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Pleistocene river valleys and ice sheet limits in the Southern Mazovian Lowland, central Poland

Marcin ŻARSKI

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The buried and present-day Vistula valleys has developed along tectonic linear structures of NW–SE trend. The Vistula river valley and its tributaries essentialy maintained their courses during the Małopolanian, Ferdynandovian, Mazovian and Eemian interglacials. During the Małopolanian, Mazovian, Ferdynandovian interglacials the gradient of the buried Vistula valley was 0.57‰, while during the Eemian Interglacial and during deposition of Vistulian terraces and Holocene flood plain deposits it was about 0.34‰, due to from tectonic movements. The width of the buried Vistula valley was the greatest during the Eemian Interglacial (15 km) and during the Vistulian (17 km) when strong lateral erosion occurred. The stratigraphy of the Quaternary deposits is based on palynologically documented sites of the Ferdynandovian, Mazovian and Eemian interglacials. This region was covered by ice sheets of the Nidanian, Sanian, Wilgian, Liviecian, Odranian and Wartanian glaciations during eight advances. Liviecian and Wartanian Glaciation maximum limits were determined in the study area. Interstadial fluvial deposits, between the premaximum and maximum stadials of the Odranian Glaciation, were recognised and termed sediments of the Gniewosznian Interstadial. The deposits of the Wartanian Glaciation have been TL dated at 146–203 ka BP and the Odranian at 212–280 ka BP.

Marcin Żarski, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, e-mail: mzar@pgi.waw.pl *(received: March 28, 2001; accepted: November 15, 2001).*

Key words: Pleistocene, Vistula river valley, ice sheet limit, glaciation.

INTRODUCTION

The study area is situated in the southern Middle Vistula river valley (Kondracki, 1998) and includes surrounding plateaus between Maciejowice and Puławy. These plateaus belong to the South Podlasian Lowland, the Middle Mazovian Lowland and the South Mazovian Heights (Fig. 1). In the south-east part the area investigated is bounded by the Lublinian Upland and covers the northern part of the Vistula gap.

The paper gives the main results of a Ph. D. thesis (Żarski, 2000), synthesising data from various sources including geological maps. Research boreholes provided important geological data, these being drilled for the *Detailed Geological Map of Poland* at the 1:50 000 scale (Sarnacka, 1986, 1990; Żarski, 1989*a*, 1993*a*, 1996, 1998). Based on samples taken from research boreholes and exposures, the following investigations were made: lithological/petrographic, palynological, micropalaeontological and soil data; TL and ^{14}C ages. The age of the deposits was determined following the stratigraphic scheme of Baraniecka (1990) (Table 1).

Research on the geomorphology, Quaternary stratigraphy and bedrock stratigraphy started at the end of 19th century (Siemiradzki and Dunikowski, 1891). Krisztafowicz's important (1896) paper outlines the stratigraphy of the Pleistocene deposits around Puławy and Kazimierz; he recognised there evidence of two glaciations.

Monographs on the Vistula river gap valley to the south were written by Pożaryski (1953, 1955) who stated that this area was glaciated three times, a view repeated in Pożaryski *et al*. (1994*a*, *b*). One of the first maps of the research area it was the *Geological Map of Poland* at the scale 1:200 000 with explanatory text for the Radom sheet (Makowska, 1968, 1969) and the Łuków sheet (Mojski, 1972).

TECTONICS

The Palaeozoic and Mesozoic bedrock is strongly faulted (Żelichowski and Kozłowski, 1983) (Fig. 2). Analyses of the

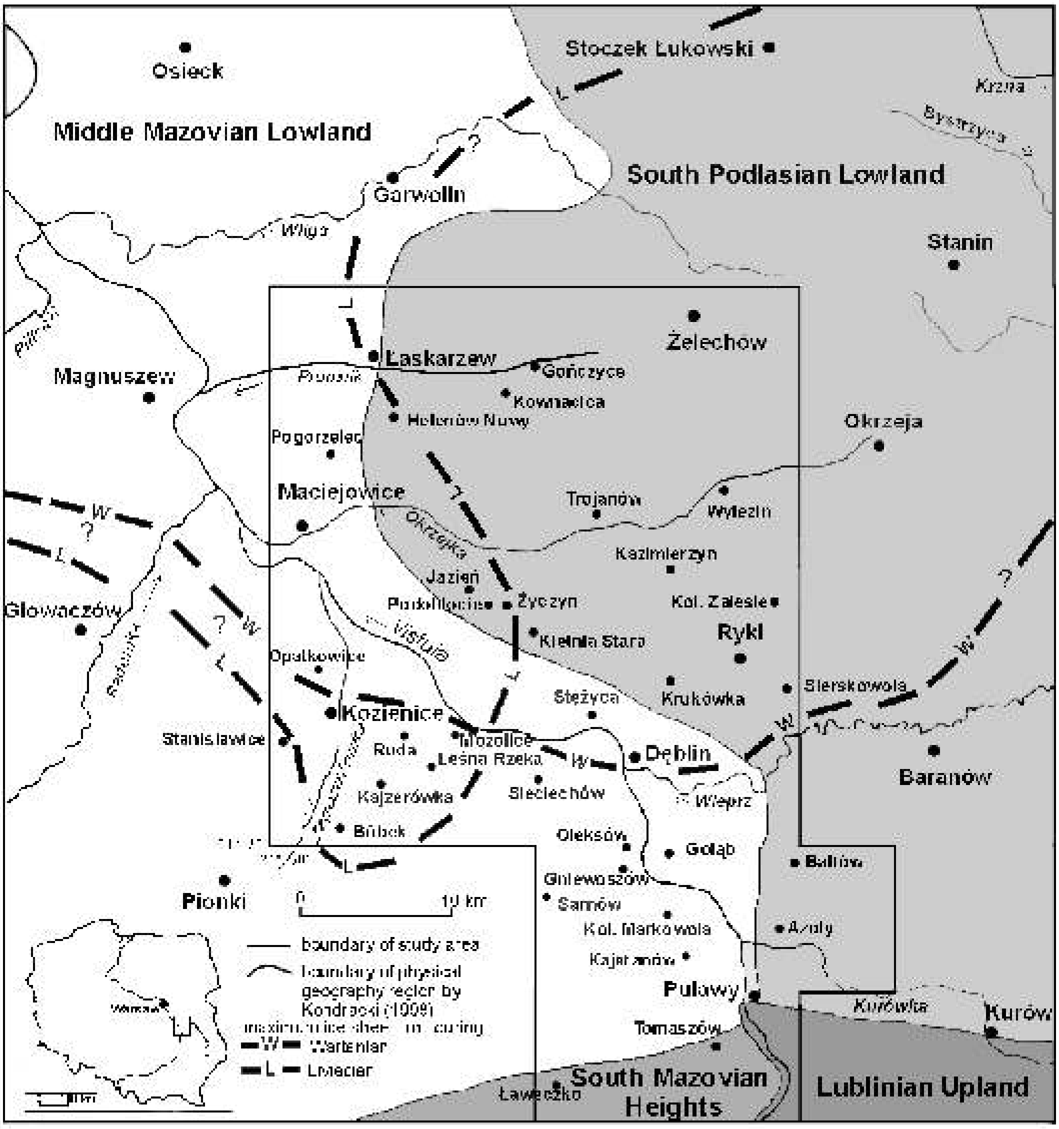


Fig. 1. Study area

Photogeological Map of Poland (Bażyński *et al*., 1984) and of maps of linear structural elements in Poland (Graniczny *et al*., 1995) recognised two main trends of lineaments (Fig. 2), NW–SE and NE–SW, with one also approximately E–W. Some of these are coincident with the course of the buried and present-day Vistula valley (Fig. 2) suggesting the possibility of tectonic influence on valley development. The faults show convergence (Fig. 2) and may also have indirectly influenced the development of smaller forms of Quaternary relief. Lineament intersections and areas with faults downthrowing in different directions coincide with depressions in the base of the Quaternary deposits, for example near Życzyn, Moszczanka and Kozienice (Fig. 2). Instability around fault intersections may also have caused glaciotectonic disturbances. Ruszczyńska-Szenajch (1976) connected depressions in the base of the Quaternary with glaciotectonic depressions in eastcentral Poland.

BEDROCK TO THE QUATERNARY DEPOSITS

The bedrock to the Quaternary deposits in the study area are deposits of Late Cretaceous and Early Paleocene, Early to Mid-Eocene, Early Oligocene and Miocene age (Fig. 3). The age of the Tertiary deposits was established using the stratigraphic scheme of Piwocki and Ziembińska-Tworzydło (1995, 1997) and Piwocki (1996). The Upper Maastrichtian is represented by siliceous marls, marls and limestones, exposed around Bochotnica, Wojszyn and Nasiłów in the Vistula water-gap valley and gently dipping NE-wards (Żarski, 1998).

Gaizes, limestones, marls and glauconitic sandstones of Early Paleocene age are exposed around Puławy, Góra Puławska and Bronowice (Żarski, 1998; Żarski *et al*., 1998).

Marine Eocene deposits occur below Quaternary deposits only in the south (Fig. 3) around Ławeczko and Sarnów. Near Kajetanów they reach 22 m thickness and are glacitectonically deformed (Fig. 3). They are Early to Mid-Eocene in age (Słodkowska, 1996).

Oligocene deposits are represented by clays, silts, glauconite and quartzose sands and gravels. Palynological research by Słodkowska (1986, 1987, 1988, 1992) established their age as Early Oligocene (Rupelian) and their environment of deposition as littoral marine.

Early to Mid-Miocene deposits comprise quartzose sands, silts and clays with intercalations of lignite and brown coal (Słodkowska and Żarski, 1991). They are lacustrine, probable

Table 1

Stratigraphic scheme of Quaternary in the study area based Baraniecka (1990)

Age			Stages ^{18}O after Bowen *et al*. (1986)	Climatostratigraphic units: Cold stages — Poland	West Europe
QUATERNARY	Holocene		1	Holocene	Holocene
	PLEISTOCENE		2–5d	Vistulian	Weichselian
			5e	Eemian	Eemian
		MIDDLE POLISH GLACIATIONS	6	Wartanian	Saalian
			7	Lublinian	
			8	Odranian 2	
				Gniewosznian	
				Odranian 1	
		GREAT INTERGLACIAL	9	Zbójnian	Holsteinian
			10	Liviecian	
			11	Mazovian	
		SOUTH POLISH GLACIATIONS	12	Wilgian	Elsterian
			13–15	Ferdynandovian	
			16	Sanian 2	
				Dęblinian	
				Sanian 1	
			17–19	Małopolanian	
			20	Nidanian	
	Prepleistocene				

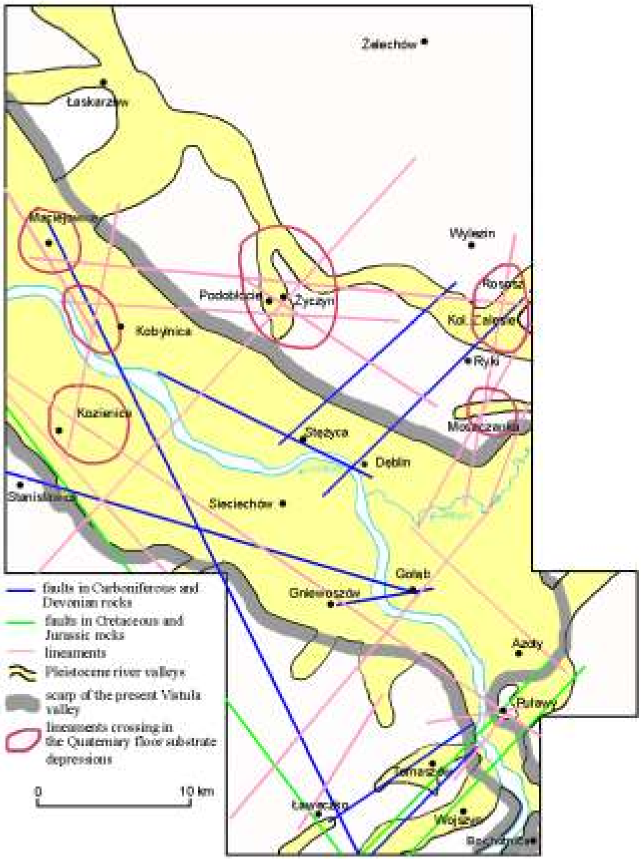


Fig. 2. Linear structural elements of the Quaternary bedrock on the basis at Żelichowski and Kozłowski (1983), Bażyński *et al*. (1984) and Graniczny *et al*. (1995)

shoreline deposits occurring north of Puławy and Gniewoszów (Fig. 3).

Late Miocene deposits comprise green-brown clays, silts and sands (formerly classified as Pliocene) occur north of Ryki and Życzyn (Fig. 3). They are lacustrine in origin (Różycki, 1972). The area investigated includes a probable southern shoreline, dating from the Late Miocene, approximately along the present-day Wieprz valley. Around Ryki Late Miocene silts are glaciotectonically deformed (Żarski, 1989*a*).

QUATERNARY

The Pleistocene succession in the study area comprises, together with Prepleistocene strata, deposits relating to the Nidanian, Sanian and Wilgian, Liviecian, Odranian, Wartanian, Vistulian glaciations and the Małopolanian, Ferdynandovian, Mazovian, Eemian interglacials (Table 1).

The buried Vistula river valley is filled with fluvial deposits of various ages totaling 40–60 m thick (Figs. 5–8). In the remaining part of the area the Quaternary sequence is 20–40 m thick.

The older glacial (pre-Odranian) deposits occur as fragmentary successions, preserved only in depressions (Fig. 2).

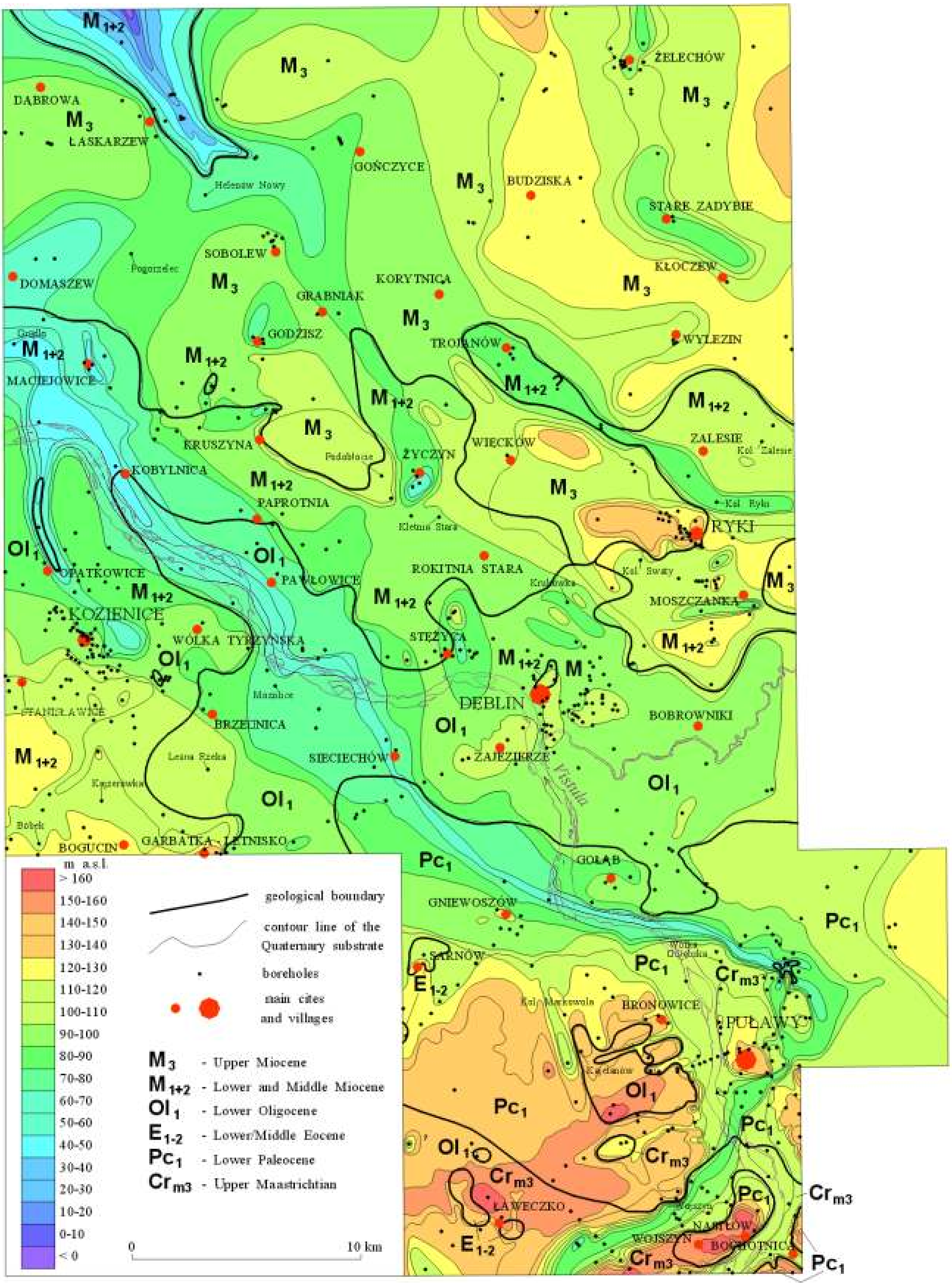


Fig. 3. Hipsometric map of Quaternary bedrock

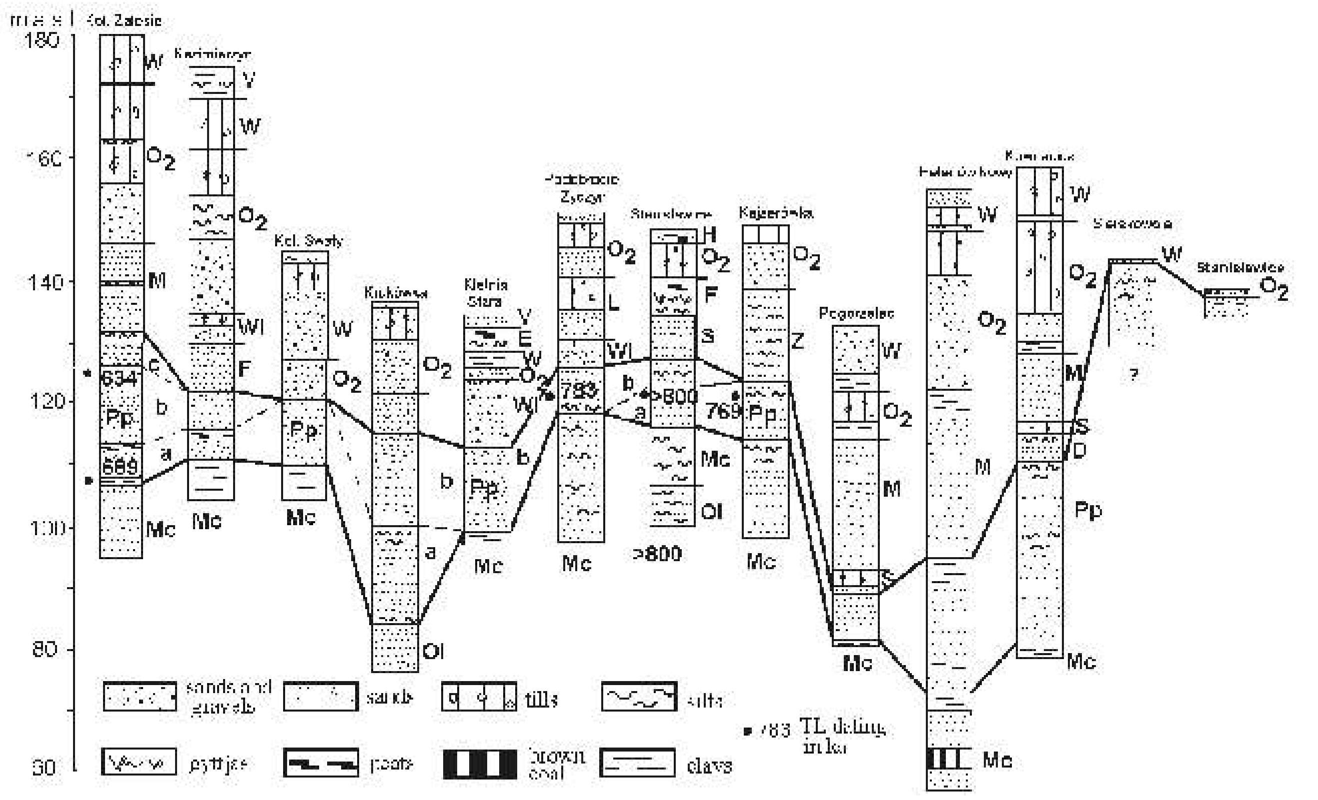


Fig. 4. Correlation profiles with Prepleistocene sediments; sections Pogorzelec, Helenów Nowy and Kownacica by Sarnacka (1986, 1990), others by Żarski (1989, 1993, 1996)

Ol — Oligocene; Mc — Miocene; Pp — Prepleistocene (a–c — fluvial series); S — Sanian Glaciation; D — Dęblinian Interstadial; F — Ferdynandovian Interglacial; Wl — Wilgian Glaciation; M — Mazovian Interglacial; L — Liviecian Glaciation; Z — Zbójnian Interglacial; O_2 — Odranian Glaciation (maximum stadial); W — Wartanian Glaciation; E — Eemian Interglacial; V — Vistulian; H — Holocene

Quaternary deposits in these depressions are 70–80 m thick. Outside depressions, deposits of the South Polish Glaciation (Elsterian) are not well preserved. In the study area there are 8 glacial units, which belong to six glaciations.

THE OLDEST FLUVIAL DEPOSITS

Prepleistocene strata are the oldest among Quaternary deposits in the study area. These represent alluvial cones deposited by rivers flowing from the south, SW and SE according to Lewiński (1929). One of these rivers was the “pre-Vistula” (Kosmowska-Ceranowicz, 1966; Sarnacka and Krysowska-Iwaszkiewicz, 1974; Makowska, 1976). Prepleistocene deposits in the study area correspond to the Kozienice horizon (Kosmowska-Ceranowicz, 1966, 1976, 1979). In studied profiles (Fig. 4) an absence of pollen has made stratigraphical correlation so far impossible (Baraniecka, 1975*a*, 1991; Winter, 1997). Prepleistocene sediments reach thicknesses of up to 30 m (Krukówka, Fig. 4). These fluvial deposits (Fig. 4) are composed of by quartz, siliceous rock fragments, quartzites and sandstones from Jurassic and Cretaceous rocks of the Southern Polish Highlands (Kosmowska-Ceranowicz, 1966). Prepleistocene deposits differ from later Quaternary deposits in petrographic composition by a lack of Scandinavian material. Heavy mineral suites are dominated by resistant minerals such as garnet, rutile, tourmaline and cyanite (Gronkowska, 1988, 1997). Amphiboles and epidotes, characteristic of the younger Pleistocene are absent (Fig. 4). The best preserved Prepleistocene deposits occur in the region of Kozienice, Kol. Zalesie and Krukówka (Figs. 4, 8 and 9). In the area of the Vistula buried valley these sediments are not preserved. Also, the base of the Prepleistocene deposits on the morainic plateau lies higher than the sand deposits filling the low parts of the buried Vistula valley (Figs. 4 and 8). It is evident that erosion during the Prepleistocene was not so deep as during Pleistocene interglacials. The Prepleistocene sediments have been TL dated at 634 to over 800 ka (Butrym, 1987, 1992) (Fig. 4).

PLEISTOCENE RIVER VALLEYS AND LAKES

The buried Vistula runs from the Nowy Janowiec region to Wojszyn and Puławy (Fig. 5). To the north of Puławy the buried Vistula valley is concordant with the contemporary Vistula valley (Fig. 5). Borehole data has enabled determination of the age of the deposits, and of their facies and composition. A common feature of the Vistula valley and its tributaries is a period-

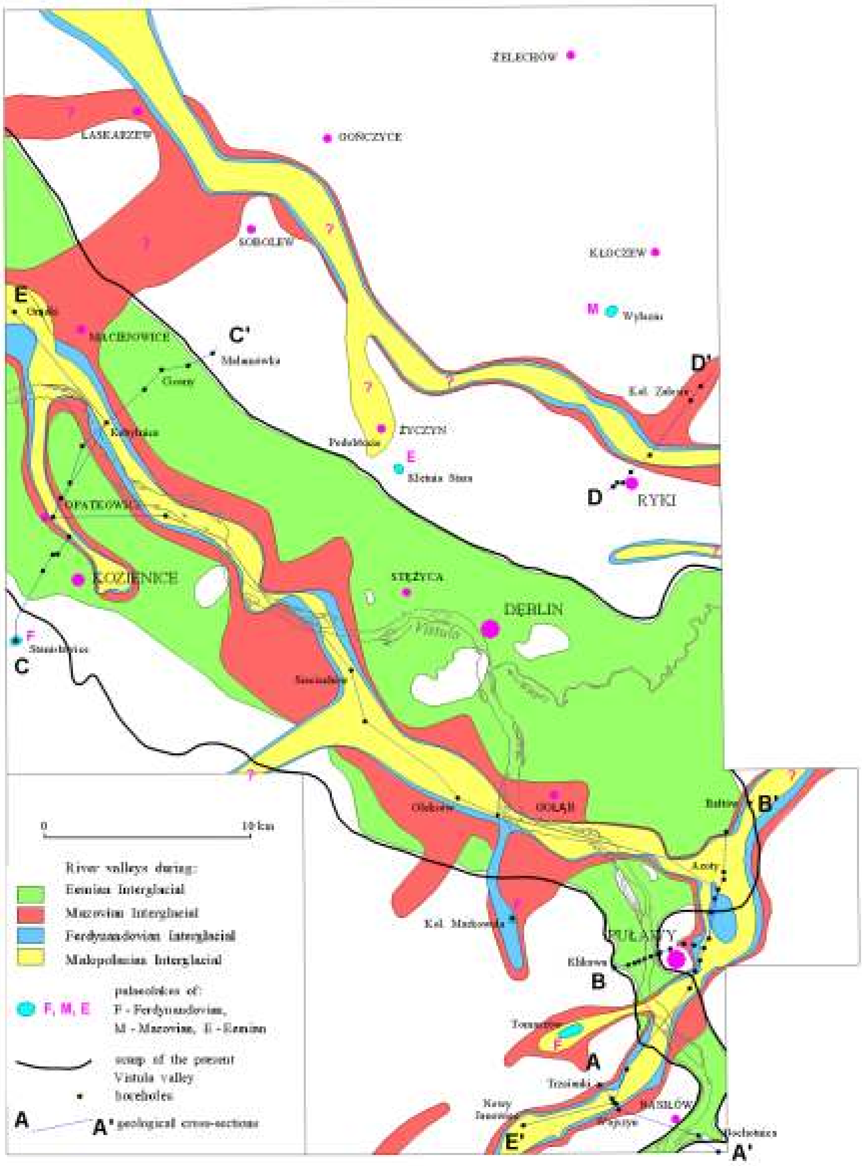


Fig. 5. Buried river valleys (after Sarnacka, 1986, 1990 and Żarski, 1989, 1996, 1998, 2000)

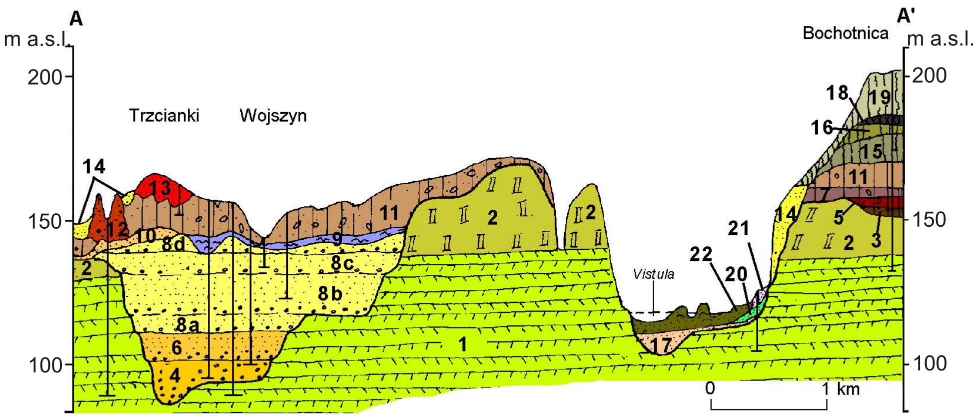


Fig. 6. Geological cross-section A–A’ between Trzcianki and Bochotnica (after Żarski, 2000)

Upper Maastrichtian: 1 — siliceous marls; **Lower Paleocene**: 2 — gaizes; **Nidanian Glaciation**: 3 — tills; **Małopolanian Interglacial**: 4 — fluvial sands and gravels; **Sanian Glaciation**: 5 — tills; **Ferdynandovian Interglacial**: 6 — fluvial sands and gravels; **Wilgian Glaciation**: 7 — tills; **Mazovian Interglacial**: 8 — fluvial sands and gravels (a–d — fluvial series); **Odranian Glaciation**: 9 — silts, 10 — lower fluvioglacial gravels and sands, 11 — tills, 12 — gravels and sands of frontal moraines, 13 — gravels and sands of dead ice moraines, 14 — upper fluvioglacial gravels and sands, 15 — loess; **Wartanian Glaciation**: 16 — loess; **Eemian Interglacial**: 17 — fluvial gravels and sands, 18 — palaeosol; **Vistulian Glaciation**: 19 — loess, 20 — fluvial gravels and sands, 21 — deluvial sands; **Holocene**: 22 — fluvial sands and muds of flood plain icity of deposition. The fluvial deposits of the Małopolanian, Ferdynandovian, Mazovian and Eemian interglacials usually are in contact with one another. Glacial strata separate the deposits of different interglacials in valley peripheries and on neighbouring plateaus (Fig. 7).

The buried valley (pre-Wilga?, Lindner *et al*., 1982) (Fig. 5) is parallel to the Vistula valley and filled with fluvial deposits dating from the Małopolanian, Ferdynandovian and Mazovian interglacials (Fig. 9).

The oldest fluvial deposits filling the buried Vistula valley relate to the **Małopolanian Interglacial** (Figs. 6–9). The width of Vistula valley in Małopolanian did not exceed 4 km (Figs. 5 and 7) and the valley gradient was about 0.57‰ — the same as that during the Ferdynandovian and Mazovian interglacials (Fig. 10). Fluvial deposits of the Małopolanian Interglacial fill the lowest part of the buried valley. They may reach to 35 m in thickness and accumulation of fluvial deposits reached a level of 115 m a.s.l. (Fig. 7). In the axis of the valley older interglacial deposits are preserved, while younger deposits occur in marginal zones (Fig.7). Małopolanian fluvial strata occur in a tributary valley at Tomaszów section also (Fig. 5). These are overlain by Sanian silts and lake deposits of the Ferdynandovian Interglacial as documented by pollen research (Krupiński, 1996). The Małopolanian Interglacial deposits are represented by: pebbles of gaizes, limestones, marls and siliceous rocks from the South Polish Uplands. Scandinavian rocks occur only sporadically. Among heavy minerals there are mostly garnets and tourmalines with a small quantity of amphiboles, supporting the fluvial genesis of these deposits (Gronkowska, 1996). Quartz grains are little rounded. Różycki (1972) referred all fluvial deposits, filling the buried Vistula valley near Puławy, to the Mazovian Interglacial. Sarnacka (1978, 1982, 1987) correlated the lower part of the succession in the buried Vistula valley with the Cromerian Interglacial. Pożaryski *et al*. (1994*b*) included the lower interval in the buried Vistula valley to Małopolanian and Ferdynandovian Interglacial combined.

I have recognised fluvial sands and gravels of the **Dęblinian Interstadial** (Table 1) in Kol. Markowola and in the Podobłocie section on the morainic plateau (Fig. 11). At Kol. Markowola these deposits are covered by fluvioglacial sands and gravels of the younger stadial of the Sanian Glaciation. Under the Dęblinian deposits there are silts and sands of the older stadial of Sanian Glaciation. The heavy mineral and carbonate content and roundness of the quartz grains indicate that the deposits of the Dęblinian Interstadial at Kol. Markowola accumulated in a fluvial environment. The sands have been TL dated at 491 ka (UG-1937, Fedorowicz and Olszak, 1994).

During the **Ferdynandovian Interglacial** the width of the buried Vistula valley reached 5–6 km (Figs. 5 and 7). In the valley axis Ferdynandovian deposits occur under Mazovian deposits. In the marginal zones of the Vistula valley at Puławy, tills of the Wilgian Glaciation separate fluvial deposits of Ferdynandovian Interglacial from deposits of the Mazovian Interglacial (Fig. 7). Fluvial deposits of the Ferdynandovian at Kol. Ryki in the buried “pre-Wilga” valley are overlain also by tills of Wilgian (Fig. 9). In the valley axis in the buried Vistula valley the oldest deposits are up to 10 m thick (Figs. 6–10). The thickness of the Ferdynandovian Interglacial succession may reach 40 m and this accumulated at some 124–128 m a.s.l. (Fig. 7). The Ferdynandovian deposits are composed of rocks from the South Polish Uplands and the admixture of Scandinavian rocks is slightly greater than in the Małopolanian Interglacial deposits. Quartz grains are well rounded. Among heavy minerals, garnets predominate with an admixture of tourmalines and amphiboles. Such a composition of heavy minerals is typical for these fluvial deposits.

The stratotype profile of the Ferdynandovian Interglacial is located nearby at Ferdynandów (Janczyk-Kopikowa, 1975; Janczyk-Kopikowa *et al*., 1981; Rzechowski 1996*a*, *b*). Outside of Vistula valley, I have documented palynological sites of Ferdynandovian age at Stanisławice (Janczyk-Kopikowa and Żarski, 1995), Tomaszów and Kol. Markowola (Krupiński, 1995, 1996) (Figs. 5 and 11). The site at Stanisławice is the only one with full palynological documentation. The organic deposits have been TL dated at 508–532 ka (Butrym, 1992; Fedorowicz and Olszak, 1993, 1994, 1995). At Stanisławice above the lacustrine succession there are tills ascribed to the Odranian Glaciation; in the Tomaszów borehole fluvial sands above the lake deposits may be referred to the Mazovian Interglacial and in Kol. Markowola borehole fluvioglacial sands and gravels relate to the Wilgian Glaciation (Fig. 11). In these three profiles, thus, lake deposits of the Ferdynandovian Interglacial are overlain by sediments belonging to three different stratigraphical units.

The width of Vistula valley during the **Mazovian Interglacial** (Holsteinian) was about 8 km (Fig. 5). In the valley axis Mazovian fluvial deposits underlie Eemian deposits. In marginal zones of the Vistula valley at Wojszyn and Bałtów, Mazovian deposits are overlain by Odranian deposits (Figs. 6 and 7). In the valley axis Mazovian deposits are up to 20 m thick because the sediments of younger series have been eroded. The thickness of Mazovian deposits can reach 45 m and these accumulated at Wojszyn to 145 m a.s.l. and around Puławy at 137 m a.s.l. (Figs. 6 and 7). Mazovian deposits in the buried Vistula valley and in the parallel buried “pre-Wilga” valley (Figs. 6 and 9) accumulated in four fluvial succession. It can not be excluded that the upper sandy succession ascribed to the Mazovian Interglacial accumulated in the Zbójnian Interglacial and crystalline rock pavements at Oleksów and Mozolice represent the Liviecian Glaciation. As regards petrographic composition local rocks predominate limestones and gaizes with siliceous rocks and Scandinavian rocks. Admixture of the latter is much greater than in deposits of the Ferdynandovian and Małopolanian interglacials. Quartz grains are very well rounded (Pruszek and Fert, 1986; Gronkowska, 1988, 1996, 1997). The fluvial deposits in the buried Vistula valley and in the parallel valley were TL dated at 399–299 ka (Butrym, 1987, 1992; Fedorowicz and Olszak, 1993, 1994, 1995). Similarly, as in deposits of the earlier interglacials, among heavy minerals garnets predominate over tourmalines together with some amphiboles, which indicates a fluvial genesis.

Lake sediments of the Mazovian Interglacial are present in the section at Wylezin (Fig. 12). Pollen studies were carried out by Dyakowska (1956) and the geology presented by Rühle (1968). Mazovian deposits are overlain by Odranian sands and gravels, and deluvial sands and tills. This site is situated low on

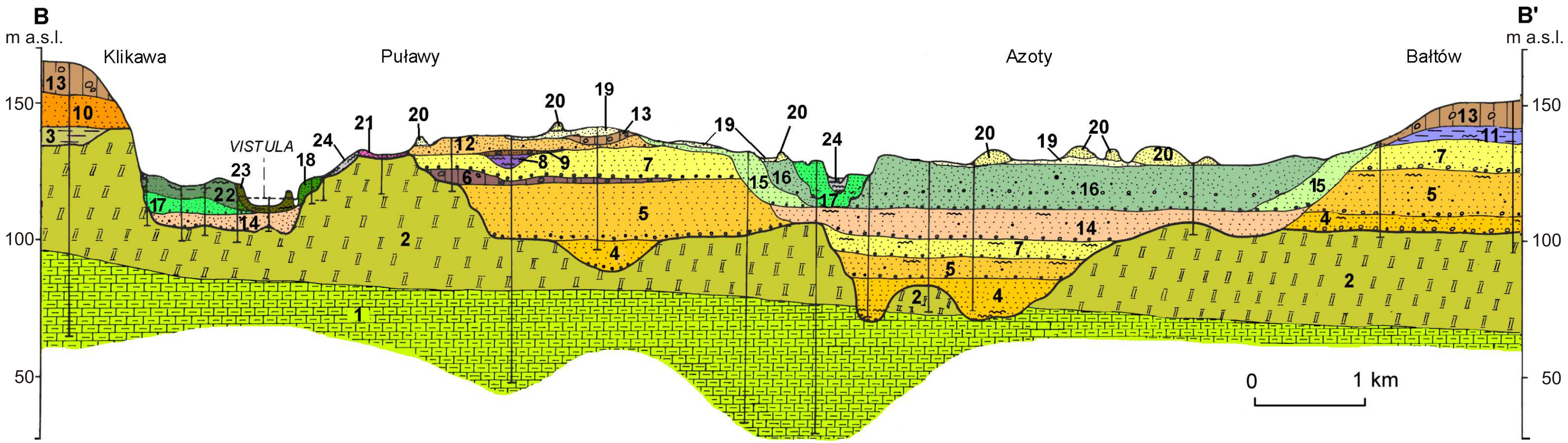


Fig. 7. Geological cross-section B–B' between Klikawa and Bałtów (after Żarski, 2000)

Upper Maastrichtian: 1 — marls; **Lower Paleocene**: 2 — gaizes; **Lower Oligocene**: 3 — clays; **Małopolanian Interglacial**: 4 — fluvial sands and gravels; **Ferdynandovian Interglacial**: 5 — fluvial sands and gravels; **Wilgian Glaciation**: 6 — tills; **Mazovian Interglacial**: 7 — fluvial sands and gravels; **Odranian Glaciation**: premaximum stadial: 8 — silts, 9 — tills; Gniewosznian Interstadial: 10 — fluvial sands; maximum stadial: 11 — clays, 12 — fluvioglacial gravels and sands, 13 — tills; **Eemian Interglacial**: 14 — fluvial gravels and sands; **Vistulian**: fluvial gravels and sands: 15 — of overbank terrace I, 16 — of overbank terrace II, 17 — of overbank terrace III, 18 — of overbank terrace IV, 19 — eolian sands, 20 — eolian sands in dunes, 21 — residual gravels and sands; **Holocene**: fluvial sands and muds: 22 — of upper flood plain, 23 —

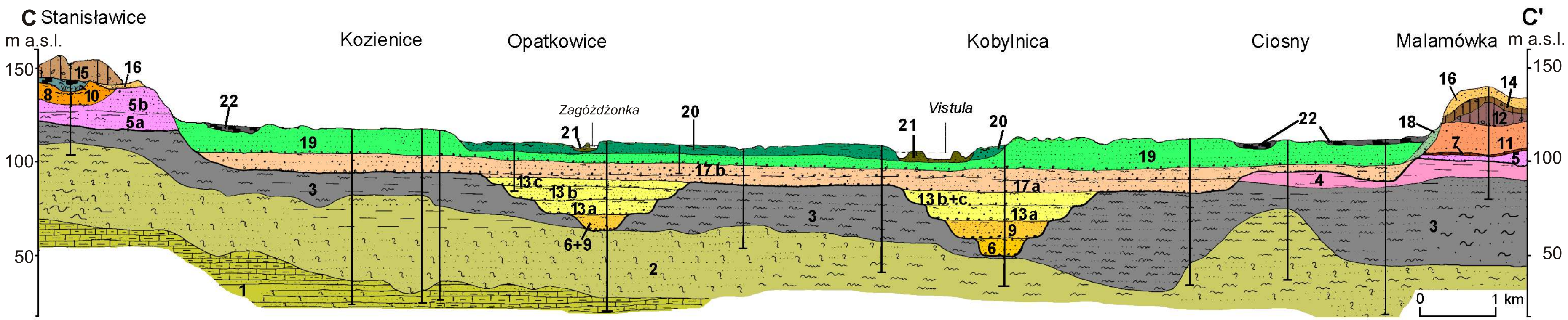


Fig. 8. Geological cross-section C–C' between Stanisławice and Malamówka (after Żarski, 2000)

Lower Paleocene: 1 — marls; **Lower Oligocene**: 2 — glauconitic sands and silts; **Miocene**: 3 — silts; **Upper Miocene**: 4 — clays; **Prepleistocene**: 5 — fluvial sands and gravels with silts (a, b — fluvial series); **Małopolanian Interglacial**: 6 — fluvial sands and gravels; **Sanian Glaciation**: 7 — tills, 8 — fluvial and fluvioglacial sands and silts; **Ferdynandovian Interglacial**: 9 — fluvial sands and gravels, 10 — peats and gyttjas; **Wilgian Glaciation**: 11 — fluvioglacial gravels and sands, 12 — tills; **Mazovian Interglacial**: 13 — fluvial sands and gravels (a–d — fluvial series); **Liviecian Glaciation**: 14 — tills; **Odranian Glaciation**: 15 — tills, 16 — fluvioglacial gravels and sands; **Eemian Interglacial**: 17 — fluvial gravels and sands (a, b — fluvial series); **Vistulian**: fluvial gravels and sands: 18 — of overbank terrace II, 19 — of overbank terrace III; **Holocene**: fluvial sands and muds: 20 — of upper flood terrace, 21 — of lower flood plain; 22 — peats

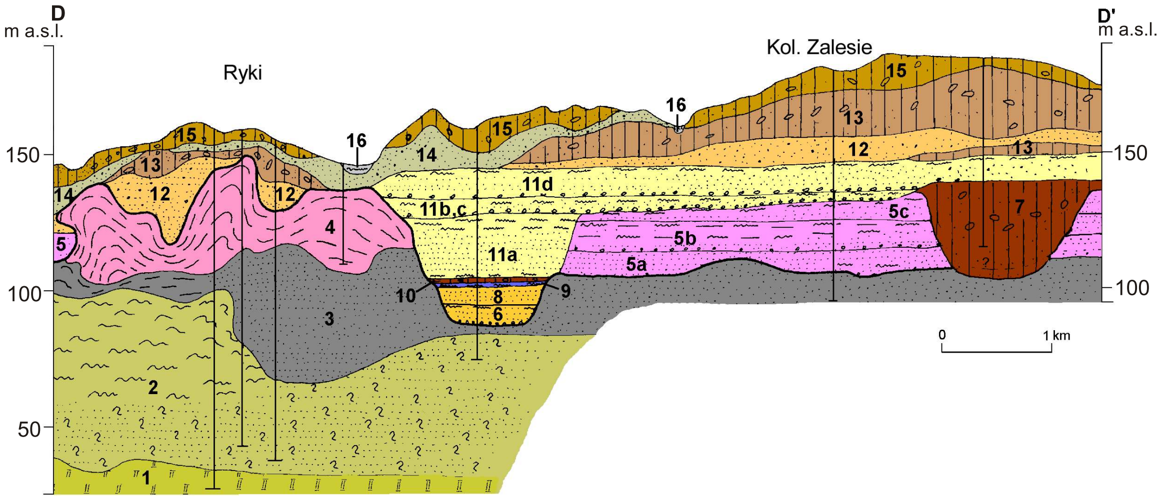


Fig. 9. Geological cross-section D–D' between Ryki and Kol. Zalesie (after Żarski, 2000)

Lower Paleocene: 1 — gaizes; **Lower Oligocene**: 2 — glauconitic sands and silts; **Miocene**: 3 — sands and silts; **Upper Miocene**: 4 — clays; **Prepleistocene**: 5 — fluvial sands, gravels and silts (a–c — fluvial series); **Małopolanian Interglacial**: 6 — fluvial sands with gravels; **Sanian Glaciation**: 7 — tills, **Ferdynandovian Interglacial**: 8 — fluvial sands and gravels; **Wilgian Glaciation**: 9 — silts, 10 — tills, **Mazovian Interglacial**: 11 — fluvial sands with gravels (a–d — fluvial series); **Odranian Glaciation**: 12 — fluvioglacial gravels and sands, 13 — tills; **Wartanian Glaciation**: 14 — fluvioglacial gravels and sands, 15 — tills; **Holocene**: 16 — fluvial silts

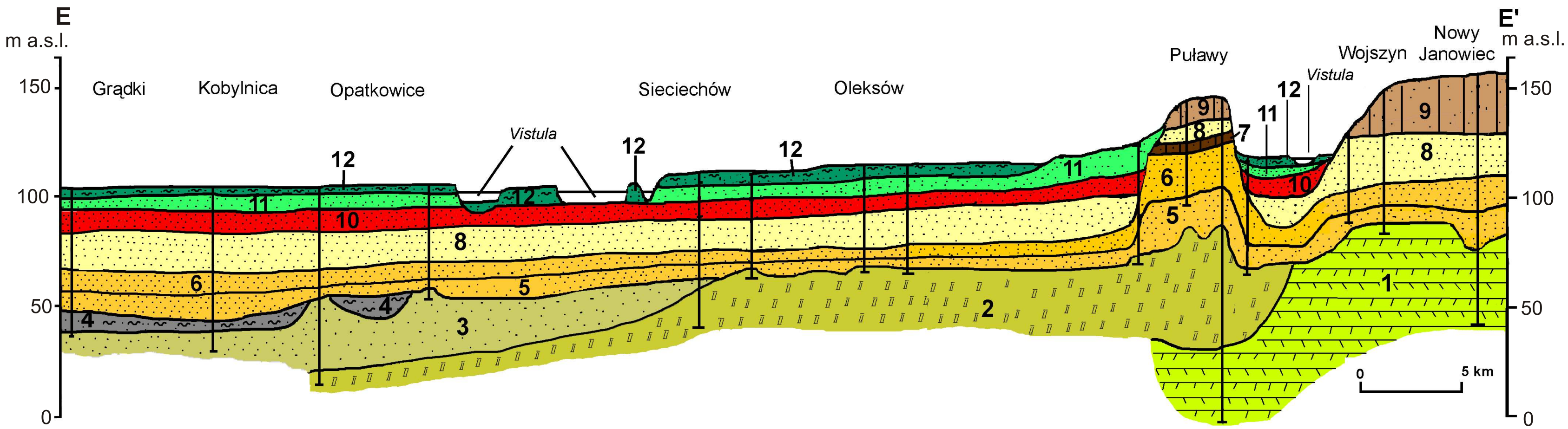


Fig. 10. Longitudinal section E–E' between Grądki and Nowy Janowiec (after Żarski, 2000)

Upper Maastrichtian: 1 — siliceous marls; **Lower Paleocene**: 2 — gaizes; **Lower Oligocene**: 3 — sands; **Miocene**: 4 — silts; **Małopolanian Interglacial**: 5 — sands and gravels; **Ferdynandovian Interglacial**: 6 — sands and gravels; **Wilgian Glaciation**: 7 — tills; **Mazovian Interglacial**: 8 — sands and gravels; **Odranian Glaciation**: 9 — sands and tills; **Eemian Interglacial**: 10 — sands and gravels; **Vistulian**: 11 — sands and gravels of overbank terraces; **Holocene**: 12 — sands and muds of flood plain

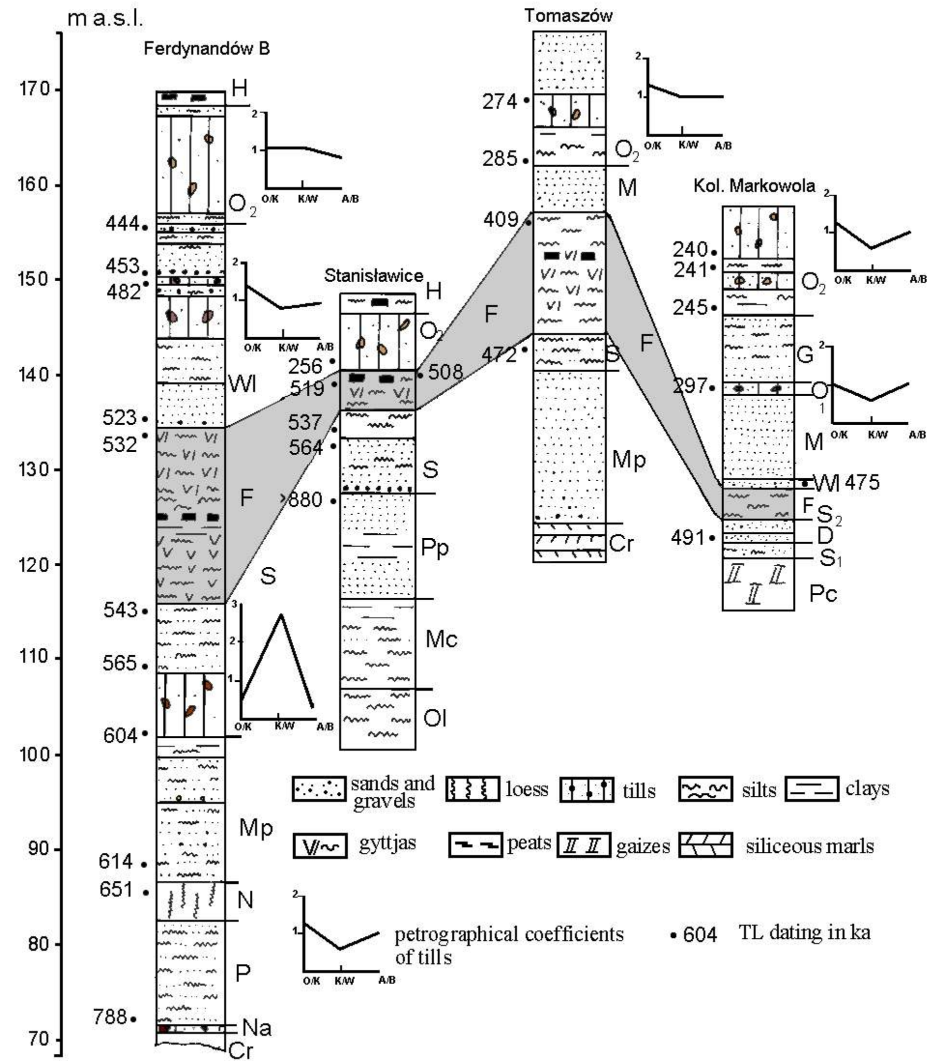


Fig. 11. Correlation geological profiles with deposits of Ferdynandovian Interglacial documented by pollen research; Ferdynandów B profile by Rzechowski (1990), others by Żarski (1996, 1998)

Cr — Cretaceous, Pc — Paleocene, Ol — Oligocene, Mc — Miocene, Na — Narevian Glaciation, P — Podlasian Interglacial, N — Nidanian Glaciation, Mp — Małopolanian Interglacial, S — Sanian glaciation, S_1 — Sanian Glaciation, older stadial, D — Dęblinian Interstadial, S_2 — Sanian Glaciation, younger stadial, F — Ferdynandovian Interglacial, Wl — Wilgian Glaciation, M — Mazovian Interglacial, O_1 — Odranian Glaciation, premaximum stadial, G — Gniewosznian Interstadial, O_2 — Odranian Glaciation, maximum stadial, H — Holocene

the Okrzejka river valley slope (Fig. 12). The Middle Polish Glaciation (Saalian) is almost completely absent here.

Fluvial deposits of the **Zbójnian Interglacial** are present at Kajzerówka on the morainic plateau outside the buried Vistula valley (Fig. 4). Silts from this profile, referred to the Zbójnian Interglacial, were TL dated at 344 ka BP (Lub-2473; Butrym, 1992).

In the study area in the buried Vistula valley fluvial deposits of the Lublinian Interglacial were not recognised, likely due to erosion during the Eemian Interglacial. Pożaryski *et al*. (1994*b*) distinguished fluvial deposits from the Lublinian and Eemian interglacials combined near Puławy.

The Lublinian Interglacial is represented in the study area by a palaeosol at Bochotnica (Żarski, 2000), lying between Odranian and Wartanian loesses.

Fluvial sands at Kol. Markowola near Gniewoszów (Figs. 5 and 11), separating tills of the premaximum and maximum stadials of the Odranian Glaciation, represent the **Gniewosznian Interstadial**. Their occurrence is limited to the edge of the Vistula valley.

In the buried Vistula valley, above deposits of the Mazovian Interglacial, there are fluvial deposits of the **Eemian Interglacial** which are 12–20 m thick (Figs. 6–8 and 10). The valley gradient is about 0.31‰ (Fig. 10), the same as the gradient on the Vistulian (Weichselian) terrace and the gradient of the present-day Vistula river-bed. This significantly lower gradient compared to those of earlier interglacials encouraged lateral erosion, and as a result the Vistula valley widened to about 15.5 km across (Fig. 5). The lower gradient in the Eemian suggests a decline of neotectonic movements: areas stopped being elevated (Baraniecka, 1975*b*, 1981). Eemian Interglacial deposits, as regards petrography, contain the largest admixture of crystalline Scandinavian rocks by comparison with deposits of earlier interglacials. Quartz grains are well rounded and typical for fluvial deposits (Gronkowska, 1988, 1997). Fluvial deposits of the Eemian Interglacial at Leśna Rzeka were TL dated at about 93 ka BP (Lub-2471; Butrym, 1992). During the Eemian the course of the buried Vistula valley was the same as that of the present Vistula river valley, as also indicated to the north and south of the study area (Marks and Pochocka, 1999).

On the morainic plateau, sedimentation of organic deposits was taking place in lakes. The Eemian Interglacial site at Kletnia Stara was analysed for pollen (Żarski, 1989*b*) confirming its age (Janczyk-Kopikowa, 1987). These deposits overlain ice-dammed lake clays of the Wartanian Glaciation (Fig. 13). Eemian deposits are covered by Vistulian sands.

The Eemian Interglacial is represented at Bochotnica (Żarski, 2000) by a palaeosol above loesses of the Wartanian Glaciation and below Vistulian loesses (Fig. 6).

Above Eemian Interglacial deposits in the Vistula valley there are **Vistulian** (Weichselian) fluvial deposits (Figs. 6–8 and 10). The maximum width of the Vistula valley during the Vistulian was about 17 km. Vistulian deposits consist of 4 fluvial units. The oldest built the highest overbank terrace I, which rises from 15 to 22 m above river level (Fig. 7). The gradient of the sand and gravel terrace is about 0.34‰, the same as the gradient of younger Vistulian terraces. It is correlated with the Puławy terrace (of high cover) delineated by Pożaryski (1953, 1955) and Pożaryski *et al*. (1999). The younger Vistulian includes the overbank terrace II which is at an altitude of 12 to 15 m above the river level (Figs. 7, 8 and 10). Channel deposits build this terrace, which is about 20 metres thick and correlates with the Otwock terrace (Baraniecka, 1976). Deposits of terrace I and II accumulated in the Leszno-Pomeranian Stadial of the Vistulian Glaciation. The third Vistulian unit comprises overbank terrace III (Praga terrace) at 5 to 12 m above river level (Figs. 7 and 8). Deposits of this terrace are 10–20 m thick and consist of channel facies: sands and gravels and overbank facies — silts (Figs. 7 and 8).

Terrace III deposits relate to the Early Bölling (Żarski, 1990*b*). Peats dated at Stężyca are ^{14}C dated at 12 940 years BP (Pazdur, 1986) (Fig. 14), older than previously considered. According to Baraniecka and Konecka-Betley (1987), accumulation started in the Older Dryas and persisted to the Allerød.

The youngest Vistulian unit forming overbank terrace IV rises from 3–5 m above river level (Fig. 7). Sands and gravels of this unit occur around Puławy and Kozienice. The width of the terrace reaches several hundred metres.

Dunes and eolian sands on the overbank terraces (Figs. 7 and 14) accumulated during the Late Glacial and the Holocene as indicated by ^{14}C dating at Stężyca (Żarski, 1990*b*) (Fig. 14).

THE HOLOCENE VISTULA VALLEY

Deposits of two Holocene flood plains of abut sediments overbank terrace deposits (Figs. 6–8 and 10). The higher flood plain rises from 2 to 4 m above river level. The width of this flood plain near Dęblin and Kozienice is about 10 km. The flow of the Vistula between Dęblin and Maciejowice on the overbank terrace stopped at around the Pleistocene/Early Holocene boundary (the age of bottom peat at Podobłocie is 9940 years BP ^{14}C method, G-d 5218; Pazdur, 1988). The course of the Holocene Vistula had moved by 6–10 km to the west. The lower parts of the higher flood plain comprise channel facies sands and gravels, while the upper parts comprise overbank facies silty clays and sandy silts. Alluvial silts from 2.5 m depth at Sieciechów were TL dated at 8500 years BP (Lub-2771; Butrym 1992). They are probably the oldest overbank deposits from the time when the Vistula changed regime from braided to meandering. The majority of alluvial soils on the flood plain accumulated during the Subboreal and Subatlantic periods (Pożaryski and Kalicki, 1995). Channel facies deposits on flood plains are less sorted than those building overbank terraces, with poor rounding of quartz grains. The lower flood plain 2 reaches to 2 m above average river level. It extends along the present-day Vistula and Wieprz river channels including all contemporary islands and sandbars. The surface of this terrace is strongly dissected by overbank flows. The gradient of river bed is 0.30‰. The Vistula is currently a braided river while the Wieprz is a meandering river.

PLEISTOCENE ICE SHEET LIMITS

The oldest recognised glacial deposits are tills of the **Nidanian Glaciation** seen, for example, in boreholes at Bochotnica (Fig. 6), Wylezin and Życzyn (Figs. 12 and 15). Petrographic coefficients of tills from Bochotnica borehole are as follows: O/K = 1.58, K/W = 0.72, A/B = 1.16 by Gronkowska (1988) (O/K, K/W, A/B — relation between different groups of Scandinavian rocks in tills, where: O — total of sedimentary rocks, K — total of crystalline rocks and northern quartz, W — total of carbonate rocks, A — total of rocks non-resistant to destruction, B — total of resistant rocks). These petrographic coefficients are characteristic of tills of the Nidanian Glaciation in this region and correlate with the N lithotypes distinguished by Rzechowski (1977) and Lisicki (1997). Beneath these tills are fluvioglacial sands and gravels. Deposits of this age occur only in hollows.

Deposits of the older stadial of the **Sanian Glaciation (San 1)** are represented by tills, fluvioglacial sands and gravels and marginal lake deposits. They were found, too, in hollows in the northern part of the researched area around Życzyn, Wylezin, Trojanów and Malamówka (Figs. 8, 12 and 15).

The TL age of deposits of the older stadial of the Sanian Glaciation, was dated by Rzechowski (1990) in the Ferdynandów B borehole and by Pożaryski *et al.* (1994*b*) at Parchatka, is 543–632 ka BP. Petrographic coefficients of tills from Ferdynandów profile have values of 0.44–2.78–0.33 (Rzechowski, 1990) (Fig. 11).

Tills of the younger stadial of the **Sanian Glaciation (San 2)** investigated in the Bochotnica borehole (Fig. 7) have petrographic coefficients of 1.14–0.97–0.93 (Gronkowska, 1998). They were TL dated at 472–564 ka BP (Fedorowicz and Olszak, 1995). There are two tills between the Ferdynandovian and Małopolanian interglacials which I correlate with the Sanian Glaciation, and between the Mazovian and Ferdynandovian interglacials I have recognised one level of tills which corresponds with the Wilgian Glaciation. Unfortu-

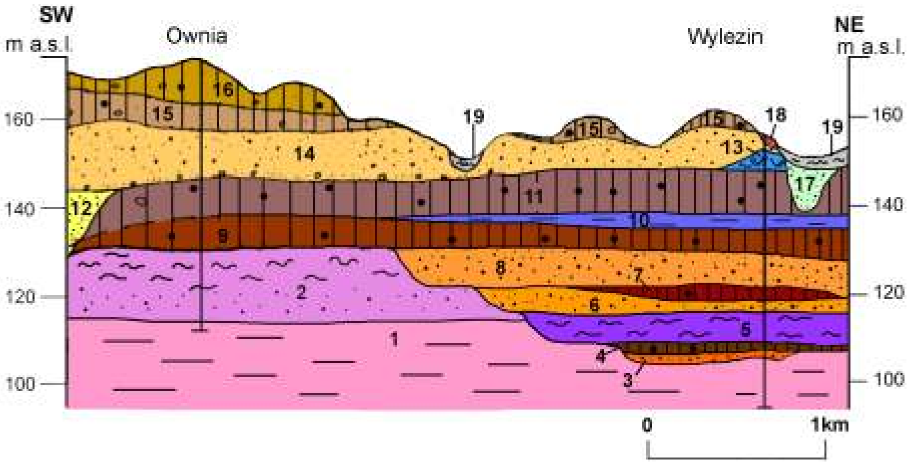


Fig. 12. Geological position of Mazovian Interglacial in Wylezin (after Rühle, 1968 and Żarski, 2000)

Miocene: 1 — clays; **Prepleistocene**: 2 — fluvial sands and silts; **Nidanian Glaciation**: 3 — fluvioglacial sands and gravels, 4 — tills; **Sanian Glaciation**, older stadial: 5 — silts, 6 — fluvioglacial sands and gravels, 7 — tills, younger stadial: 8 — fluvioglacial sands and gravels, 9 — tills; **Wilgian Glaciation**: 10 — clays, 11 — tills; **Mazovian Interglacial**: 12 — fluvial sands and gravels, 13 — gyttjas; **Odranian Glaciation**: 14 — fluvioglacial sands and gravels, 15 — tills; **Wartanian Glaciation**: 16 — tills, 17 — fluvioglacial sands and gravels; **Vistulian**: 18 — deluvial sands and tills; **Holocene**: 19 — fluvial silts

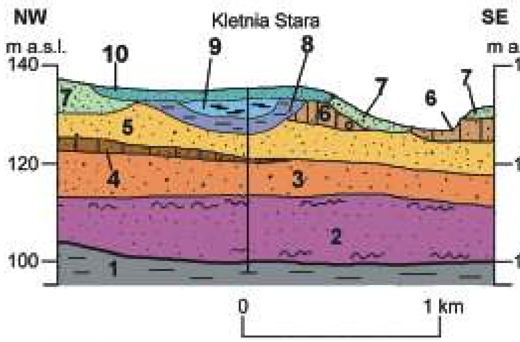


Fig. 13. Geological setting of Eemian Interglacial at Kletnia Stara (after Żarski, 2000)

Miocene: 1 — clays; **Prepleistocene**: 2 — fluvial sands and silts; **Wilgian Glaciation**: 3 — fluvioglacial sands and gravels, 4 — tills; **Odranian Glaciation**: 5 — fluvioglacial sands and gravels, 6 — tills; **Wartanian Glaciation**: 7 — fluvioglacial sands and gravels, 8 — clays; **Eemian Interglacial**: 9 — peats; **Vistulian**: 10 — fluvial sands

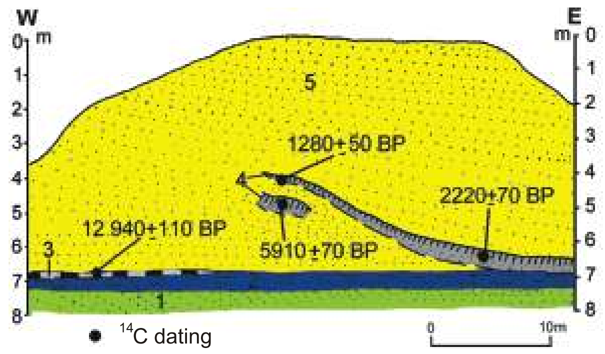
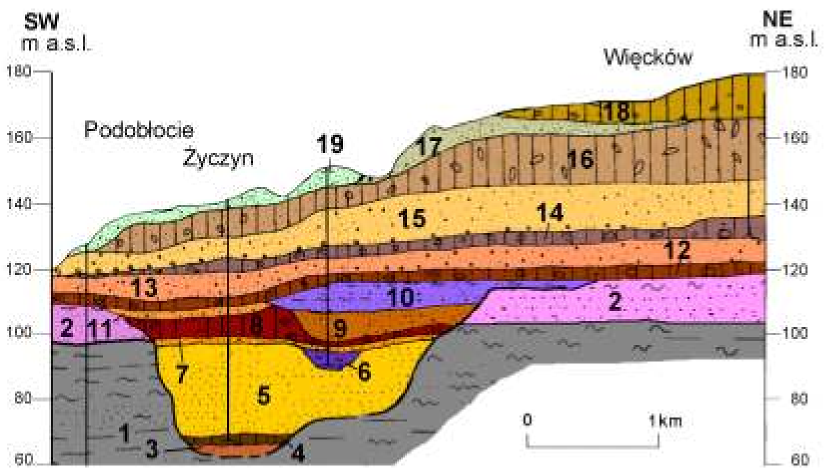


Fig. 14. Dune at Stężyca (after Żarski, 1990)

Vistulian: 1 — fluvial sands of the III overbank Vistula terrace (the Praga terrace), 2 — fluvial muds of the III overbank Vistula terrace (the Praga terrace), 3 — peats; **Holocene**: 4 — palaeosol, 5 — eolian sands, 6 — ^{14}C dating

Fig. 15. Sediments in Quaternary depression in Życzyn (after Żarski, 2000)

Miocene: 1 — silts and clays; **Prepleistocene**: 2 — fluvial sands, gravels and silts; **Nidanian Glaciation**: 3 — fluvioglacial gravels and sands, 4 — tills; **Małopolanian Interglacial**: 5 — fluvial sands; **Sanian Glaciation**, older stadial: 6 — clays, 7 — fluvioglacial gravels and sands, 8 — tills; **Dęblinian Interstadial**: 9 — fluvial sands; **Sanian Glaciation**: younger stadial: 10 — ice dammed silts and sands, 11 — fluvioglacial gravels and sands, 12 — tills; **Wilgian Glaciation**: 13 — fluvioglacial gravels and sands, 14 — tills; **Odranian Glaciation**: 15 — fluvioglacial gravels and sands, 16 — tills; **Wartanian Glaciation**: 17 — lower fluvioglacial gravels and sands, 18 — tills, 19 — upper fluvioglacial gravels and sands



nately, in no profiles on the study area do deposits of the Sanian Glaciation, Ferdynandovian Interglacial, Wilgian Glaciation and Mazovian Interglacial occur in superposition. Correlation of tills of the Wilgian and Sanian glaciations is by reference to sites with palynologically documented interglacial deposits: Ferdynandovian (Ferdynandów B, Stanisławice, Tomaszów, Kol. Markowola; Fig.11) and Mazovian (Wylezin, Poznań; Fig. 12). This showed that deposits of the younger stadial of the Sanian Glaciation occurred beneath Ferdynandovian Interglacial deposits. Tills of the upper stadial have different petrographical coefficients than tills of the Wilgian Glaciation. TL dating shows that deposits of the Wilgian Glaciation are younger than deposits of the younger Sanian Glaciation stadial. In the study area the deposits of the younger stadial of the Sanian Glaciation (tills, fluvioglacial sands and gravels) occur more commonly than older stadial deposits. Deposits of the younger stadial of the Sanian Glaciation have been recognised around Wylezin, Trojanów, Niwa Babicka and Życzyn in the northern part of the study area and at Tomaszów, Kol. Markowola and Moszczanka, south of Ryki (Figs. 12 and 15).

The **Wilgian Glaciation** is represented by fluvioglacial sands and gravels, marginal lake sediments and tills (Figs. 6–13, 15 and 16). These deposits were TL dated at 413–519 ka (Butrym, 1992; Fedorowicz and Olszak, 1995). Petrographic coefficients of tills, e.g. from the Bochotnica borehole, are 1.31–0.86–1.03 (Gronkowska, 1996) and correlate with petrographic coefficients of Wilgian Glaciation tills in Ferdynandów B (Rzechowski, 1996*a*). Tills have been examined petrographically in the Bóbek, Ruda and Jazień profiles. The first two profiles show petrographic characteristics similar to that of Bochotnica. At Jazień it is different. Deposits of the Wilgian Glaciation are more common than those of the Sanian Glaciation, occuring in boreholes and at surface. Spatial correlation of deposits of this age was made on many cross-sections.

Deposits of the **Liviecian Glaciation** have been recognised for the first time on the study area, moving the maximum extent of this glaciation tens kilometres to the south of the previous limit (Żarski, 1994). These deposits were TL dated at 354–393 ka BP (Butrym, 1992) (Fig. 16). Petrographic coefficients of the tills at Jazień are 1.56–0.63–1.38. Deposits of the Liviecian Glaciation occur in the Vistula valley zone only (Fig. 1). This was probably the short glacial episode during the Great Interglacial (Holsteinian). Deposits of the Liviecian Glaciation were recognised in the Kozienicka Forest and around Życzyn, Podobłocie, Jazień and Malamówka (Figs. 8 and 16). They comprise tills, marginal lake and fluvioglacial deposits. The correlative units are tills only a few metres thick (Fig. 16). Deposits of the Liviecian Glaciation outcrop and are also found in boreholes at Bóbek and Podobłocie-Życzyn (Fig. 16). It cannot be excluded that crystalline rocks occurring in the roof of the Mazovian Interglacial, distinguished at Mozolice and Oleksów, represent the Liviecian Glaciation. Deposits of the Liviecian Glaciation are often separated from deposits of the Odranian Glaciation by fluvioglacial sands and gravels, as are deposits of the premaximum stadial of the Odranian Glaciation (Fig. 17). The lithology, petrography and absolute age of the latter suggest that they belong to the Liviecian Glaciation. The wider extent of Liviecian Glaciation deposits is problematic because of a scarcity of researched boreholes.

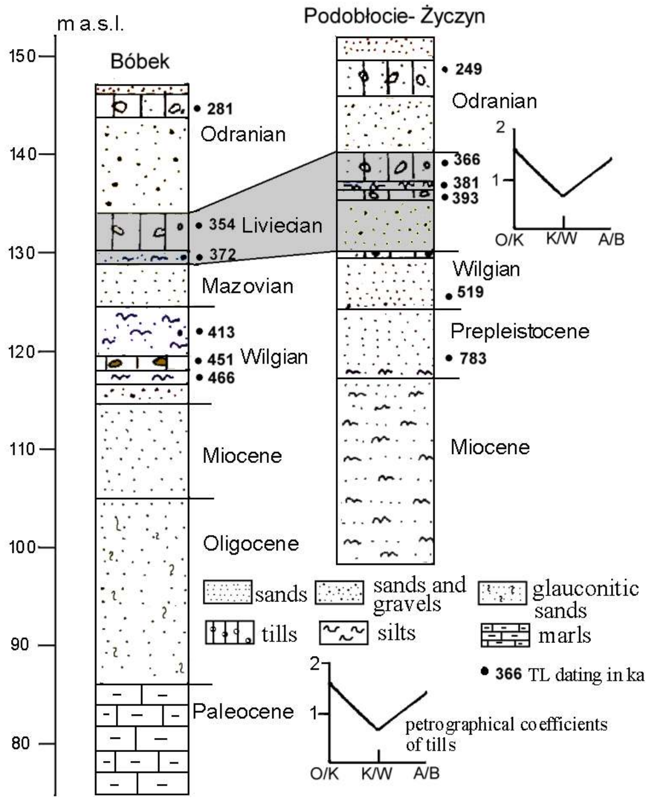


Fig. 16. Boreholes with deposits of the Liviecian Glaciation (after Żarski, 2000)

Deposits of the **premaximum stadial** of the **Odranian Glaciation** are represented by tills and marginal lake deposits. Tills were TL dated at 297 ka BP at Kol. Markowola (Fedorowicz and Olszak, 1994) (Figs. 11 and 17). The petrographic coefficients of tills at Kol. Markowola are 1.04–1.14–0.76 (the quantity of gravels is less than 100). Tills of the premaximum stadial differ from tills of the Liviecian Glaciation by different petrographic coefficients and also by a considerably younger age. Deposits of the premaximum stadial were distinguished around Kol. Markowola, Ławeczko and Puławy.

Deposits of the **maximum stadial** of the Odranian Glaciation occur on the plateau surface in the southern and eastern parts of the study area. The plateau surface, on the left Vistula bank between Wojszyn and Gniewoszów, is at an altitude of 150 to 177 m a.s.l. Around Kozienice the plateau is denuded; its surface is at a height of 145 to 155 m a.s.l. Deposits of the maximum stadial are fluvioglacial sands and gravels, marginal lake deposits, tills, esker sands and gravels, end moraines, dead ice moraines, crevasse forms and kame sands and silts. In the study area the Odranian ice sheet has end moraines around Trzcianki, Wojszyn and Kozienice. The deposits of the maximum stadial were TL dated at 212–280 ka BP (more than twenty datings: Butrym, 1987, 1992; Fedorowicz and Olszak, 1993, 1994, 1995). The average petrographic coefficients of tills from 11 boreholes (Fig. 17) are 1.33–0.87–1.05 and characterise a local till lithotype (Żarski, 2000). Maximum stadial deposits are easily recognised because of their extensive outcrop the study area

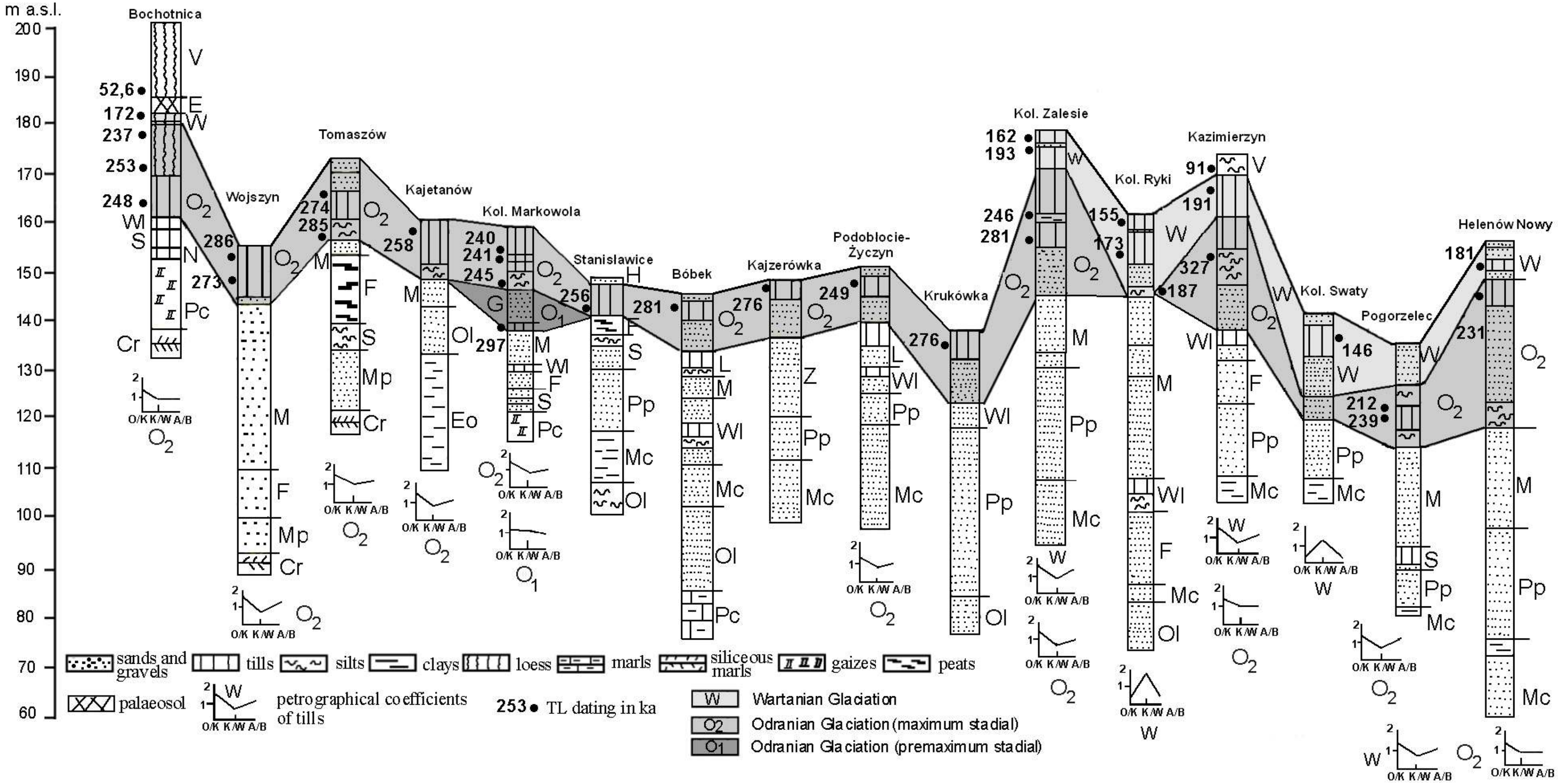


Fig. 17. Correlation boreholes with sediments of Odranian and Wartanian glaciations by Żarski (2000), sections Pogorzelec and Helenów Nowy by Sarnacka (1986)

Cr — Cretaceous, Pc — Paleocene, Eo — Eocene, Ol — Oligocene, Mc — Miocene, Pp — Prepleistocene, N — Nidanian Glaciation, Mp — Małopolanian Interglacial, S — Sanian Glaciation, F — Ferdynandovian Interglacial, Wl — Wilgian Glaciation, M — Mazovian Interglacial, L — Liviecian Glaciation, Z — Zbójnian Interglacial, O_1 — Odranian Glaciation, premaximum stadial, G — Gniewosznian Interstadial, O_2 — Odranian Glaciation, maximum stadial, W — Wartanian Glaciation, E — Eemian Interglacial, V — Vistulian, H — Holocene facilitating their spatial correlation. In the south of the study area the tills has an intercalation of marginal lake deposits. Tills lying above and beneath these marginal lake deposits have similar petrographic coefficients. These deposits probably correlate with the postmaximal stadials of the Odranian Glaciation. Lindner *et al*. (1985) distinguished two postmaximal stadials of the Odranian Glaciation in central Poland. Deposits of the maximum stadial of the Odranian Glaciation lie on Quaternary sediments of different age and on bedrock (Fig. 17), exemplifying the geological complexity of the study area.

The **Wartanian Glaciation** reached the Wieprz valley, at least (Fig. 1). Formerly, it was considered that this ice sheet only reached the southern Pilica valley. Deposits of Wartanian Glaciation are represented by fluvioglacial and marginal lake deposits, glacial sands and gravels of end moraines, dead ice moraines, crevasse forms, kame sands and silts and loesses (Fig. 12). A long-term still stand is marked by end moraines and marginal valleys of which the biggest is the Wieprz valley. The Wieprz valley has a different course than older parts of the Wieprz river valley (dating from the Wartanian ice sheet limit). A change of trend from N–S to E–W took place during the Wartanian deglaciation. Deposits of the Wartanian Glaciation were TL dated at 146–203 ka BP (Butrym, 1987) (Fig. 17). Two clusters of dates (190–170 and 160–140 ka BP) are reflected in a duality of tills (Żarski, 1990*a*, 1993*b*), which are petrographically indistinguishable. Two petrographic tills types are distinguished. The first has petrographic coefficients of 1.68–0.66–1.19 and the second of 0.93–1.48–0.70, characteristic of tills exposed to denudation (Żarski, 2000). Wartanian Glaciation loesses are also present (Fig. 6). In the final phase of deglaciation intensive erosion took place of deposits of the Middle Polish Glaciation (Saalian) on the area of the Kozienice Forest. The Wartanian plateau is at 160 to 190 m a.s.l. It is located about 20 m higher than plateau surfaces which are over 25 km to the south of study area and out of the range of the Wartanian Glaciation.

DISCUSSION

The age of the Vistula valley is controversial. In Sawicki's (1925) opinion, the buried Vistula valley is as old as Pliocene. Lewiński (1914) and Samsonowicz (1922) correlated it with the Prepleistocene. This was supported by investigations of Pożaryski (1953, 1955) and Pożaryski *et al*. (1994*a*, *b*) in the Vistula river gap in the South Polish Uplands. Pożaryski *et al.* (1994*a*, *b*) showed that the buried Vistula valley contains 4 fluvial interglacial units. Laskowska-Wysoczańska (1993) correlated the age of the Vistula valley gap with the Odranian deglaciation. In the buried Vistula valley my investigations (Żarski, 2000) upheld the occurrence of 4 fluvial depositional units of Małopolanian, Mazovian, Ferdynandovian and Eemian Interglacial age, with differing petrographic compositions. Fluvial Prepleistocene deposits were recognised outside the buried Vistula valley.

Six glaciations were distinguished in the study area. The area lay within the maximum limit of the Narevian Glaciation but deposits of this glaciation were not preserved (Lindner and Marks, 1995; Lindner and Wojtanowicz, 1997).

Further investigations are needed as regards deposits of the Liviecian Glaciation. These deposits were documented only in a few profiles in the Vistula valley around Kozienice and Życzyn (Figs. 1 and 16) A maximum ice sheet limit of Liviecian Glaciation is likely present (Fig. 16).

CONCLUSIONS

1. Deposits of Upper Maastrichtian, Lower Paleocene, Lower Oligocene, Lower/Middle Eocene and Miocene age are a bedrock to the Quaternary. These strata decline generally northeastwards by several degrees. The area contains a marine margin from the Oligocene and a lake margin from the Miocene.

2. Prepleistocene strata represent the oldest fluvial Quaternary deposits. They are alluvial cones deposited by rivers flowing from the south.

3. The buried and present-day Vistula valleys were developed along linear tectonic structures of NW–SE trend. The buried Vistula valley was filled with fluvial units of 40–60 m thickness of the Małopolanian, Mazovian, Ferdynandovian and Eemian interglacials. In the valley axis, these are in superposition and in marginal zones they are locally separated by tills. In the axial part of the valley deposits of older interglacials are preserved while in marginal zones younger deposits occur.

4. The Vistula valley gradient shown by Małopolanian, Mazovian and Ferdynandovian interglacial deposits is 0.57‰; Eemian Interglacial, Vistulian and Holocene deposits show a gradient of about 0.34‰. The change of gradient was the result of tectonic movements, abating in early Eemian Interglacial times. The buried Vistula valley was widest during the Eemian Interglacial (15 km) and during the Vistulian (17 km), when strong lateral erosion occurred.

5. During the Vistulian deposits of overbank terraces accumulated; during the Holocene deposits of flood plains predominated.

6. Lacustrine Ferdynandovian (at Stanisławice, Tomaszów, Kol. Markowola), Mazovian (Wylezin) and Eemian (Kletnia Stara) Interglacial deposits have been documented by pollen research.

7. This region was covered by ice sheets of the Nidanian, Sanian, Wilgian, Liviecian, Odranian and Wartanian glaciations during eight advances. Deposits of Nidanian and Sanian occur in hollows in the Quaternary bedrock. These usually occur where lineaments and faults intersect. In these hollows Quaternary deposits are up to 70–80 m thick.

8. In the study area, Liviecian and Wartanian glaciation limits were determined. The Wartanian ice sheet reached the Wieprz valley and the Liviecian ice sheet reached the Kozienice–Życzyn line.

9. Fluvial deposits of the Gniewosznian Interstadial, between the premaximum and maximum stadials of the Odranian Glaciation, were recognised.

10. Local petrographic lithotypes of Odranian Glaciation tills (petrographic coefficients: 1.33–0.87–1.05) and Wartanian Glaciation tills (1.68–0.66–1.19) were defined in the study area. The Wartanian Glaciation deposits were TL dated at 146–203 ka BP and the Odranian at 212–280 ka BP.

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