Kotliny Sandomierskiej, można ją streścić następująco. W późnym miocenie (tortonie) trwała płytkomorska sedymentacja w ustępującym ku wschodowi zbiorniku Paratetydy. Zbiornik ten był zasypywany przez rzeki z dominującą dostawą materiału z Karpat (seria witowska). Podczas pliocenu i wczesnego czwartorzędu powstawały na progu Karpat dwa poziomy powierzchni zrównań, a powierzchnia Kotliny Sandomierskiej wznosiła się na wysokości około 250 m n.p.m. Układ sieci rzecznej zmienił się z kierunku południowo wschodniego (ku zanikającemu zbiornikowi morskiemu) na północno-wschodni – powstały przełomy rzeczne przez pas Wyżyn Małopolskich i grzbiet Roztocza. Podczas zlodowacenia sanu 2 sieć rzeczna uległa całkowitej przebudowie – nastąpiło zatamowanie przepływu ku północy. Po ustąpieniu lądolodu sieć drenażu zaczęła przypominać układ dzisiejszy, a główną rzeką stała się Wisła, która na drodze kaptażu włączyła w swe dorzecze górny bieg Sanu oraz swój górny odcinek wraz z Sołą (Fig. 16).