Geological Quarterly, 2007, **51** (1): 79–90

Paleogene marginal marine sedimentation in central-western Poland

Marek WIDERA and Agnieszka KITA

Widera M. and Kita A. (2007) — Paleogene marginal marine sedimentation in central-western Poland. Geol. Quart., **51** (1): 79–90. Warszawa.

The Paleogene deposits of central-western Poland area have been studied in more than 300 boreholes and several outcrops with lithological, mineralogical and sedimentological methods. Grain-size analyses, heavy mineral analyses, XRD analyses and pebble analyses were mainly used to characterize these deposits. From the Late Eocene until the Late Oligocene central-western Poland area was a marginal part of the NW European Tertiary Basin. For this time interval five informal lithostratigraphical units have been determined: the Pomorze, Lower Mosina, Czempiń, Upper Mosina and Leszno “formations” and additionally the Kaolinite Sand Unit. Their correlation is based on lithological features obtained from archival descriptions of borehole profiles. Deposits from boreholes and newly discovered exposures are mainly marine while only the Czempiń “Formation”, with lignite intercalations, represent a non-marine environment. These findings help reconstruct the structural and palaeogeographic evolution of the eastern, marginal fragment of the NW European Tertiary Basin. The succession shows evidence of at least four interregional transgressive-regressive cycles. Moreover, the present-day extent of the Paleogene deposits has been determined much more precisely. The southern limit of marine sedimentation in Paleogene times should be pushed at least a few tens of kilometres south in the vicinity of Konin and Turek, central-western Poland.

Marek Widera, Institute of Geology, A. Mickiewicz University, Maków Polnych 16, PL-61-606 Poznań, Poland, e-mail: widera@amu.edu.pl; Agnieszka Kita, Turek District, Kaliska 59, PL-62-700 Turek, Poland, e-mail: rolnictwo@powiat.turek.pl *(received: March 23, 2006; accepted: October 25, 2006).*

Key words: Paleogene, lithostratigraphy, palaeogeography, kaolinite sands, deposit extent.

INTRODUCTION

Paleogene deposits have been known in Poland, including the area studied here, since the second half of the 19th century (Piwocki, 2001, 2004). During the 20th century they were documented and examined in numerous boreholes situated in the central-western parts of Poland as well as in their surroundings (Pożaryski, 1953; Areń, 1957–1964; Wolańska, 1962; Osijuk and Piwocki, 1964; Woźny, 1965; Odrzywolska-Bieńkowa, 1966, 1973, 1975; Olempska, 1973; Ciuk, 1974, 1977; Dyjor, 1974; Pożaryska and Odrzywolska-Bieńkowa, 1977; Matl and Śmigielska, 1977; Ciuk and Pożaryska, 1982; Kosmowska-Ceranowicz and Bühmann, 1982; Ciuk and Grabowska, 1991; Kozydra and Skompski, 1995; Widera, 2002, 2004; Kita, 2003). These authors provided the lithological, mineralogical and palaeontological documentation of the succession.

No outcrops with Paleogene deposits were known in central-western Poland until the last decade of the 20th century. In the summer of 1991 two students of the Institute of Geography, Adam Mickiewicz University, Paluszkiewicz and Iwanejko, found by chance a Paleogene fauna in the town of Konin (Fig. 1). Further exposures with a marine fauna were then discovered around Konin (Stankowski *et al*., 1992; Widera, 2002). We have subsequently found, a few new exposures of Paleogene deposits close to Turek and Konin during the last three years (Fig. 1C).

The main objective of this study is to analyze geologically the Paleogene deposits along their southern extent in central-western Poland. The lithological, mineralogical and sedimentological characteristics have been studied in five outcrops. Then, the thickness and lithological composition of these deposits have been examined in more than three hundred archival borehole profiles, and the lithostratigraphical correlation has been revised in places. Combining the results from outcrops and boreholes, the lithostratigraphy of these deposits as well as the palaeogeography of the Paleogene in central-western Poland has been determined more precisely. Based on all data obtained the maximum limit of the southern extent of Paleogene deposits in the study region has been delineated.

This paper is partly a continuation of a study by Biernacka and Wojewoda (1992), Wojewoda (1992*a*, *b*), Widera (2002) and Kita (2003). It also revises the southern extent of the Paleogene deposits in the central-western Poland as established

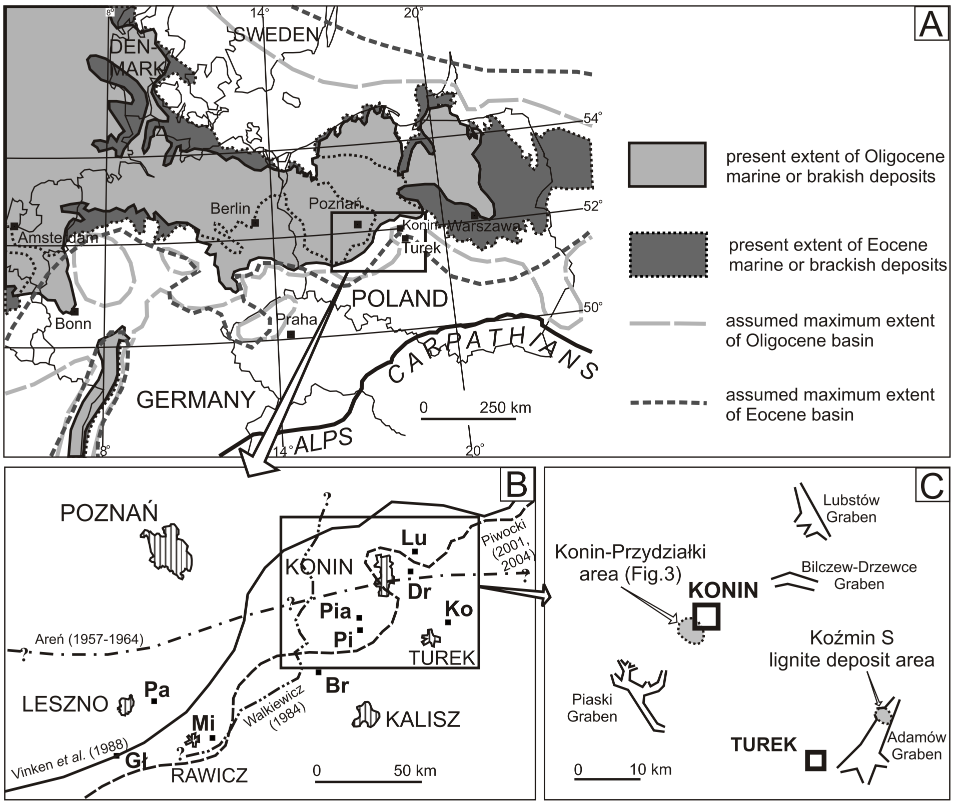

Fig. 1. Location map of central-western Poland with areas studied

A — study area against the background of the NW European Tertiary Basin in Eocene and Oligocene (after Vinken *et al*., 1988); B — central-western Poland with Paleogene extent after various authors, and location of borehole profiles examined: Gł — Głobice 1, Pa — Pawłowice 1, Mi — Miejska Górka 63.5/26.5, Br — Brzezie 54/98, Pi — Piaski 209, Pia — Piaski 221, Dr — Drzewce 14/38, Lu — Lubstów 28/42, Ko — Koźmin N 72.75/16.00 (Fig. 8); C — outcrop areas and tectonic grabens with Paleogene deposits in the vicinity of Konin and Turek towns, eastern part of the study area

by Areń (1957–1964), Walkiewicz (1984), Piwocki *et al*. (1996) and Piwocki (2001, 2004). The results help improve the understanding of the distribution of Paleogene deposits within the NW European Tertiary Basin (Vinken *et al*., 1988), while published correlative schemes are compared in Figure 1B.

MATERIAL AND METHODS

Fieldwork was carried out in 2000–2005. More significant discoveries, sedimentological observations and sampling have been made over the last three years. Using the terminology of Allen (1963, 1965) sedimentary structures were recorder in the field. Additionally, the most noteworthy structures and deposits were photographed with a digital camera. All photographs included in this paper were taken between August 2001 and September 2005.

140 samples of sandy deposits were collected for grain-size analysis from exposures near Konin (Fig. 1), situated about 100 m from the Powa River in the southwestern part of Konin and the southern part of Stare Miasto. The exposures usually lie 5–10 m above the Powa valley basement. Their length ranges from 15 m up to 50 m and the height is between 1.5 and 8 m, the sampled and described exposures ranging from 1.5 m to *ca*. 4.5 m high. They are overlain by Pleistocene and Holocene deposits 0.5–1.0 m thick. Samples of the Paleogene deposits for laboratory investigations were collected at different depths; all were dried and sieved. A few samples including a fine-grained fraction were analysed by the aerometric method. In this way, samples for further examination were selected, i.e. 119 samples for Visher's (1969) lithodynamic analysis and statistical analysis (Folk and Ward, 1957), 4 samples (< 2 μm) for X-ray diffraction analysis (XRD) and 7 samples (0.1–0.25 mm) for heavy mineral analysis. In the last case fractions between 0.1 mm and 0.25 mm were used following the standard procedure of the *Detailed Geological Map of Poland* at a scale 1:50 000.

To define the grain-size in sediments the Wentworth scale (Wentworth, 1922) was used. It includes the major classes and their subdivisions, e.g. fine sand (0.25–0.125 mm) and so on. However, statistical calculations and graphic presentations employed phi (ϕ) diameters, e.g. fine sand (2–3 ϕ). The phi (ϕ) scale may be easily computed by the following equation:

$$\phi = -\log 2\,(\text{grain-size, mm})$$

Cumulative probability curves were used for determining statistical parameters: median (M_{50}), mean (M), standard deviation (D) = sorting, skewness (S) and kurtosis (K). In this graphic method, the ϕ_n value is read off the cumulative curves. All these parameters were defined according to the set of formulae proposed by Folk and Ward (1957). For ten samples the graphic median (M_{50}), mean (M), standard deviation (D), skewness (S) and kurtosis (K) were computed by the following equations:

$$M_{50} = \phi_{50}$$

$$M = (\phi_{16} + \phi_{50} + \phi_{84})/3$$

$$D = (\phi_{84} - \phi_{16})/4 + (\phi_{95} - \phi_5)/6.6$$

$$S = (\phi_{84} + \phi_{16} - 2\phi_{50})/2(\phi_{84} - \phi_{16}) + (\phi_{95} + \phi_5 - 2\phi_{50})/2(\phi_{95} - \phi_5)$$

$$K = (\phi_{95} - \phi_5)/2.44(\phi_{75} - \phi_{25})$$

Moreover, the terminology of sediment types based on the mean (M), sorting based on the standard deviation (D), asymmetry of frequency based on the skewness (S) and departure from the "normal" frequency based on the kurtosis (K) were characterized using the Folk and Ward (1957) classifications. In the case of sediment types the Folk and Ward (1957) classification with a logarithmic scale — in ϕ corresponds strictly to the Wentworth (1922) classification with a linear scale (mm).

15 samples of gravelly deposits and more than 1000 pebbles (2–64 mm) were collected from the Koźmin S lignite deposit (Fig. 1C). The summed length of exposures with gravels reaches a few hundred metres in various axial fragments of the lignite open-cast pits, the thickness of gravelly deposits not exceeding 0–50 cm. Here, the Wentworth (1922) classification was also used to determine the grain-size subdivisions. The heavy mineral composition and the petrology of the pebbles are still being examined in detail at the Geological Enterprise PROXIMA in Wrocław. Other investigations were made at the Institute of Geology, Adam Mickiewicz University in Poznań.

The number of the borehole profiles where the Paleogene deposits were identified is about three hundred. This is only a small part of the profiles, numbering more than two thousand, which were examined. Most of these boreholes were drilled in the search for lignite deposits. Unfortunately, no borehole cores with Paleogene deposits have yet been preserved, limiting interpretation of the borehole profile descriptions.

All the profiles studied were collected from geological archives of: the Lignite Mine "Konin" in Kleczew, the Lignite Mine "Adamów" in Turek, Konin District, Turek District and the Polish Geological Institute in Warsaw. The borehole profile data were kindly provided as photocopies or digitized copies of the originals. The depth of these boreholes ranged from a few tens to more than 400 m and quite often reached the Mesozoic substratum. The data used in this study comprises eight boreholes located along the southern limit of the Paleogene deposits in central-western Poland (Fig. 1); these are between 125 and 370 m in depth.

LITHOSTRATIGRAPHIC FRAMEWORK

The Paleogene lithostratigraphy of the Polish Lowlands, including central-western Poland, was established by Ciuk (1974). Then it was simplified and slightly modified by Piwocki *et al.* (1996), Piwocki (2001, 2004) and Widera (2002). Taking into consideration the results of our investigations, we divided the study area into eastern and western parts (Fig. 2). Generally, the lithostatigraphic column is most complete in Western Poland and may be quite easily correlated with the lithostratigraphy of other parts of the NW European Tertiary Basin (Vinken *et al.*, 1988). Such lithostratigraphic comparison is necessary, especially for the neighbouring territories of Western Poland (Piwocki, 2001, 2004) and Eastern Germany (Grimm *et al.*, 2002). Thus, two lithostratigraphical columns are shown tied to the chronostratigraphy recommended by the International Commission on Stratigraphy (Gradstein *et al.*, 2004).

Neither the Paleogene nor the Neogene lithostratigraphy of Polish Lowlands have yet been established formally. Thus the names of informal units are indicated by quotation marks in the text, e.g. the Leszno "Formation" or the Czempiń "Formation". This is why in the present lithostatigraphical scheme of the Paleogene of Polish Lowlands, including western-central Poland, the words Lower and Upper are present, i.e. the Lower Mosina "Formation" and the Upper Mosina "Formation" (Fig. 2). Due to unfavourable facies conditions, and common noncalcareous shallow marine-brackish to terrestrial (limnic, fluviatile) environments, microfossils are rare. Thus, stratigraphic correlation is based on a comparison of facies, lithology and sequences of the Paleogene deposits. Only the detailed palynological investigations of the Czempiń Lignite Group (= the Fifth Lusatian Seam Horizon) are useful in regional or interregional correlation in a parastratigraphic sense (Vinken *et al.*, 1988). Microfauna, such as foraminifers, calcareous nannoplankton and dinocysts, provide only occasional support for the lithostratigraphical zonation in central-western Poland (Piwocki *et al.*, 1996; Piwocki, 2001, 2004).

In the western part of the study area five informal lithostratigraphic units have been determined: the Pomorze, Lower Mosina, Czempiń, Upper Mosina and Leszno "formations" (Fig. 2). Their position in the chronostratigraphic scheme has been discussed by Piwocki (2001, 2004). Thus, the age of sedimentation of the Pomorze "Formation" is defined as Late Eocene. In places, it cannot be excluded that the Eocene-Oligocene boundary is located in the lower parts of the Lower

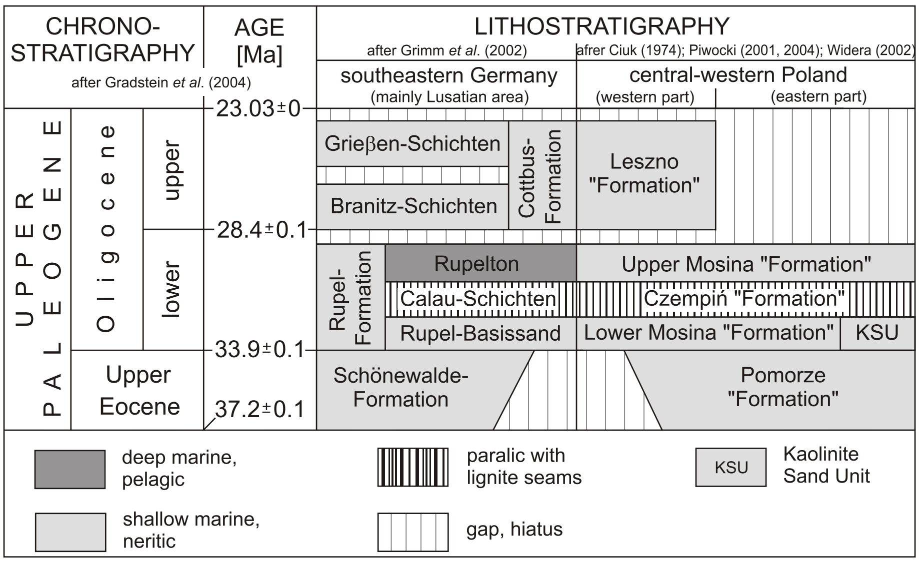

Fig. 2. Correlation between Paleogene lithostratigraphic successions for the neighbouring territories of Germany and Poland with inferred position of the Kaolinite Sand Unit

Mosina "Formation" (Piwocki *et al*., 1996; Piwocki, 2001, 2004). In general, the age of the Lower Mosina, Czempiń and Upper Mosina "formations" has been extended from the earliest Oligocene almost until the end of the Early Oligocene (Fig. 2). Consequently, the age of the Leszno "Formation", occurring in the SW part of the study territory only, is determined as Late Oligocene (Piwocki, 2001, 2004).

The Pomorze "Formation" consists of calcareous marls, with intercalations of glauconitic sands and clays (Pożaryski, 1953; Ciuk 1977). This unit has very good micropalaeontological documentation in the most southwestern and northeastern parts of the study area (Pożaryski, 1953; Odrzywolska-Bieńkowa, 1966, 1973, 1975; Pożaryska and Odrzywolska-Bieńkowa, 1977; Matl and Śmigielska, 1977). The Pomorze "Formation" in Western Poland may be correlated with the Schönewalde-Formation in neighbouring Eastern Germany (Fig. 2). The Oligocene deposits start with intensely green glauconitic sands of the Lower Mosina "Formation", which lies unconformably on the Pomorze "Formation" or on pre-Paleogene rocks. Locally, at the base of the Lower Mosina "Formation", coarse sands and fine gravels are present (Ciuk, 1974; Piwocki *et al*., 1996; Piwocki, 2001, 2004). This is comparable with the Rupel-Basissand of the Rupel-Formation (Grimm *et al*., 2002). The Czempiń "Formation" is composed of various non-marine deposits developed as limnic and fluviatile facies. Only at some localities of the most southwestern areas studied were intercalations of brackish glauconitic sands observed (Osijuk and Piwocki, 1964; Dyjor, 1974; Ciuk, 1974, 1977; Ciuk and Pożaryska, 1982; Piwocki, 2001, 2004). Generally, this lithostratigraphical unit consists of silts, clays and silty sands with lignite seams, termed the Czempiń Lignite Group. These lignites and the entire Czempiń "Formation" likely correspond to the Calau-Schichten with the Fifth Lusatian Seam Horizon (Fig. 2). In central-western Poland the Upper Mosina "Formation" and the Lower Mosina "Formation" are lithologically almost the same. Thus, the Upper Mosina "Formation" is developed as greenish glauconitic sands of shallow marine origin and locally with coarse sands and fine gravels at the base. Lithostratigraphicaly, the Upper Mosina "Formation" in Western Poland refers to the Rupelton of the Rupel-Formation in Eastern Germany (Fig. 2). In contrast, in the neighbouring territories of Germany (Vinken *et al*., 1988; Grimm *et al.*, 2002) as well as in northwestern and northern Poland (Piwocki, 2001, 2004) they mainly consist of clays of deep marine origin. These deposits may also be correlated with the "Septaria clays" in other parts of the NW European Tertiary Basin (Vinken *et al*., 1988). The Leszno "Formation" is correlative with the Cottbus-Formation (Ciuk and Pożaryska, 1982; Piwocki *et al*., 1996). It unconformably overlies Early Oligocene formations only in the southwestern parts of the study area. Fine gravels are sometimes developed at the base, followed by shallow marine glauconitic sands and brackish micaceous silts or fine-grained sands (Osijuk and Piwocki, 1964; Ciuk, 1974; Piwocki, 2004).

In the eastern part of central-western Poland area Upper Oligocene deposits are not known and a stratigraphical hiatus is inferred (Fig. 2); it was probably a period of uplift and erosion in Late Oligocene time (Widera, 2004). In contrast, the Lower Oligocene occurs in the eastern part of the study territory but in residual form. In this case the Paleogene deposits also comprise the Lower Mosina, Czempiń and Upper Mosina "formations". However, a new informal lithostratigraphic unit has been suggested for deposits exposed in the vicinity of Konin, i.e. the Kaolinite Sand Unit (Widera, 2002). This unit roughly correlates with the Lower Mosina "Formation" and its age may be determined as the earliest Oligocene (Fig. 2). On the other hand, according to Piwocki (2001, 2004), by contrast with the Lower Mosina "Formation", the age of the Kaolinite Sand Unit should be extended from the latest Eocene to the earliest Early Oligocene (Widera, 2002).

RESULTS OF INVESTIGATION

DEPOSITS STUDIED IN EXPOSURES

In the SW part of Konin and in the southernmost part of Stare Miasto at least six exposures of Paleogene deposits have been known since 1991 (Fig. 3). Unfortunately, only two small exposures located on the right bank of the Powa River at the Konin-Przydziałki locality and one situated on the left bank of the Powa River at the Stare Miasto-Cmentarz locality were exposed already during fieldwork in 2005. Here, deposits from the Konin-Przydziałki and Stare Miasto-Cmentarz localities were examined in detail. Additionally, some interesting information, obtained especially from a former exposure located on the left bank of the Powa River at the Konin-Przydziałki locality, are included in this paper (Fig. 3).

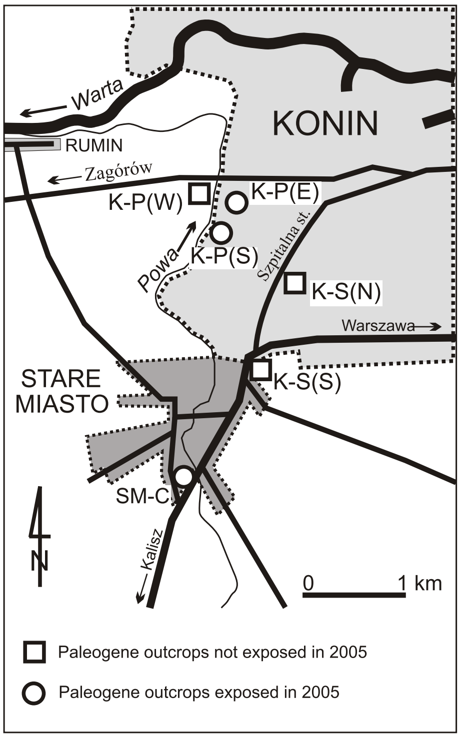

Fig. 3. Location of the Paleogene outcrops in the vicinity of Konin and Stare Miasto towns

K-P(W) — Konin-Przydziałki (west), K-P(E) — Konin-Przydziałki (east), K-P(S) — Konin-Przydziałki (south), K-S(N) — Konin-Szpitalna (north), K-S(S) — Konin-Szpitalna (south), SM-C – Stare Miasto-Cmentarz

The first description of the Paleogene deposits from Konin-Przydziałki were made by Ciszewska (1992, marine fauna), Biernacka and Wojewoda (1992, texture), Wojewoda (1992*a*, structure) and Wojewoda (1992*b*, age and palaeogeography). Then geological and lithostratigraphical studies were carried out at the Stare Miasto-Cmentarz locality by Widera (2002) and Kita (2003). Finally, these investigations are supplemented by results given below.

The most characteristic feature of deposits from the Konin-Przydziałki and Stare Miasto-Cmentarz sites is the presence of a marine fauna and a relatively large content of kaolinite (Figs. 4 and 5). According to Ciszewska (1992) this poorly preserved fauna comprise the gastropod *Turritella* and the bivalve *Glycymeris* (Figs. 4A, A’ and 5A).

At Konin-Przydziałki various types of small-scale lamination dominate, i.e. planar cross-lamination, trough cross-lamination, wavy and horizontal. In this case individual laminae sets are usually bounded by reactivation surfaces (Fig. 4B, B’). It is noteworthy that the sandy laminae, between neighbouring sets, include bidirectional herring bone structures (Fig. 4B, B’). The clayey laminae vary from less than 1 mm to *ca*. 2 cm, usually separate two sets of cross-laminated sands and locally from more or less continuous laminae within sandy-clayey sets (Fig. 5B, E). Moreover, the clay-rich balls, interpreted as kaolinite intraclasts, are incorporated into the sand-rich deposits (Figs. 4 and 5A, D). Apart from the small-scale stratification, a few examples of larger-scale stratification have been documented, e.g. planar cross-stratification and horizontal stratification (Fig. 5C, E). In contrast, the internal architecture of the Paleogene deposits exposed at the Stare Miasto-Cmentarz locality is much less diverse. The sands are not stratified (Fig. 5A). Only sporadically and locally, when a large content of clay is present, is it possible to observe deformational structures (Fig. 5B).

Cumulative probability curves and results of statistical calculations are given in this paper on the basis of ten samples from both sites (Fig. 6, Table 1). These samples represent fine sands with mean grain-size ranges from 2.43 to 2.70 phi, i.e. between 0.15 and 0.19 mm (Wentworth,1922; Folk and Ward, 1957). The deposits are characterized by very good sorting, where the standard deviation is less than 0.35 (Folk and Ward, 1957; Gradziński *et al.*, 1986). Only three samples, i.e. “e”, “A” and “E”, are medium to well sorted. Relatively good and very good sorting of the Paleogene sands from the Konin-Przydziałki and Stare Miasto-Cmentarz is clearly visible in Figure 6. All the cumulative curves described are high-angle, similar in shape and located very close to each other (Fig. 6). Additionally, when calculated by Folk and Ward’s (1957) graphic method, the values of skewness range from –0.08 to 0.19 and those of kurtosis are between 0.94 and 1.98 (Table 1). Five out of ten samples are negatively or strongly negatively skewed, i.e. $S < -0.10$. These samples are weighted towards the fine end. Only sample “A” is positive skewed, with relatively more coarse than fine fraction (Folk and Ward, 1957). Most of the samples described are meso- or leptokurtic. Only samples “e” and “C” have very leptokurtic distributions, i.e. $K > 1.50$ (Table 1). This indicates that their centres is better sorted than their ends (Folk and Ward, 1957).

Until recently, the clay fraction has been determined as kaolinite by appearance only. Due to the importance of the clay

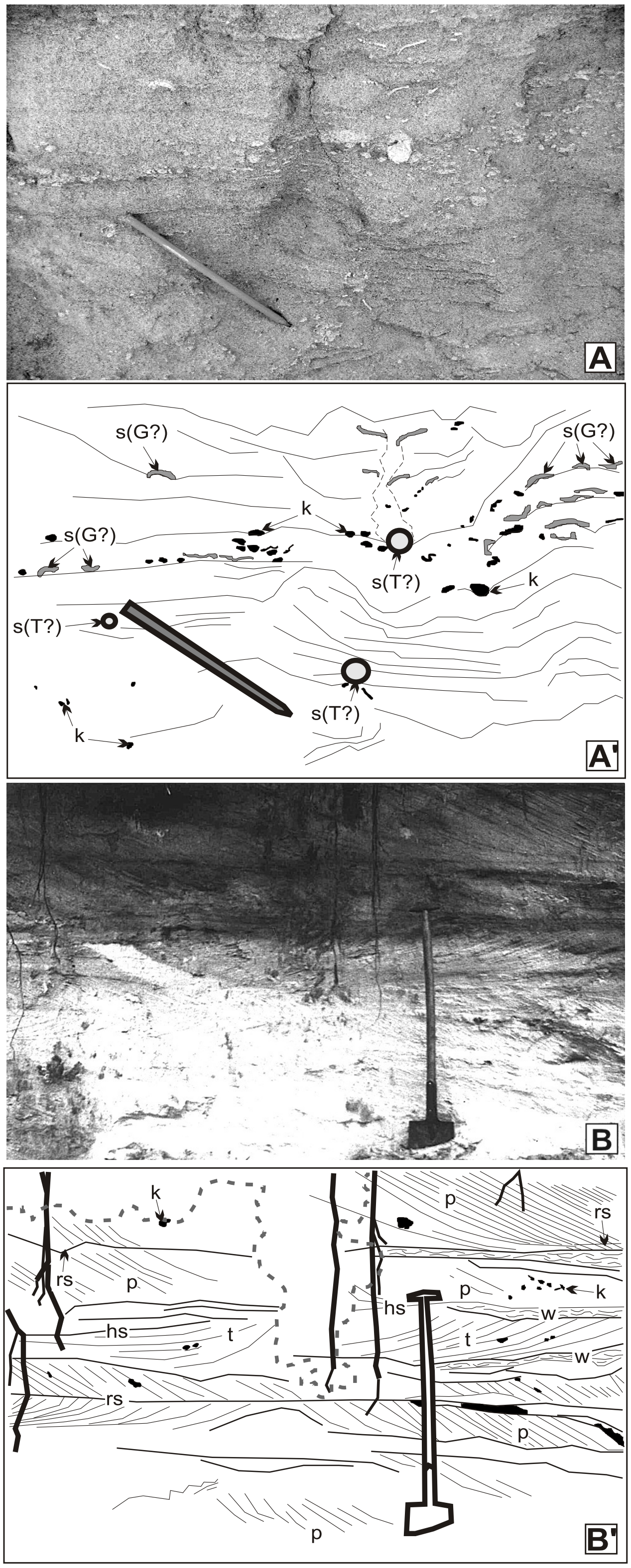

Fig. 4. Paleogene deposits at the Konin-Przydziałki locality

A — sands with remains of marine fauna and kaolinite intraclasts on the right bank of the Powa River — K-P(E) in May 2003; A’ — line drawing showing details presented in Figure 4A, s(T?) — *Turritella* fossils, s(G?) — *Glycymeris* fossils, k — kaolinite intraclasts; B — sedimentary structures of sands on the left bank of the Powa River — K-P(W) in August 2001; B’ — line drawing showing details shown in Figure 4B, cross-stratification: p — planar, t — trough, w — wavy, hs — horizontal stratification, rs — reactivation surface, k — kaolinite intraclast

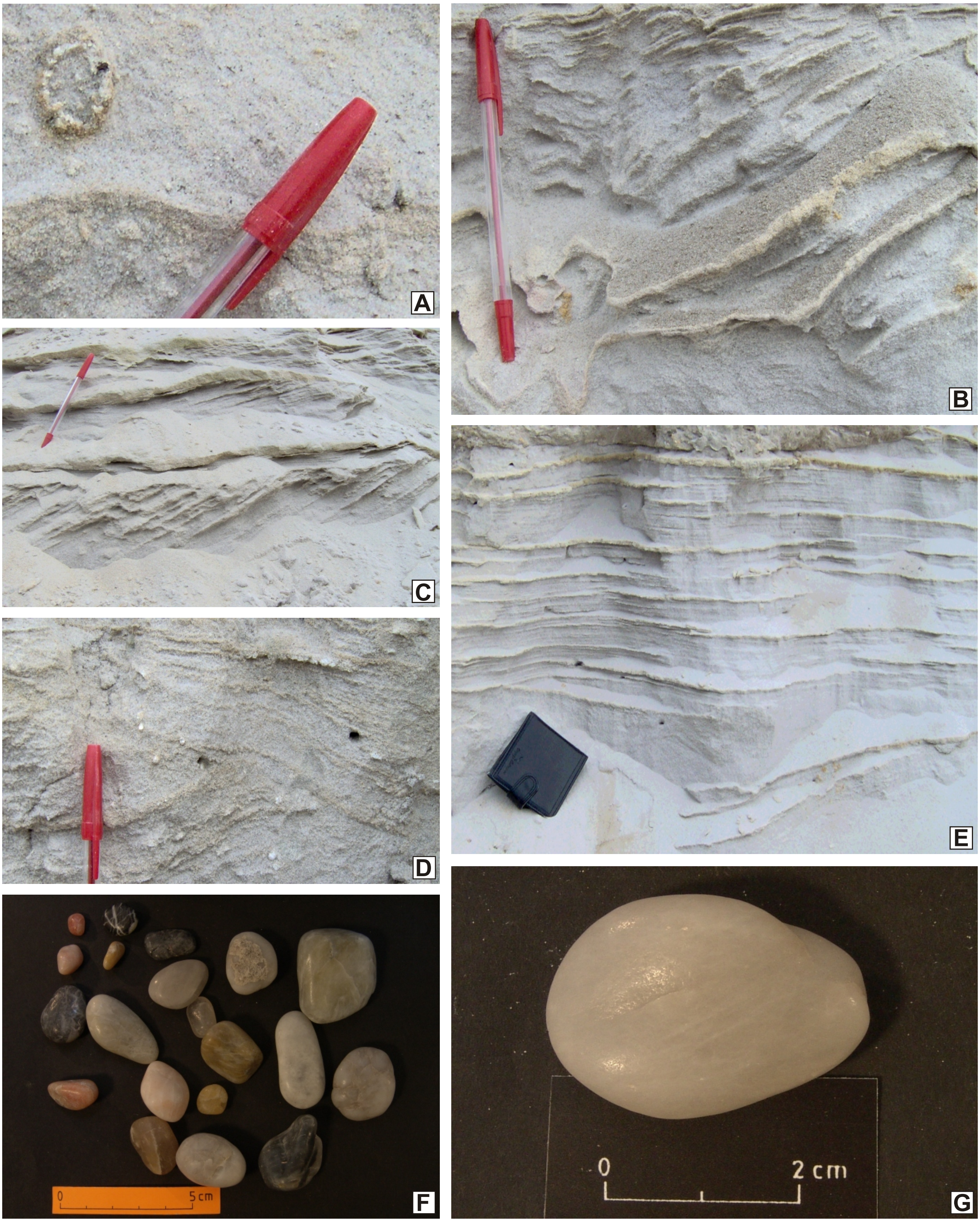

Fig. 5. Structure and texture of the Paleogene deposits in exposures

A — non-stratified sands with visible remains of *Turritella* (left upper corner), Stare Miasto-Cmentarz locality — SM-C in June 2004; **B** — synsedimentarily deformed sands with kaolinite layers, Stare Miasto-Cmentarz site — SM-C in June 2004; **C** — large-scale planar cross-stratified sands, southern part of the Konin-Przydziałki locality — K-P(S) in September 2005; **D** — trough cross-stratified sands in small scale, eastern part of the Konin-Przydziałki site — K-P(E) in May 2003; **E** — large-scale horizontally stratified sands, southern part of the Konin-Przydziałki locality — K-P(S) in September 2005; **F** — gravels from open-cast of the Koźmin South lignite deposit; **G** — an example of a well-rounded oval quartz pebble with smoothed surface, open-cast pit in the Koźmin South lignite deposit; for location see Figures 1 and 3

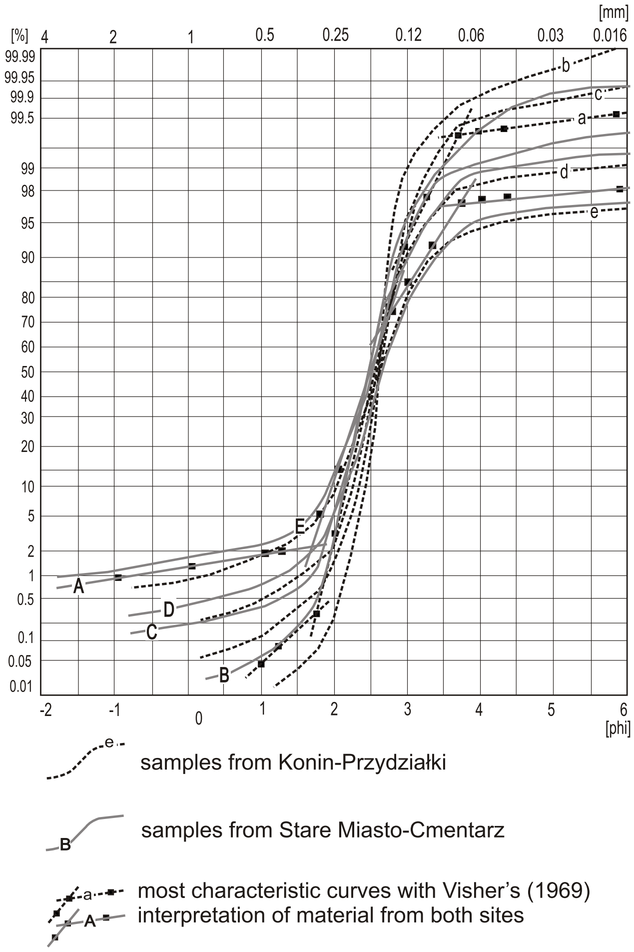

Fig. 6. Cumulative grain-size distributions of selected samples of the Paleogene sands

Table 1

Statistical parameters calculated using method of Folk and Ward (1957) for 10 selected samples shown in Figure 6

Sample in Fig. 6	Median [phi]	Mean grain-size [phi]	Standard deviation [phi]	Skewness	Kurtosis
Konin-Przydziałki locality					
a	**2.6**	**2.57**	**0.29**	**–0.08**	**1.08**
b	2.7	2.63	0.13	–0.80	1.23
c	2.7	2.65	0.21	–0.34	1.31
d	2.7	2.65	0.28	–0.15	0.94
e	2.7	2.67	0.59	0.07	1.98
Stare Miasto-Cmentarz locality					
A	**2.4**	**2.43**	**0.50**	**0.19**	**1.20**
B	2.5	2.47	0.27	–0.16	1.06
C	2.7	2.70	0.22	0.08	1.72
D	2.5	2.53	0.34	–0.01	1.18
E	2.5	2.50	0.40	–0.31	1.04

Resultes obtained for curves "a" and "A" are typed in bold (see Fig. 6)

mineral composition in palaeogeographical reconstructions X-ray diffraction analysis (XRD) has been applied. Here, only two diffractograms for samples from both sites are shown. Fortunately, kaolinite is mainly visible on diffractograms of the clay fraction (Fig. 7).

Heavy mineral examination has been aimed at indicating similarities between various Paleogene deposits and differences between them and the Neogene deposits. The most characteristic feature is a consistently high content of muscovite, which varies from 8 to 29% of the heavy mineral assemblage. Moreover, amphiboles and pyroxenes are very rare in the Paleogene deposits exposed at the Konin-Przydziałki and Stare Miasto-Cmentarz localities (Table 2).

An unexpected discovery was made in the summer of 2004 in the Koźmin South lignite open-cast pit near Turek (Fig. 1): coarse gravels form the basal layer in the northernmost and axial part of the Adamów Graben (Fig. 1C). These deposits, according to Folk's (1954) sediment classification scheme, comprise gravelly sands — sands > 75%, gravels *ca*. 25% and muds < 5%. Furthermore, the gravel clasts are mainly pebbles with sporadic cobbles after Wentworth's (1922) nomenclature. It is worth emphasizing that such coarse gravels are not known within Paleogene and Neogene deposits elsewhere within the whole Polish Lowlands (Piwocki, 2004).

During the fieldwork the petrography, roundness and surface quality of pebbles were determined visually only. The pebbles from the Koźmin South lignite open-cast pit are composed of two groups: angular and well-rounded. The first consists of local Miocene sandstones and Cretaceous marls and/or

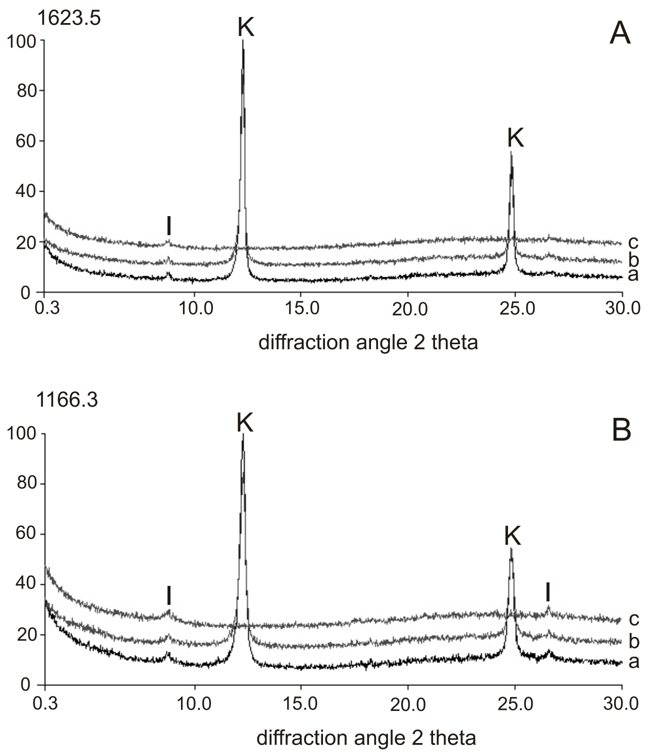

Fig. 7. X-ray diffraction (XRD) patterns of clay fraction of the Paleogene deposits

A — samples from Konin-Przydziałki; B — samples from Stare Miasto-Cmentarz, a — oriented samples, b — glycolated samples, c — samples heated to 500°C, K — kaolinite, I — illite siltstones. In contrast, the main pebbles of the second group are represented by flints (among them hornstones and lydites; Dobosz, pers. comm.) and primarily by quartz (Fig. 5F). The quartz pebbles can be further divided into: white, milky-white, grayish-blue, pink and honey-yellow in colour. They are disc-shaped as well as very well-rounded and quite often their surface is markedly smoothed (Fig. 5G).

DEPOSITS STUDIED IN BOREHOLES

Several hundred borehole profiles, penetrating or reaching the Paleogene deposits, have been examined. Only some of these are shown in Figure 8. However, the eight most typical lithostratigraphical profiles are presented in this paper. These profiles show the simplified lithology and altitude of the Paleogene lithostratigraphical units. Moreover, taking into account their stratigraphical position and lithological similarities, the Paleogene deposits have been correlated between these boreholes, which are approximately representative of this interval of regional stratigraphy (Fig. 8).

The most complete lithostratigraphical profile of the Paleogene deposits is known in the southwestern part of the study area, in the vicinity of Leszno and Rawicz (Ciuk, 1974; Piwocki *et al*., 1996; Piwocki, 2004). It is clearly seen in the Miejska Górka 36.5/26.5 and Pawłowice 1 boreholes, where all four formations can be distinguished (Fig. 8). In other territories the succession is less complete, with variations in lithology and thickness. Thus, three Paleogene units, i.e. the Lower Mosina, Czempiń and Upper Mosina “formations”, are present in the Lubstów 28/42, Drzewce 14/38, Piaski 221 and Głobice 1 boreholes and two in the Piaski 209, Koźmin 72.75/16.00 and Brzezie 54/98 boreholes (Fig. 8). In areas associated with lignite deposits, located in the Piaski, Bilczew-Drzewce and Adamów grabens, and in the Lubstów Graben several dozen and more than a hundred boreholes have been drilled, respectively, through the Paleogene deposits (Fig. 1C; Widera, 2002; Kita, 2003).

INTERPRETATION OF RESULTS

Detailed age estimation is not available for fossil marine molluscs identified in the Konin-Przydziałki and Stare Miasto-Cmentarz sites (Figs. 3–5). These range from the Cretaceous to the present. Among these, fossil as well as recent turritellids have been used for investigations to determine palaeoenvironmental conditions during the Cenozoic (Allmon, 1988; Andreasson and Schmitz, 1996; Latal *et al*., 2006; and references therein). The recent turritellids live most commonly in shallow marine waters less than 100 m deep with normal marine salinities, but locally they tolerate lower salinities (Allmon, 1988). Thus, it may be stated that the Paleogene deposits from both sites described have been deposited in comparable palaeoenvironmental conditions as those inhabited by recent turritellids.

Analysis of some cumulative curves by Visher’s (1969) method reveals at least three main grain populations within the sands: traction, saltation and suspension. However, of most important for this study is dividing the saltation population into two subpopulations — especially marked in curves “a” and “A” (Fig. 6). Such a pattern is interpreted as typical of deposits from the nearshore zone of a marine basin (Visher, 1969; Gradziński *et al*., 1986; Racinowski *et al*., 2001). Such structural and textural features are typical of nearshore bars (Pruszak *et al*., 1997; Fenies and Tastet, 1998; Gelfenbaum and Brooks, 2003; Moore *et al*., 2003; Masselink *et al*., 2006; Swales *et al.*, 2006; and references therein). The origin of such bars is connected with wave-dominated (Pruszak *et al*., 1997; Gelfenbaum and Brooks, 2003; Swales *et al*., 2006), tide-dominated (Moore *et al*., 2003; Masselink *et al*., 2006) as well as wave and tide-dominated environments (Fenies and Tastet, 1998). These examples clearly show that nearshore bars are form today in a wide range of coastal and climatic conditions. Therefore, the internal architecture of the deposits described from the Konin-Przydziałki and Stare Miasto-Cmentarz localities does not provide any additional information about the age of their deposition.

Significant amounts of kaolinite, small amounts of illite and the lack of other clay minerals (Fig. 7) clearly indicate the source (feldspar minerals), the climate (warm temperate or subtropical) and weathering conditions (pH < 5 of kaolinite origin) (Sharma and Rajamani, 2000; Skiba, 2001). Furthermore, the Cenozoic palaeoclimatic maximum, during the Middle Eocene, is recognized as the first interval of time for optimal conditions for kaolinite formation in northern Europe (Burchardt, 1978; Andreasson and Schmitz, 1996). Thus, kaolinite sands from both sites in the vicinity of Konin and Stare Miasto were certainly deposited after the Middle Eocene. It is noteworthy, that generally the kaolinite content is low in the Paleogene deposits except in those representing nearshore areas (Vinken *et al*., 1988), consistent with results of the investigations reported here. The kaolinite content in the Konin-Przydziałki and Stare Miasto-Cmentarz localities is higher than in other territories studied in central-western Poland.

The lack or the small amount of amphiboles and pyroxenes are very important for two reasons (Table 2). Firstly, it may indicate the source minerals of kaolinite, which were mainly sourced from feldspars, but also partially from weathering of amphiboles and pyroxenes (Sharma and Rajamani, 2000; Skiba, 2001; Biernacka, 2004). Secondly, amphibole-rich heavy mineral assemblages are typical of Pleistocene and Holocene deposits in the Polish Lowlands territory, including central-western Poland (Kosmowska-Ceranowicz, 1979; Stankowski and Krzyszkowski, 1991; Czerwonka and Krzyszkowski, 1994; Stankowski *et al*., 1995; Widera, 2000; Kita, 2003). These were obviously supplied from the Scandinavian rocks. Thus, the heavy mineral composition of the Paleogene sands clearly differs from that of Pleistocene and Holocene deposits. On the other hand, there are no significant features, based on qualitative and quantitative heavy mineral analysis, which are typical of Paleogene or of Neogene deposits only. The Paleogene marine sands and the Neogene alluvial sediments have quite similar heavy mineral assemblages in the vicinity of Konin (Biernacka and Wojewoda, 1992; Stankowski and Krzyszkowski, 1991; Kita, 2003; Wagner, 2004). Moreover, the results obtained for the Paleogene deposits exposed in the eastern part of the study area (Table 2; Biernacka and Wojewoda, 1992; Kita, 2003) differ from those for deposits in the surrounding areas

Table 2

Composition of the transparent heavy minerals (in grain %, in 0.1–0.25 mm fraction)

Mineral	Konin-Przydziałki site (n = 3)			Stare Miasto-Cmentarz site (n = 4)		
	min.	max.	**mean**	min.	max.	**mean**
amphibole	0	0	**0**	0	4	**1.5**
andalusite	1	5.5	**4**	0.5	7	**3**
apatite	0	3.5	**2**	1.5	5	**2.5**
zircon	10	26	**15**	5	12	**8**
disthene	7.5	21	**14**	3	16	**7**
epidote	5	13.5	**9**	5	20	**13**
glauconite	0	0	**0**	0	0	**0**
garnet	7	17	**10**	6	31	**19**
muscovite	8	28	**13**	12	29	**18**
rutile	3.5	22.5	**7**	0	3	**1**
staurolite	4	13	**9**	7	14	**10**
sillimanite	4	9	**6**	2	7	**4**
tourmaline	5	21	**9**	8	16	**11**

n — number of samples; mean values are typed in bold; analyses by Dr. Kicińska IG UAM and Kita with co-operation of Kicińska

(Kosmowska-Ceranowicz and Bühmann, 1982; Biernacka, 2004) and in other parts of Poland (Kosmowska-Ceranowicz, 1979; Kramarska, 2004). Therefore, heavy minerals separated from the Paleogene deposits cannot be used for lithostratigraphical correlation at a regional scale, or for estimation of the age of the deposits described (Biernacka and Wojewoda, 1992; Biernacka, 2004). Additionally, such correlation at an inter-regional scale in the NW European Tertiary Basin is difficult due to the fact that different fractions have been examined: a reason why the results of heavy mineral analyses are often not directly comparable (Vinken *et al*., 1988).

Marine faunal remains, textural features (excluding structural ones), the presences of kaolinite and the heavy mineral composition directly indicate a similar age and sedimentary environment of deposits from the Konin-Przydziałki and Stare Miasto-Cmentarz localities. However, these data do not determine the age of the deposits. Additionally, taking into account palaeogeographic and palaeotectonic data, the age of these deposits may be estimated only indirectly. Lower Miocene and the Pleistocene deposits overlie the kaolinite-bearing sands (Stankowski *et al.*, 1995; Widera, 1998, 2000, 2002; Kita, 2003). Although they occur close to the present topographic surface, during their sedimentation the entire area had to have undergone subsidence and then uplift. Such an assumption is necessary to explain this currently elevated position of well-preserved sands with kaolinite. At the top of these Paleogene deposits, in both comparative sites, an erosional hiatus is also present. Moreover, the first Paleogene tectonic movements in Central Poland occurred around the Eocene-Oligocene boundary or in the earliest Early Oligocene — Pyrenean phase (Widera, 1998, 2004). Thus, the age of deposits from the Konin-Przydziałki and Stare Miasto-Cmentarz localities may be extended from the uppermost Eocene to the lowermost Lower Oligocene. These deposits are probably the lithostratigraphical equivalent of the Lower Mosina "Formation" in other areas (Ciuk, 1974; Walkiewicz, 1984; Piwocki, 2001, 2004; Widera, 2002, 2004). However, this age estimation must be treated as an unresolved geological problem. Recently, because of the importance of deposits exposed in the vicinity of Konin and Stare Miasto for the Paleogene lithostratigraphy and palaeogeography, a new lithostratigraphical unit was proposed. This is the Kaolinite Sand Unit (Widera, 2002), useful in constructing the *Detailed Geological Map of Poland* at 1:50 000 scale.

The gravelly sands occur mainly at the base of the Koźmin Formation, the deposition of which began in the Early Miocene during the Savian tectonic phase (Widera, 2002, 2004). Moreover, these deposits are underlain by Mesozoic rocks or by "blue clays" or "green clays" (Czarnik, 1972). Previously the age of these clays was regarded as Middle Miocene and included in the Adamów Formation (Czarnik, 1972) while recently they have been ascribed to the Lower Oligocene (Rupelian) Czempiń "Formation" (Widera, 2002). Therefore, the age of the gravely deposits should be constrained by the depositional age of the Czempiń and Koźmin "formations". and thus were deposited between the late part of the Early Oligocene and the end of the Late Oligocene (Table 2).

In our opinion, taking into account the stratigraphical position and macroscopic observations (Fig. 5F, G), these deposits are probably a residuum of beach gravels referred to the Upper Mosina "Formation", late Lower Oligocene in age (Fig. 2). Similarly smooth pebbles are also known from Paleogene marine gravels (though the latter are finer), located in the Fore-Sudetic Monocline (Dobosz, pers. comm.). Consequently, the southern margin of the Paleogene sea should be located to the south of the Koźmin South open-cast lignite pit in the vicinity of Turek. The character of these deposits may yield further indications of provenance (e.g. whether were derived from the Sudetes, Fennoscandian shield, Holy Cross Mts., Carpathians *etc.*), sedimentary conditions and transport directions, which can lead to improved palaeogeographic reconstruction; more detailed petrographical, mineralogical and sedimentological investigations are required.

SOUTHERN EXTENT OF THE PALEOGENE DEPOSITS

The contemporary extent of the Paleogene deposits in western-central Poland is determinable on the basis of the location of exposures and boreholes (Fig. 8). Two territories important for Paleogene stratigraphy have been considered: the Głobice-Szaszorowice-Miechów area (Odrzywolska-Bieńkowa, 1973, 1975; Ciuk, 1977; Matl and Śmigielska, 1977) and the Izbica Kujawska area (Pożaryski, 1953; Odrzywolska-Bieńkowa, 1966).

The established southern limit of the Paleogene deposits is generally orientated NE–SW, but in detail it shows much variation (Fig. 8). Along this line, in boreholes marked in Figure 8, the deposits studied change in thickness from 2.5 to 26.1 m. They comprise nearshore facies with a marine fauna and/or characteristic sedimentary structures as at the Konin-Przydziałki and Stare Miasto localities and beach gravels in the

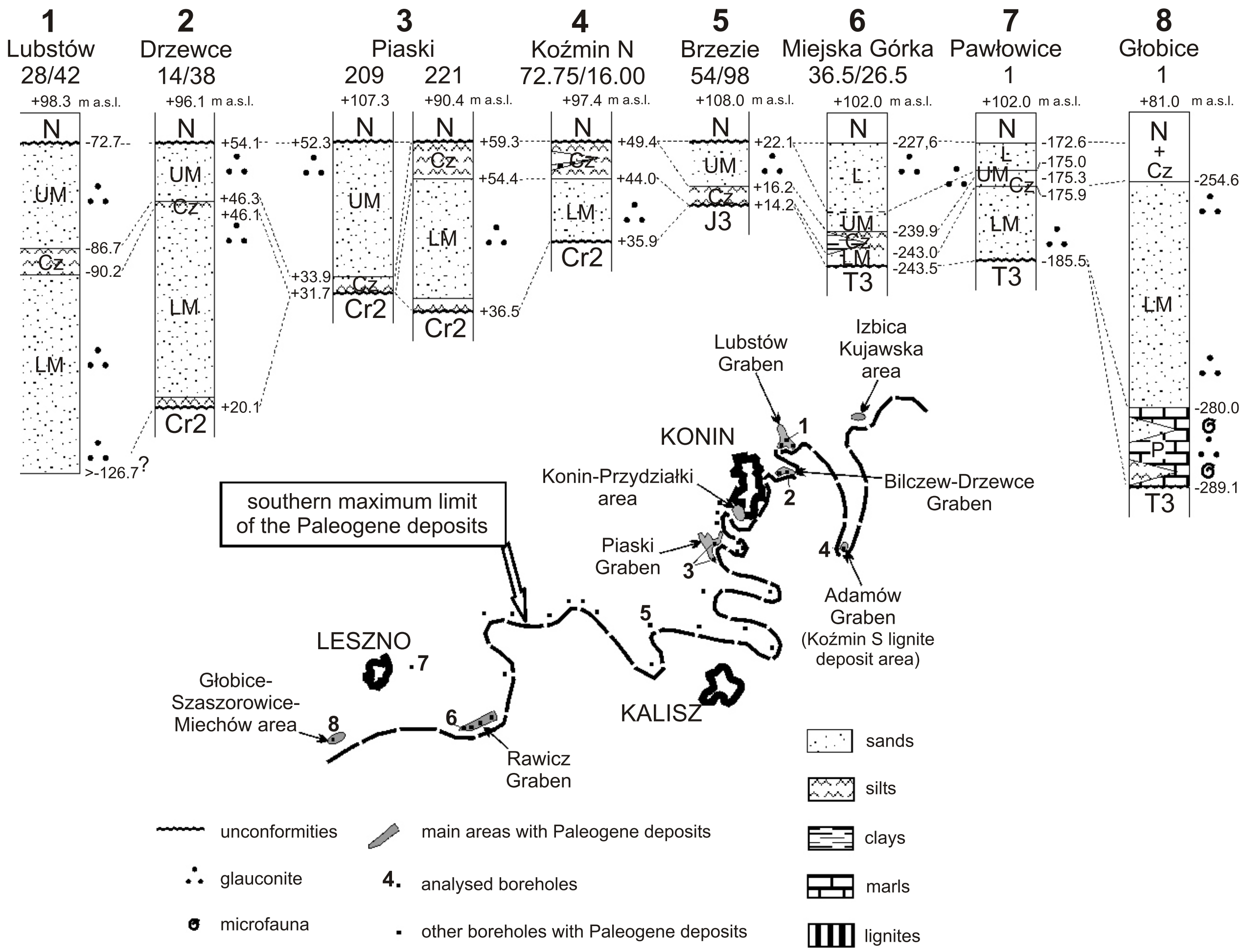

Fig. 8. Southern extent of the Paleogene deposits in central-western Poland with a few typical profiles

Lithostratigraphic "formations": P — Pomorze, LM — Lower Mosina, Cz — Czempiń, UM — Upper Mosina, L — Leszno; chronostratigraphic units: N — Neogene, T3 — Upper Triassic, J3 — Upper Jurassic, Cr2 — Upper Cretaceous

Koźmin South open-cast lignite pit. By contrast, glauconitic sands are typical of offshore marine environments as seen in borehole profiles of the Pomorze, Lower Mosina, Upper Mosina and Leszno "formations" (Fig. 8). Between the marine sands and at the top the successions lie fluvial and lacustrine deposits with lignite intercalations, which belong to the Czempiń "Formation". In this case, the presence of these deposits must be treated as a result of sedimentation and erosion processes against a background of Cenozoic tectonic activity of the Pyrenean and Savian phases (Ciuk and Pożaryska, 1982; Widera, 1998, 2004). Therefore, the maximum Paleogene shoreline should be placed at least a few kilometres south of the present-day outcrop (Fig. 8).

This newly delineated shareline may be considered as a significant revision of the outcrop of the Paleogene deposits of central-western Poland established mainly by Areń (1957–1964), Walkiewicz (1984), Piwocki (2001, 2004) and Vinken *et al*. (1988) (Fig. 1B). These authors were not aware of the deposits in the southwestern and in the eastern parts, respectively, of the study area. This was partly caused by the state of knowledge then and partly by a simplified approach (Areń, 1957–1964; Dyjor, 1974; Walkiewicz, 1984). By contrast, the margin of the Paleogene deposits described here is much more detailed than that proposed by Vinken *et al*. (1988), Piwocki *et al*. (1996) and Piwocki (2001, 2004). These differences reflect the map scales used in the different studies.

CONCLUSIONS

Central-western Poland formed, in the Paleogene, a marginal part of the NW European Tertiary Basin. From the Late Eocene to the Late Oligocene the study area was flooded by boreal seas generally encroaching from the North Sea. Therefore, the lithostratigraphic successions of the neighbouring areas of Eastern Germany and Western Poland are easily comparable. In both countries the lithostratigraphic units represent similar facies. An exception is the Upper Mosina "Formation" which in central-western Poland is developed in a shallow marine facies (glauconitic sands). In contrast, its equivalent in Eastern Germany, i.e. the Rupelton of the Rupel Formation, consists of deep marine facies (the Septaria clays).

The Paleogene deposits in central-western Poland are informally divided into five lithostratigraphic units: the Pomorze, Lower Mosina, Czempiń, Upper Mosina and Leszno "formations". Only the Czempiń "Formation" with lignite seams comprises non-marine facies. The remaining formations are developed as typical shallow marine deposits: glauconitic and/or micaceous sands. Among them the Pomorze "Formation" with a calcareous component and foraminiferal microfauna represents the Late Eocene warm sea. Most of the units are bounded by unconformities, except for the Czempiń "Formation", have coarse sands and fine gravels are often developed at their base.

A few exposures of Paleogene deposits were discovered in the eastern part of the area studied during the last few years and have been investigated by the present authors in detail using lithological, mineralogical and sedimentological methods. Kaolinite-rich sands typical of marine nearshore bars have been described in the vicinity of Konin. Due to their significance for the Paleogene lithostratigraphy and palaeogeography of central-western Poland area a new lithostratigraphical unit has been suggested: the Kaolinite Sand Unit. Moreover, exceptionally developed gravels, which vary in size, shape and petrographical composition, have been examined in the open-cast pit exposing the Koźmin South lignite deposit. These gravels were initially regarded as residual marine beach deposits. The age of both the kaolinite sands and the gravels age is poorly constrained and requires further investigation.

On the basis of all data obtained from the archival borehole profiles and from exposures the maximum southern extent of the Paleogene deposits of central-western Poland has been amended (Fig. 8). The lithological character and thickness of these deposits suggests that the Paleogene seas of the NW European Tertiary Basin extended farther south than Konin and Turek.

Four transgressive-regressive cycles, reflecting eustatic pulses and tectonic movements, can be recognized in central-western Poland. This area was flooded at the beginning of the Late Eocene (the Pomorze "Formation"). During the Pyrenean phase around the Eocene-Oligocene boundary the entire area was elevated and eroded. The next cycle (the Lower Mosina "Formation") commenced at the beginning of the Oligocene. The regressive stage of this cycle is represented by the limnic-fluviatile Czempiń "Formation". The last two transgressive-regressive cycles correspond to the Upper Mosina and Leszno "Formations", respectively. Tectonic uplift connected with the Savian phase, around the Oligocene-Miocene boundary, finally terminated Paleogene sedimentation in central-western Poland.

Acknowledgements. The authors would like to thank Dr. Kicińska for heavy mineral determinations, MSc. Kubiak for XRD analyses as well as for his help in their interpretation Msc. Fryś for macrophotographs of pebbles and Msc. Dobosz for preliminary petrographical studies of pebbles. We are truly grateful to Dr. Biernacka for valuable mineralogical remarks and discussion. Special thanks are extended to reviewers Drs Grimm and Kasiński for their critical but valuable remarks which helped to improve the quality of the manuscript as well as to Prof. Narkiewicz for his editorial and linguistic comments. This paper was financially supported by the Institute of Geology, A. Mickiewicz University in Poznań.

REFERENCES

ALLEN J. R. L. (1963) — The classification of cross-stratified units, with notes on their origin. Sedimentology, **2**: 93–114.

ALLEN J. R. L. (1965) — A review of the origin and characteristics of recent alluvial sediments. Sedimentology, Spec. issue, **5**: 89–191.

ALLMON W. D. (1988) — Ecology of recent Turritelline gastropods (Prosobranchia, Turritellidae): current knowledge and paleontological implications. Palaois, **3**: 259–284.

ANDREASSON F. P. and SCHMITZ B. (1996) — Winter and summer temperatures of the early middle Eocene from Turritella ^{18}O profiles. Geology, **24** (12): 1067–1070.

AREŃ B. (1957–1964) — Geological Atlas of Poland on scale of 1:3000000 (in Polish with English summary). Pol. Geol. Inst. Warszawa.

BIERNACKA J. (2004) — Heavy mineral suites in Oligocene-Miocene sediments (Fore-Sudetic Monocline, SW Poland): Provenance signals versus weathering alteration. Geol. Sudet., **36**: 1–19.

BIERNACKA J. and WOJEWODA J. (1992) — Cechy teksturalne osadów (in Polish with English summary). In: Marine, Lacustrine and Peat Sediments (Tertiary), and Glacigenic Sediments (Quaternary) of the Konin Area (eds. W. Stankowski *et al.*): 19–23. Proc. Sediment. Sympos. Wyd. Inst. Geol. UAM, Poznań.

BURCHARDT B. (1978) — Oxygen isotope palaeotemperatures from the Tertiary period in the North Sea area. Nature, **275**: 121–123.

CISZEWSKA M. (1992) — Malakofauna (in Polish with English summary). In: Marine, Lacustrine and Peat Sediments (Tertiary), and Glacigenic Sediments (Quaternary) of the Konin Area (eds. W. Stankowski *et al.*): 25–26. Proc. Sediment. Sympos. Wyd. Inst. Geol. UAM, Poznań.

CIUK E. (1974) — Lithostratigraphic schemes of the Palaeogene in Poland except for the Carpathians and the Carpathian Foredeep (in Polish with English summary). Biul. Inst. Geol., **281**: 7–48.

CIUK E. (1977) — New localities of the Upper Eocene and Lower Oligocene from the areas of Głobice, Szaszorowice and Miechów (Leszno voivodeship), SW part of Fore-Sudetic Monocline (in Polish with English summary). Prz. Geol., **25** (1): 1–6.

CIUK E. and GRABOWSKA I. (1991) — Synthetic stratigraphic section of the Tertiary in the Lubstów brown coal deposit at Lubstów, Konin district (in Polish with English summary). Biul. Państw. Inst. Geol., **365**: 47–72.

CIUK E. and POŻARYSKA K. (1982) — On paleography of the Tertiary of the Polish Lowland. Pr. Muz. Ziemi, **35**: 81–88.

CZARNIK J. (1972) — Paleogeography of the environs of Turek in the Upper Tertiary and Pleistocene (in Polish with English summary). Studia Geol. Pol., **40** (1): 147–160.

CZERWONKA J. A. and KRZYSZKOWSKI D. (1994) — Pleistocene stratigraphy and till petrography of the central Great Poland Lowland, western Poland. Folia Quarter., **65**: 7–71.

DYJOR S. (1974) — The Oligocene of the Lowland section of Lower Silesia and Ziemia Lubuska (in Polish with English summary). Biul. Inst. Geol., **281**: 119–138.

FENIES H. and TASTET J-P. (1998) — Facies and architecture of an estuarine tidal bar (the Trompeloup bar, Gironde Estuary, SW France). Mar. Geol., **150**: 149–169.

FOLK R. L. (1954) — The distinction between grain size and mineral composition in sedimentary rock nomenclature. J. Geol., **62** (4): 344–359.

FOLK R. L. and WARD W. C. (1957) — Brazos River bar: a study in the significance of grain size parameters. J. Sediment. Petrol., **27**: 3–26.

GELFENBAUM G. and BROOKS G. R. (2003) — The morphology and migration of transverse bars off the west-central Florida coast. Mar. Geol., **200**: 273–289.

GRADSTEIN F. M., OGG J. G., SMITH A. G., BLEEKER W. and LOURENS L. J. (2004) — A new Geologic Time Scale, with special reference to Precambrian and Neogene. Episodes, **27** (2): 83–100.

GRADZIŃSKI R., KOSTECKA A., RADOMSKI A. and UNRUG R. (1986) — Zarys sedymentologii. Wyd. Geol., Warszawa.

GRIMM K. *et al*. (2002) — Tertiary. In: German Stratigraphic Commission (ed.). Stratigraphic Table of Germany 2002.

KITA A. (2003) — Osady paleogeńskie na obszarze elewacji konińskiej. Pr. Magister., Arch. Inst. Geol. UAM, Poznań: 1–83.

KOSMOWSKA-CERANOWICZ B. (1979) — Lithological variability and origin of the Tertiary clastic sediments from some selected areas of north and central Poland in the light of analyses of the transparent heavy minerals (in Polish with English summary). Pr. Muz. Ziemi PAN, **30**: 3–73.

KOSMOWSKA-CERANOWICZ B. and BÜHMANN D. (1982) — Translucent heavy minerals and clay minerals in Tertiary sediments of Gołębin Stary and Kuleszewo (Poland). Pr. Muz. Ziemi , **35**: 89–110.

KOZYDRA Z. and SKOMPSKI S. (1995) — Unique character of the Eemian Interglacial site in Ruszkówek, Pojezierze Kujawskie, central Poland (in Polish with English summary). Prz. Geol., **43** (7): 572–575.

KRAMARSKA R. (2004) — Lithology, lithostratigraphy and heavy mineral assemblages in the Paleogene and the Neogene deposits from the profilen at Łęczyca near Lębork (in Polish). Prz. Geol., **52** (8/1): 697–698.

LATAL CH., PILLER W. E. and HARZHAUSER M. (2006) — Small-scaled environmental changes: indications from stable isotopes of gastropods (Early Miocene, Kroneuburg Basin, Austria). Int. J. Earth Sc., **96**: 95–106.

MASSELINK G., KROON A. and DAVIDSON-ARNOTT R. G. D. (2006) — Morphodynamics of intertidal bars in wave-dominated coastal settings — a review. Geomorphology, **73**: 33–49.

MATL K. and ŚMIGIELSKA T. (1977) — Paleogene marine sediments between Głogów and Sieroszowice (Lower Silesia — Poland). Rocz. Pol. Tow. Geol., **47** (1): 11–25.

MOORE L. J., SULLIVAN CH. and AUBREY D. G. (2003) — Interannual evolution of multiple longshore sand bars in a mesotidal environment, Truro, Massachusetts, USA. Mar. Geol., **196**: 127–143.

ODRZYWOLSKA-BIEŃKOWA E. (1966) — Microfaunistic boundary between the Eocene and Oligocene in the Kujawy Area (in Polish with English summary). Kwart. Geol., **10** (4): 1072–1078.

ODRZYWOLSKA-BIEŃKOWA E. (1973) — Early Tertiary microfauna in Sieroszowice region (in Polish with English summary). Prz. Geol., **21** (7): 376–377.

ODRZYWOLSKA-BIEŃKOWA E. (1975) — Paleogene deposits in Miechów borehole in the light of micropalaeontological studies (in Polish with English summary). Prz. Geol., **23** (8): 407–408.

OLEMPSKA E. (1973) — Upper Eocene nummulites from Damasławek borehole (Northwestern Poland) (in Polish with English summary). Acta Palaeont. Pol., **18** (2): 211–218.

OSIJUK D. and PIWOCKI M. (1964) — The Oligocene between Rawicz and Gostyń (in Polish with English summary). Kwart. Geol., **8** (2): 291–296.

PIWOCKI M. (2001) — Nowe poglądy na litostratygrafię paleogenu w Polsce północnej. Streszcz. Refer. Pol. Tow. Geol., **10**: 50–60.

PIWOCKI M. (2004) — Paleogen. In: Budowa Geologiczna Polski, t. 1, Stratygrafia, część 3a, Kenozoik — paleogen, neogen (eds. T. M. Peryt and M. Piwocki): 22–70. Wyd. Państw. Inst. Geol., Warszawa.

PIWOCKI M., OLSZEWSKA B. and GRABOWSKA I. (1996) — Korelacja biostratygraficzna paleogenu Polski z innymi obszarami. In: Budowa Geologiczna Polski, Atlas Skamieniałości, T. III, cz. 3a (eds. L. Malinowska and M. Piwocki): 25–35. Wyd. Pol. Agen. Ekol., Warszawa.

POŻARYSKI W. (1953) — Marine sediments of the younger Oligocene in Kujawy (Middle Poland) (in Polish with English summary). Biul. Inst. Geol., **87**: 9–20.

POŻARYSKA K. and ODRZYWOLSKA-BIEŃKOWA E. (1977) — On the Upper Eocene in Poland (in Polish with English summary). Kwart. Geol., **21** (1): 59–68.

PRUSZAK Z., RÓŻYŃSKI G. and ZEIDLER R. B. (1997) — Statistical properties of multiple bars. Coast. Eng., **31**: 263–280.

RACINOWSKI R., SZCZYPEK T. and WACH J. (2001) — Prezentacja i interpretacja wyników badań uziarnienia osadów czwartorzędowych . Wyd. Univ. Silesia, Katowice.

SHARMA A. and RAJAMANI V. (2000) — Weathering of gneissic rocks in the upper reaches of Cauvery river, south India: implications of neotectonics of the region. Chem. Geol., **166**: 203–223.

SKIBA M. (2001) — The origin of kaolinite from the Tatra Mts podzols. Mineral. Pol., **32** (2): 67–77.

STANKOWSKI W., BIEDROWSKI W., BIERNACKA J., CISZEWSKA M., STANKOWSKA A. and WOJEWODA J. (1992) — Marine, lacustrine and peat sediments (Tertiary), and glacigenic sediments (Quaternary) of the Konin area (in Polish with English summary). Proc. Sediment. Sympos. Wyd. Inst. Geol. UAM, Poznań: 16–36.

STANKOWSKI W., BIEDROWSKI W., STANKOWSKA A., KOŁODZIEJ G., WIDERA M. and WILKOSZ P. (1995) — Cainozoic of the Konin area with special emphasis on stratigraphy of Quaternary deposits. Quarter. Stud., **13**: 101–108.

STANKOWSKI W. and KRZYSZKOWSKI D. (1991) — The Quaternary stratigraphy of the Konin area (in Polish with English summary). In: Przemiany środowiska geograficznego obszaru Konin–Turek (ed. W. Stankowski): 11–31. Wyd. Nauk. UAM, Poznań.

SWALES A. OLDMAN J. W. and SMITH K. (2006) — Bedform geometry on a barred sandy shore. Mar. Geol., **226**: 243–259.

VINKEN R. et al. (1988) — The Northwest European Tertiary Basin, Results of the International Geological Correlation Programme, Project No 124. Geol. Jahrb. Reihe A, Hannover.

VISHER G. S. (1969) — Grain size distribution and depositional processes. J. Sediment. Petrol., **39**: 1074–1106.

WAGNER M. (2004) — Charakterystyka strukturalno-teksturalna neogeńskich osadów podwęglowych w KWB Konin. Master Thesis., Arch. Inst. Geol. UAM, Poznań.

WALKIEWICZ Z. (1984) — The Tertiary in Wielkopolska (in Polish with English summary). Wyd. Nauk. UAM, Ser. Geol., 10, Poznań.

WENTWORTH C. R. (1922) — A scale of grade and class terms for clastic sediments. J. Geol. **30**: 377–392.

WIDERA M. (1998) — Palaeomorphological and palaeotectonical evolution of the Konin Elevation (in Polish with English summary). Geologos, **3**: 55–103.

WIDERA M. (2000) — Stratigraphy and lithology of Quaternary sediments in the Kleczew region and in key sections of the eastern Wielkopolska Lowland, central Poland. Geol. Quart., **44** (2): 212–220.

WIDERA M. (2002) — Problemy litostratygrafii trzeciorzędu wschodniej Wielkopolski. Streszcz. Refer. Pol. Tow. Geol., **11**: 15–31.

WIDERA M. (2004) — Phases of Paleogene and Neogene tectonic evolution of selected grabens in the Wielkopolska area, central-western Poland. Ann. Soc. Geol. Pol., **74** (3): 295–310.

WOJEWODA J. (1992*a*) — Cechy strukturalne osadów (in Polish with English summary). In: Marine, Lacustrine and Peat Sediments (Tertiary), and Glacigenic Sediments (Quaternary) of the Konin Area (eds. W. Stankowski et al.): 23–24. Proc. Sediment. Sympos. Wyd. Inst. Geol. UAM, Poznań.

WOJEWODA J. (1992*b*) — Rekonstrukcja paleogeograficzna i wiek osadów (in Polish with English summary). In: Marine, Lacustrine and Peat Sediments (Tertiary), and Glacigenic Sediments (Quaternary) of the Konin Area (eds. W. Stankowski et al.). Proc. Sediment. Sympos. Wyd. Inst. Geol. UAM, Poznań.

WOLAŃSKA H. (1962) — Micropalaeontological stratigraphy of the Oligocene of Western Poland (in Polish with English summary). Kwart. Geol., **6** (1): 149–156.

WO NY E. (1965) — The Oligocene of western Poland and its fauna (in Polish with English summary). Biul. Inst. Geol., **192**: 169–218.