Acta Geologica Polonica, Vol. 58 (2008), No. 4, pp. 455-471

Cenozoic tectonic evolution of the Poznań-Oleśnica Fault Zone, central-western Poland

MAREK WIDERA[1], WOJCIECH ĆWIKLIŃSKI[2] & ROBERT KARMAN[2]

[1]*Institute of Geology, A. Mickiewicz University, Maków Polnych 16,PL- 61-606 Poznań, Poland.*
E-mail: widera@amu.edu.pl
[2]*Hebo Poznań Sp. z o.o., Podolska 27a,PL-60-615 Poznań, Poland.*
E-mails: rumburak113@wp.pl, rkarman@wp.pl

ABSTRACT:

WIDERA, M., ĆWIKLIŃSKI, W. & KARMAN, R. 2008. Cenozoic tectonic evolution of the Poznań-Oleśnica Fault Zone, central-western Poland. *Acta Geologica Polonica*, **58** (4), 455-471. Warszawa.

The Poznań-Oleśnica Fault Zone (P-OFZ) of central-west Poland is an over 150 km long, up to 10 km wide, and up to 200 m deep graben that developed during Early Oligocene to Pliocene times on the flank of the NE-dipping Fore-Sudetic Homocline. Fault systems of this extensional structure appear to reach pre-Zechstein basement in the area of the Fore-Sudetic Homocline that forms an integral part of the Bohemian Massif. The P-OFZ was affected by several stages of subsidence, separated by periods of inversion and/or tectonic quiescence between the Triassic and Cenozoic. Structurally, this dislocation zone can be linked with the Variscan faults, reactivated at that time. During the second half of the last century, the northern parts of the P-OFZ graben were intensively explored by cored boreholes because of their lignite content. Conventional back-stripping methods could not be applied to the tectonic analysis of the P-OFZ due to the limited thickness of the graben fill, its poor dating and the presence of relatively thick lignite seams. Therefore, phases of accelerated subsidence were determined by comparing the thickness of individual lithostratigraphic units within the graben and on its flanks. The total subsidence of the different graben segments was quantified by determining the aggradation coefficient (*AC*) and by taking the consolidation coefficient (*CC*) of lignite seams into consideration. Subsidence analyses indicate that the initial Early Oligocene extensional phase of the P-OFZ was followed by an Early–Middle Miocene extensional subsidence phase and a probably latest Miocene–Pliocene final extensional phase.

Key words: Poznań-Oleśnica Fault Zone, Tectonic subsidence, Tectonic phases, Lignite, Cenozoic.

INTRODUCTION

The over 150 km long Poznań-Oleśnica Fault Zone (P-OFZ) is located in central-western Poland (Text-fig. 1). This paper addresses the central and northern segments of the P-OFZ, which consist of NNE–SSW- to NNW–SSE-trending narrow grabens that extend over a distance of 100 km between the cities of Poznań and Gostyń (Text-fig. 2).

The P-OFZ, which is associated with a negative Bouguer gravity anomaly with vertical amplitude ranging from 2 to 6 mGal/km (see CIUK 1978), was discovered in the 1950s. At that time, this anomaly was interpreted as being related to the presence of Zechstein salt structures at depth (DĄBROWSKI & KARASZEWSKI 1957). However, after the drilling of numerous boreholes during the next two decades, it was recognized that this gravity anomaly is related to thick Miocene lignite seams that occur in the central and northern segments of the P-OFZ (Ciuk 1970, 1978; Deczkowski & Gajewska 1977, 1980; Karnkowski 1980; Kasiński 1984, 1985).

The evolution of the P-OFZ has been the subject of numerous investigations, including palaeotectonic ones, some of which were carried out during the last few years (Widera 2004, 2007; Widera & *al.* 2004; Widera & Karman 2007). In this paper, we present the results of quantitative calculations of the Cenozoic evolution of the P-OFZ, combining results of various palaeotectonic analysis methods that aim at identifying phases of increased subsidence. Moreover, we relate the Cenozoic tectonics of the P-OFZ to fractures as well as to faults occurring in the Palaeozoic and Mesozoic sedimentary cover. Another aim of this paper is to compare the different deformation phases of the P-OFZ with synchronous tectonic phases recorded in other parts of Poland (Dyjor 1995; Oszczypko 1999, 2001; Krysiak 2000; Gotowała & Hałuszczak 2002; Widera 2004, 2007; Widera & *al.* 2004; and references therein) and Europe (Malkovsky 1987, Ziegler 1992a, Hippolyte & Sandulescu 1996, Meulenkamp & *al.* 1996, Peterek & *al.* 1997, Sissingh 1998, Michon & *al.* 2003, Dèzes & *al.* 2004, Cloetingh & *al.* 2005, Schäfer & *al.* 2005, Ziegler & Dèzes 2007; and references therein).

GEOLOGICAL SETTING

Pre-Cenozoic tectonics

The P-OFZ is located between the Bohemian Massif and the East European Craton and is superimposed on the external parts of the Variscan orogen (Text-fig. 1; Dadlez 2006, Mazur & *al.* 2006). In the study area, crustal thicknesses change from 30 km in the southwest to 35 km in the northeast (Guterch & Grad 1996, Guterch & *al.* 1999, Malinowski & *al.* 2005). Moreover, deep seismic sounding profiles provide information on the velocity structure of the crystalline crust and define the crustal-scale Dolsk Fault (Dadlez 2006). At the intersection of the Dolsk Fault and the P-OFZ, the strike of the latter changes from NNE–SSW to NNW–SSE in the area of the Czempiń Graben (Text-figs 1, 2).

Geometrically and obviously also genetically the P-OFZ is linked with the Poznań-Szamotuły Fault Zone (P-SzFZ) and the Poznań-Kalisz Fault Zone (P-KFZ). Their junction is situated in the vicinity of the City of Poznań (see Text-fig. 1). The P-SzFZ and P-KFZ, as well as the Dolsk Fault, are roughly parallel to the southwest boundary of the East European Craton and to the northeast boundary of the Sudetes in the Bohemian Massif (Text-fig. 1b). In contrast, the investigated P-OFZ trends obliquely to these major structural

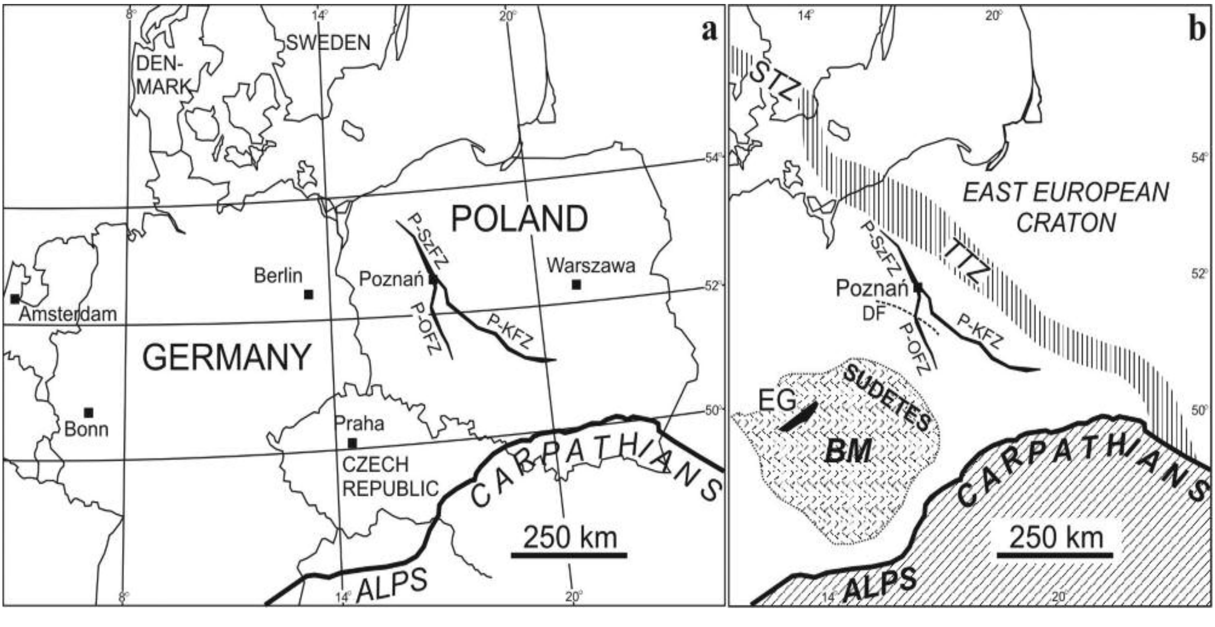

Fig. 1. (a) Location map of the Poznań-Oleśnica Fault Zone in Central Europe. (**b**) Simplified tectonic sketch of Central Europe. Variscan massif: BM Bohemian Massif. Cenozoic graben: EG Eger (Ohre) Graben (after: Michon & *al.* 2003; Ziegler & Dèzes 2005, 2007). Tectonic zones: STZ Sorgenfrei-Tornquist Zone, TTZ Teisseyre-Tornquist Zone (after: Pharaoh 1999; Krzywiec 2002, 2006); P-KFZ Poznań-Kalisz Fault Zone, P-SzFZ Poznań-Szamotuły Fault Zone, P-OFZ Poznań-Oleśnica Fault Zone (after: Deczkowski & Gajewska 1980; Kasiński 1984, 1985; Widera 2007; DF Dolsk Fault (after Dadlez 2006)

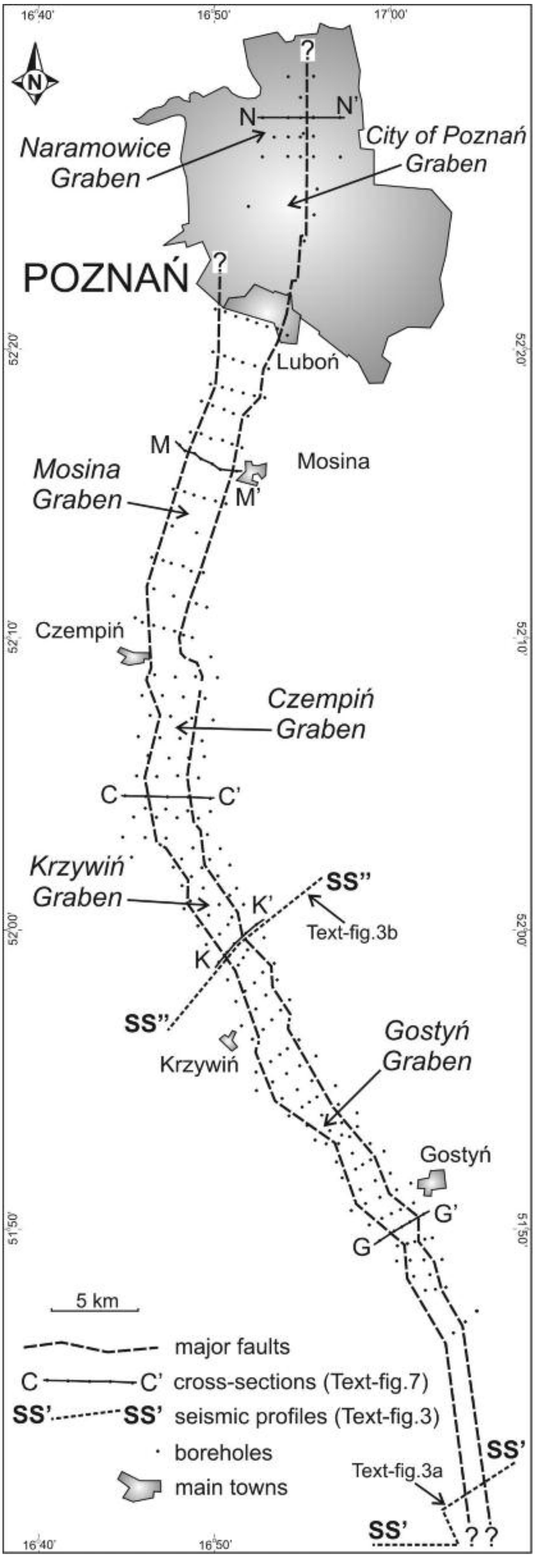

Fig. 2. Northern and central segments of the Poznań-Oleśnica Fault Zone (P-OFZ), showing distribution of boreholes and locations of seismic profiles shown in Text-fig. 3 and cross-sections shown in Text-fig. 7

features (SOKOŁOWSKI 1967; DADLEZ 1997, 2006; KRZYWIEC 2002, 2006).

It is evident that there is a close relationship between the NW–SE-orientated palaeotectonic structures: the P-SzFZ, P-KFZ, Dolsk Fault and the above-mentioned boundaries of the East European Craton and of the Sudetes (see Text-fig. 1b). On a regional scale, they can be linked to the main Variscan trends regarded as the interaction between the Carpathian-Alpine orogen and the East European Craton (ARTHAUD & MATTE 1977; STACKENBRANDT & FRANZKE 1989; ZIEGLER 1990, 1992a, 1992b; ZIEGLER & *al.* 1995; DADLEZ & *al.* 1995; PHARAOH 1999; LAMARCHE & *al.*, 2002; DÈZES & *al.*, 2004; ZIEGLER & DÈZES 2005, 2007; and references therein). During pre-Zechstein times, dextral displacements along the basement blocks are suggested in the northeast boundary of the Sudetes in the Bohemian Massif and the Dolsk Fault areas (DADLEZ 2006, MAZUR & *al.* 2006) as well as in the P-KFZ in the Mesozoic (Kwolek 2000). Thus, the investigated P-OFZ is located in the transition zone between the northeast boundary of the Sudetes and the P-KFZ. In contrast, strike-slip movements have been not determined till now in the P-OFZ. In our opinion, this interesting geological problem can be resolved with the use of the geophysical methods, including 3-D seismic profiles.

During Permian and Mesozoic times, the area of the P-OFZ was affected by several stages of subsidence and/or inversion. The first vertical movements took place in the Early Permian (KARNKOWSKI 1980). Negative vertical movements subsequently took place in the late Triassic (KWOLEK 2000) or from the Late Triassic (Rhaetian) to the Early Jurassic (DECZKOWSKI & GAJEWSKA 1977, 1980). During the Permian, Triassic, Jurassic and Cretaceous the area was affected by regional thermal subsidence with apparent activity of the P-OFZ (KARNKOWSKI 1980). Based on thickness data (isopach maps) on both flanks of the P-OFZ, KARNKOWSKI (1980) documented the existence of a wrench-faulting zone characterized by subsidence rates that are even some times higher between the western and eastern shoulders of the P-OFZ for some intervals of the Permian–Cretaceous period (KARNKOWSKI 1980).

The seismic profile (Text-fig. 3a: for location see Text fig. 2) shows that the P-OFZ corresponds to Mesozoic evolution of a graben bounded by conjugate extensional faults that merge at the level of the Zechstein evaporates. The fact that this graben evolved already during the Mesozoic is evidenced by thickness changes of sedimentary layers across faults (DECZKOWSKI & GAJEWSKA 1977). The fault systems cut the pre-Zechstein series and can be interpreted, according to the terminology of HARDING (1985), as a typical positive flower structure in the southern segments of the P-OFZ (DECZKOWSKI & GAJEWSKA 1977, 1980). The seismic profile for the central section of the P-OFZ presented in Text-fig. 3b (for location see Text-fig. 2) also shows the above-mentioned graben bounded by conjugate extensional faults that merge at the level of the Zechstein evaporites; the western master fault here pierces the Zechstein evaporites and extends through them, cutting the pre-Zechstein basement. This example, in contrast, can be interpreted as a typical negative flower structure.

During the latest Cretaceous to Eocene times, the entire study area was significantly uplifted and subjected to erosion in conjunction with the inversion of the Polish Trough (KRZYWIEC 2006) and uplift of basement blocks forming the Bohemian Massif (ZIEGLER 1990,

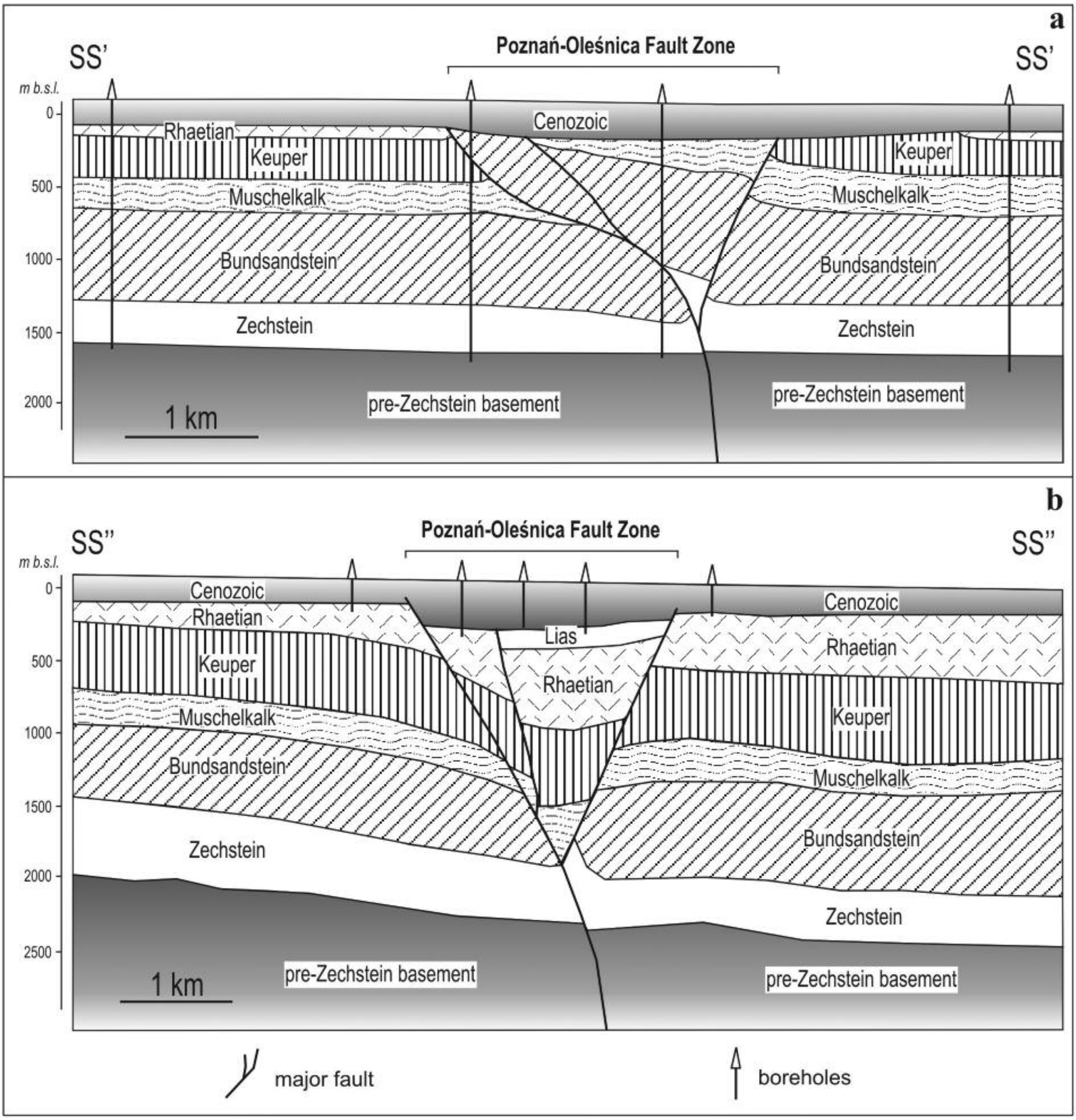

Fig. 3. Geological interpretation of deep reflection seismic profiles: (**a**) Through the area south of central segment of the P-OFZ showing a positive flower structure (modified after: DECZKOWSKI & GAJEWSKA 1977); (**b**) Through central segment of the P-OFZ showing a negative flower structure (modified after: DECZKOWSKI & GAJEWSKA 1980); *m b.s.l.* metres below sea level

ZIEGLER & DÈZES 2007). A positive flower structure developed south of the Gostyń Graben (see Text-figs 2, 3a; DECZKOWSKI & GAJEWSKA 1977), suggesting that the study area was affected by convergent strike-slip faulting during this inversion stage (SOKOŁOWSKI 1967; CIUK 1978; DECZKOWSKI & GAJEWSKA 1977, 1980; KARNKOWSKI 1980; JASKOWIAK-SCHOENEICHOWA 1981). Subsequently, extensional tectonics controlled the evolution of the P-OFZ, albeit most of Central Poland was characterized by regional tectonic subsidence during Early Oligocene to Pliocene times. The exception took place during the Late Oligocene when the entire area of central Poland was uplifted (WALKIEWICZ 1984; KASIŃSKI 1984, 1985; WIDERA & *al.* 2004; WIDERA 2007).

Cenozoic lithostratigraphy

The P-OFZ is the lithostratigraphic type locality of the pre-Pleistocene Cenozoic series of the Polish Lowlands (CIUK 1970, 1978; WIDERA 2007; WIDERA & KITA 2007). Since the Polish Lowlands formed during the Cenozoic part of the NW European Paleogene–Neogene Basin (VINKEN & *al.* 1988), the stratigraphic position of its formations and members is shown in Text-fig. 4 in the framework of modern chronostratigraphic schemes (STEININGER & RÖGL 1983, DANIELS & *al.* 1985, STEININGER & *al.* 1987, GRADSTEIN & *al.* 2004).

The Paleogene and Neogene series of central-western Poland (P-OFZ) may be readily correlated with those of neighbouring areas in southwestern Poland and most of all with those in southeastern Germany (GRIMM & *al.* 2002) which can be closely dated owing to the occurrence of microfaunas and dinocysts (STANDKE & *al.* 1993). In contrast, microfaunas and microfloras provide very rare support for the stratigraphic zonation of the Cenozoic series of southwestern and central-western Poland (PIWOCKI & ZIEMBIŃSKA-TWORZYDŁO 1997, PIWOCKI 1998, WIDERA & KITA 2007). Therefore, three lithostratigraphical columns are presented in this paper (Text-fig. 4). In their interregional correlation, lignite seams play an important parastratigraphic role (SCHINDEWOLF 1960, VINKEN & *al.* 1988, PIWOCKI 1998).

The Cenozoic succession of the P-OFZ consists of an up to 130 m thick Lower Oligocene partly marine succession that is separated by a regional hiatus from an up to 300 m thick continental Miocene series, which in turn is unconformably overlain by late Pleistocene and Holocene glaciogenic deposits that can attain thicknesses of up to 100 m (Text-fig. 4).

The Early Oligocene succession commences with the glauconitic marine sands of the Lower Mosina Formation, which is conformably overlain by the limnofluvial to brackish Czempiń Formation that contains the 5th Czempiń Lignite Seam. The latter corresponds to the 5th Lusatian Seam of southeastern Germany (AHRENS & LOTSCH 1963, STANDKE & *al.* 1993). The Czempiń Formation is conformably overlain by the glauconitic shallow marine sands of the Upper Mosina Formation, which equates with the Rupel Formation in adjacent Germany, where it is developed in the open marine facies of the Rupel Clays (Rupelton) (PIWOCKI & ZIEMBIŃSKA-TWORZYDŁO 1997, WIDERA & KITA 2007). The Late Oligocene hiatus reflects uplift and erosion of the P-OFZ (WIDERA 2004, 2007; WIDERA & *al.* 2004, 2007).

The Miocene sequence of the P-OFZ begins above a basal 4th Dąbrowa Lignite Seam (equivalent of Lusatian Seam 4) with the fluviatile sands of the Rawicz Formation; these are followed by the Ścinawa Formation, which contains the 3rd Ścinawa and the 2nd Lusatian Lignite Seams, which make up large parts of this lithostratigraphic unit (WALKIEWICZ 1984; KASIŃSKI 1984, 1985; WIDERA & *al.* 2004). These two seams equate with the 3rd and 2nd Lusatian Seams of southeastern Germany (AHRENS & LOTSCH 1963, STANDKE & *al.* 1993, KUPETZ & *al.* 2004). Fluvial sands, containing intercalations of clays and silts that are attributed to the Pawłowice and Naramowice formations respectively, conformably overlie the lignite-bearing Ścinawa Formation (Text-fig. 4). The Miocene succession in the P-OFZ terminates with the Poznań Formation, which consists of the Middle-Polish and Wielkopolska members. The lower of these includes the 1st Middle-Polish Lignite Seam, which corresponds to the 1st Lusatian Seam in southeastern Germany. The Wielkopolska Member, which consists of fluvial and/or lacustrine clays and silts, is very well developed in southwestern and central-western Poland whilst in southeastern Germany the equivalent Rauno Formation it is preserved in residual form only (AHRENS & LOTSCH 1963, STANDKE & *al.* 1993, GRIMM & *al.* 2002, KUPETZ & *al.* 2004). The top of the Wielkopolska Member is erosional.

METHODS AND MATERIALS

Analysis of the Cenozoic tectonic evolution of the P-OFZ requires unique research methods. These include only some elements of the backstripping method that is commonly used to quantify tectonic subsidence (VAN HINTE 1978; TEN VEEN & KLEINSPEHN 2000). The reliability of a tectonic subsidence curve derived by the backstripping routine from a given sedimentary sequence depends, however, on the accuracy of the chronostratigraphic dating of the latter and on reliable decompaction curves. Unfortunately, the Cenozoic sedimentary sequence contained in the grabens of the P-OFZ is poorly dated and its stratigraphic zonation is based mainly on correlation of lithological units with those of the Lusatian Basin in adjacent Germany (see Text-fig. 4; CIUK 1970, WIDERA 2007, WIDERA & KITA 2007). Consequently, detailed tectonic subsidence rates, expressed in mm/ky or in m/My, cannot be determined for the P-OFZ nor can reliable tectonic subsidence curves be developed for its different graben segments.

In an attempt to distinguish phases of rapid subsidence of the grabens forming part of the P-OFZ, sediment aggradation coefficients (*AC*) were calculated. These quantify how many times the average thickness of a given lithostratigraphic unit within a graben exceeds the average thickness of the same lithostratigraphic unit on the graben flanks. Due to the great content of lignites in the grabens, the compaction curves and/or equations that are appropriate for clastic deposits (SCLATER & CHRISTIE 1980, BALDWIN & BUTLER 1985, SHELDON & RETALLACK 2001) cannot be used in the case of the P-OFZ. Therefore, we took into consideration the consolidation coefficient (*CC*), which defines the ratio between the peat bog thickness before burial and the present thickness of the resulting lignite seam (HAGER & *al.* 1981, ZAGWIJN & HAGER 1987, WIDERA 2002, WIDERA & *al.* 2007). The *CC* values obtained for the two main lignite seams in central Poland, namely the 1st Middle-Polish Lignite Seam and the 2nd Lusatian Lignite Seam, are about 2.0 and 2.5 (WIDERA 2002, WIDERA & *al.* 2007). The consolidation of peat

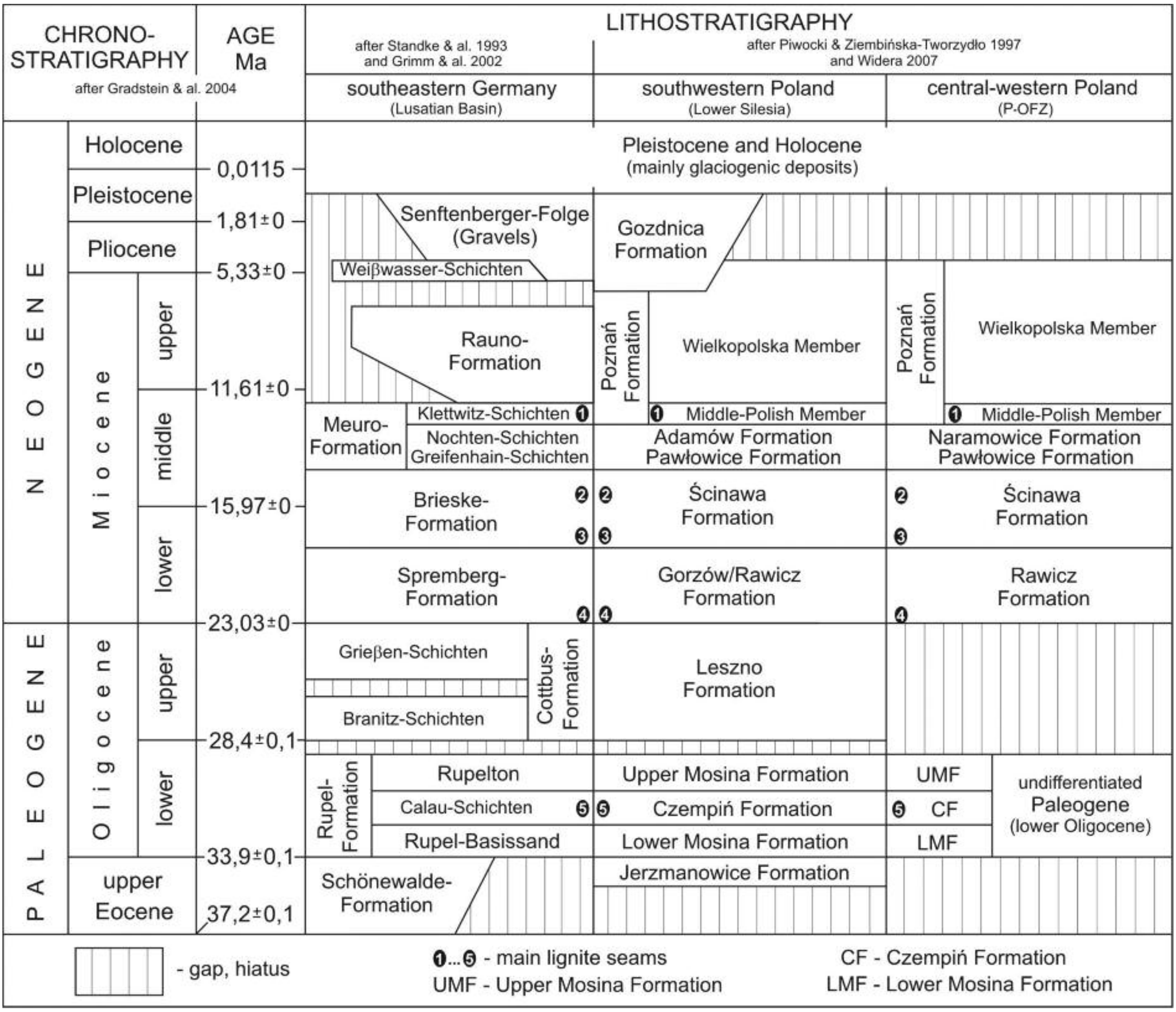

Fig. 4. Correlation of lithostratigraphic units of the P-OFZ and neighbouring Lower Silesia of southwestern Poland and the Lusatian Basin of southeastern Germany

and its transformation into lignite is of great importance for correct estimates of the tectonic subsidence in the study area, as in some formations or members the lignite content reaches up to 60% (CIUK 1978, WALKIEWICZ 1984, WIDERA & *al*. 2004).

The combined *AC* and *CC* information enables distinguishing between the tectonic and compaction-induced subsidence of the depositional surface. On the basis of the *AC*, and taking into consideration a higher *CC* value of 2.5 and a maximum 60% lignite

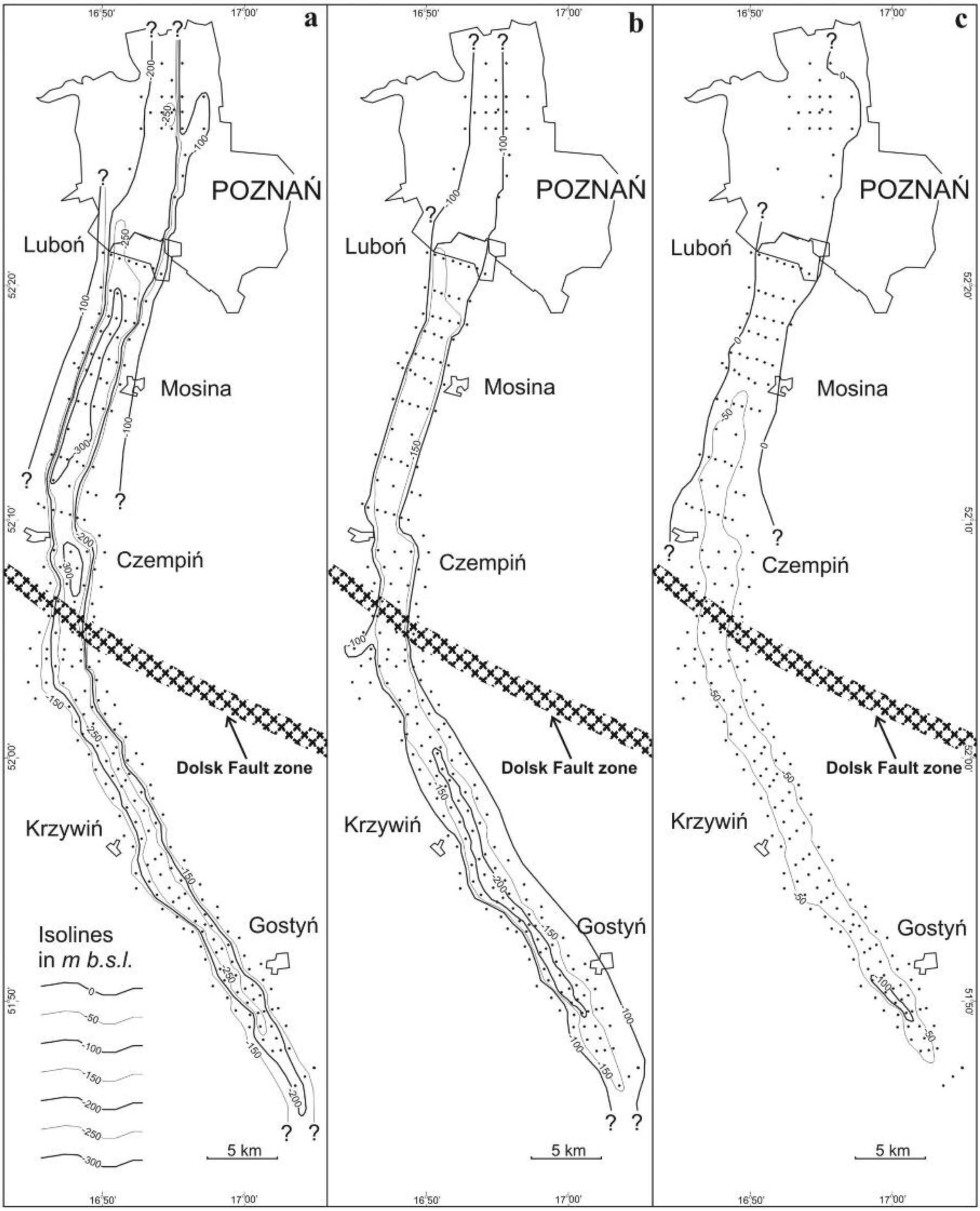

Fig. 5. Structural maps: **(a)** Base of the Paleogene (= top of the Mesozoic); **(b)** Base of the Ścinawa Formation; **(c)** Base of the Poznań Formation (= base of the Middle-Polish Member)

Cross-section line (graben)	Borehole original numeration	Thickness of lithostratigraphic units [m]								
		LMF	CF	UMF	Undiff. Paleogene LMF + CF + UMF	RF	ŚF	PF + NF	PNF	
									MPM	WM
N–N’ (Naramowice Graben)	**Piątkowo 1**	**12.0**	**6.0**	**0.0**	**18.0**	**79.8**	**12.4**	**52.6**	**5.4**	**29.6**
	30/16	**n.d.**	**>40.5**	**0.0**	**>40.5**	**58.1**	**37.4**	**32.6**	**9.4**	**73.5**
	31/16	**n.d.**	**>14.5**	**0.0**	**>14.5**	**63.6**	**51.6**	**38.6**	**9.6**	**78.2**
	32/16	1.5	7.2	0.0	8.7	56.0	3.5	23.5	20.7	41.8
	Różany Młyn	8.0	3.5	8.5	20.0	31.0	15.0	35.7	7.9	30.4
M–M’ (Mosina Graben)	Jeziory 23/94	0.0	17.0	0.0	17.0	34.4	3.3	57.0	5.3	5.3
	168/42	3.9	19.3	0.0	23.2	36.0	7.7	54.2	2.9	11.3
	Mosina 24/93,5	**11.0**	**89.4**	**23.5**	**123.9**	**18.2**	**58.3**	**71.1**	**4.5**	**74.1**
	166/46	**21.5**	**39.5**	**69.6**	**130.6**	**22.0**	**51.9**	**72.1**	**5.1**	**45.1**
	Mosina 25/93	**9.6**	**33.5**	**45.3**	**88.4**	**32.6**	**53.6**	**68.4**	**13.7**	**37.6**
	163/50	**0.0**	**>27.3**	**48.4**	**>75.7**	**46.9**	**44.2**	**73.2**	**13.7**	**31.7**
	Mosina 26/92,5	0.0	21.9	4.0	25.9	35.5	8.5	62.5	14.3	19.7
C–C’ (Czempiń Graben)	18cz	0.0	0.0	21.3	21.3	22.6	51.3	37.5	17.0	51.7
	19cz	0.0	0.0	24.8	24.8	39.2	38.4	35.0	9.2	88.4
	20cz	**18.1**	**20.2**	**23.5**	**61.8**	**46.7**	**85.3**	**37.9**	**6.6**	**124.8**
	21cz	**4.6**	**19.2**	**18.2**	**42.0**	**51.6**	**59.7**	**55.9**	**15.0**	**105.8**
	22cz	6.4	2.2	5.0	13.6	40.5	29.0	53.7	10.3	65.0
K–K’ (Krzywiń Graben)	Świniec 25/64	0.0	0.0	13.6	13.6	18.4	48.8	51.4	1.1	97.7
	Krzywiń 50/50	**0.0**	**4.7**	**29.2**	**33.9**	**28.0**	**59.0**	**49.7**	**7.0**	**117.3**
	Jerka 26/65	**8.3**	**3.1**	**22.0**	**33.4**	**29.4**	**99.0**	**35.7**	**2.7**	**142.6**
	Krzywiń 54/54	0.0	0.0	7.4	7.4	42.8	44.2	37.4	17.9	72.3
	Łuszkowo 27/66	0.0	0.0	0.0	0.0	39.0	54.0	30.0	3.0	65.6
G–G’ (Gostyń Graben)	Gostyń 9g	0.0	0.0	28.7	28.7	26.1	22.2	32.5	13.8	109.6
	Czajkowo 2	**4.3**	**1.5**	**19.2**	**25.0**	**20.6**	**91.5**	**21.9**	**28.3**	**143.5**
	Czajkowo 1	**0.0**	**1.3**	**12.1**	**13.4**	**25.9**	**78.3**	**24.3**	**23.1**	**156.6**
	Brzezie-Huby 1	**0.0**	**0.0**	**24.4**	**24.4**	**9.8**	**71.9**	**21.6**	**24.1**	**106.3**
	Gostyń 10g	0.0	0.0	23.0	23.0	8.2	31.0	37.7	14.6	122.0

Table 1. Input data for cross-section preparation and calculation of the aggradation coefficient (*AC*). Data derived from boreholes located inside the grabens are typed in bold

content, two major limits are indicated, namely when *AC* = 100% and when *AC* = 150% (2.5 × 60% = 150%). In the case when *AC* ranges between 100% and 150%, the graben was affected by compaction-driven subsidence and/or by tectonic subsidence. When *AC* > 150%, the total graben subsidence consists of a tectonic and a compaction-driven subsidence component. In contrast, an *AC* < 100% suggests that the graben was tectonically uplifted and/or was affected by uplift and erosion later. Thus, *AC* values < 100% and > 150% are indicative of tectonic phases affecting the P-OFZ, with an *AC* value > 150% indicating that tectonic subsidence played a significant role in the graben evolution (WIDERA 2002, WIDERA & *al.* 2007).

Data derived from 248 boreholes, drilled in 1961–1978, were used to define the outlines of the graben segments of the P-OFZ. The following number of boreholes is located in particular segments of the P-

Cross-section line	Aggradation coefficient [%]								
	LMF	CF	UMF	Undiff. Paleogene LMF + CF + UMF	RF	ŚF	PF + NF	PNF	
								MPM	WM
N–N’	n.d.	>376	0	>169	154	345	139	57	167
M–M’	808	244	3510	>476	84	800	130	123	389
C–C’	543	>2814	123	>261	144	183	112	89	169
K–K’	∞	100	370	129	90	160	110	70	170
G–G’	∞	∞	70	81	110	300	60	180	120

Table 2. Aggradation coefficient (*AC*) calculated along all examined cross-sections (Text-fig. 7). For location of cross-sections see Text-fig. 2; for input data see Table 1 and for other explanations see the text

OFZ: 18 in the Naramowice Graben, 4 in the City of Poznań Graben, 63 in the Mosina Graben, 42 in the Czempiń Graben, 48 in the Krzywiń Graben and 73 in the Gostyń Graben (Text-fig. 2).

The extensive literature, presented as references below, as well as published seismic profiles (Text-fig. 3), were used for the description of the pre-Cenozoic geology of the P-OFZ. Similarly, the lithostratigraphic diagram presented in Text-fig. 4 was compiled from previous German, Polish and the authors' own studies. The structural and isopach maps were constructed on the basis of data from the above-mentioned boreholes retrieved from the archive of the Polish Geological Institute in Warsaw. These boreholes reach total depths between about 200 m to more than 400 m, with most of them bottoming in the pre-Cenozoic series (Text-figs 5, 6). Moreover, data from selected boreholes were used to construct five cross-sections through the different graben segments, with the exception of the City of Poznań Graben (Text-fig. 7, Table 1). Along these cross-sections, the aggradation coefficient (*AC*) was calculated for each lithostratigraphic unit (Table 2).

CENOZOIC TECTONIC EVOLUTION

Five representative cross-sections through the P-OFZ between Poznań and Gostyń, illustrating its extensional nature, are given in this paper (Text-fig. 7). These cross-sections are based exclusively on borehole data, except for profile G (Text-fig. 7e), which is supported by a reflection-seismic line (see text-fig. 3b). Structural contour maps for the base of the Paleogene sequence (= top-Mesozoic), the base of the Ścinawa Formation and the base of the Poznań Formation are presented in graphic form (Text-fig. 5). Isopach maps for the undifferentiated Paleogene, the Ścinawa and the Poznań formations are also given in this paper (Text-fig. 6).

At the top-Mesozoic level, the maximum throw on faults delimiting the P-OFZ graben system decreases from around 200 m in its northern segment to 100–120 m in its southern, shallower parts (Text-fig. 5a). These differences result from the Paleogene and Neogene tectonic subsidence that was characterized by fault activity. The Paleogene fault throw was much higher in the northern segment of the P-OFZ than in its southern part. On the other hand, the Neogene subsidence was most intense in the southern segment of the study area. Combining both the Paleogene and Neogene tectonic vertical movements, the top of the Mesozoic outside the P-OFZ dips south. In contrast, the bottom of this graben system dips north and the deepest area is located close to Mosina (Text-fig. 5a).

In general, the depth to the base of the Ścinawa Formation increases southward, with structural contours paralleling the strike of the P-OFZ (Text-fig. 5b). On the flanks of the P-OFZ this palaeosurface lies at an elevation of *ca.* 100 m b.s.l., while in the graben to the west of Gostyń it is downfaulted to more than 200 m b.s.l. The base of the Poznań Formation displays a similar, albeit somewhat subdued relief compared to that of the Ścinawa Formation. It lies about 100 m above the base of the latter and is characterized by fault offsets of the order of 40–60 m (Text-fig. 5c).

The thickness of the Paleogene series ranges from 25 m to *ca.* 130 m, with the greatest thicknesses occurring between Czempiń and Mosina in the northerly-trending segment of the P-OFZ (Text-fig. 6a). The average thickness of the Ścinawa Formation is about 50–75 m in the axial part of the P-OFZ and between 0–25 m on its flanks. A characteristic feature is the southward displacement of depocentres into the northwesterly-trending segment of the P-OFZ, namely the area between Czempiń and Krzywiń and the Gostyń area (Text-fig. 6b). The thickness variations of the Poznań Formation result from a combination of tectonic subsidence and Pleistocene glaciogenic deformation (WIDERA 2004, 2007; WIDERA & *al.* 2004). Nevertheless a tectonic control on the thickness distribution is clearly evident. On the graben flanks, the thickness of the Poznań Formation increases from about 25 m in the north to about 75 m in the south, while within the southern parts of the P-OFZ a depocentre is evident in which thicknesses increase to 150 m and more between Krzywiń and Gostyń (Text-fig. 6c).

Along each of the cross-sections given in Text-fig. 7 and on the basis of the available borehole data (Table 1) the aggradation coefficient (AC) was estimated (Table 2). In this respect it should be noted that the aggradation coefficient can only be calculated in areas where the respective lithostratigraphic units are also present on the graben shoulders (KWOLEK 2000; WIDERA 2004, 2007; WIDERA & *al.* 2004). This is the case for the Naramowice, Mosina, Czempiń, Krzywiń and Gostyń graben segments (Table 2) while for the City of Poznań segment the available borehole control on its flanks is insufficient (WIDERA & KARMAN 2007). In the following we discuss the tectonic evolution of the different graben segments.

THE NARAMOWICE GRABEN forms the northernmost part of the P-OFZ and trends N–S (Text-fig. 2). It is about 6 km long and widens from 4 km in the south to more than 10 km in the north (WIDERA & *al.* 2004, WIDERA 2007, WIDERA & KARMAN 2007). The top of the Mesozoic occurs within the graben at depths of 200 to 280 m b.s.l. and on its eastern shoulder at about 100 m b.s.l., accounting for a maximum graben depth of about 175 m (Text-fig. 7a; WIDERA & *al.* 2004). The eastern border fault of the Naramowice Graben is located between boreholes 31/16 and 32/16, while the position of its eastern border fault is unknown. Subsidence of the Naramowice Graben commenced during the deposition of the Lower Mosina

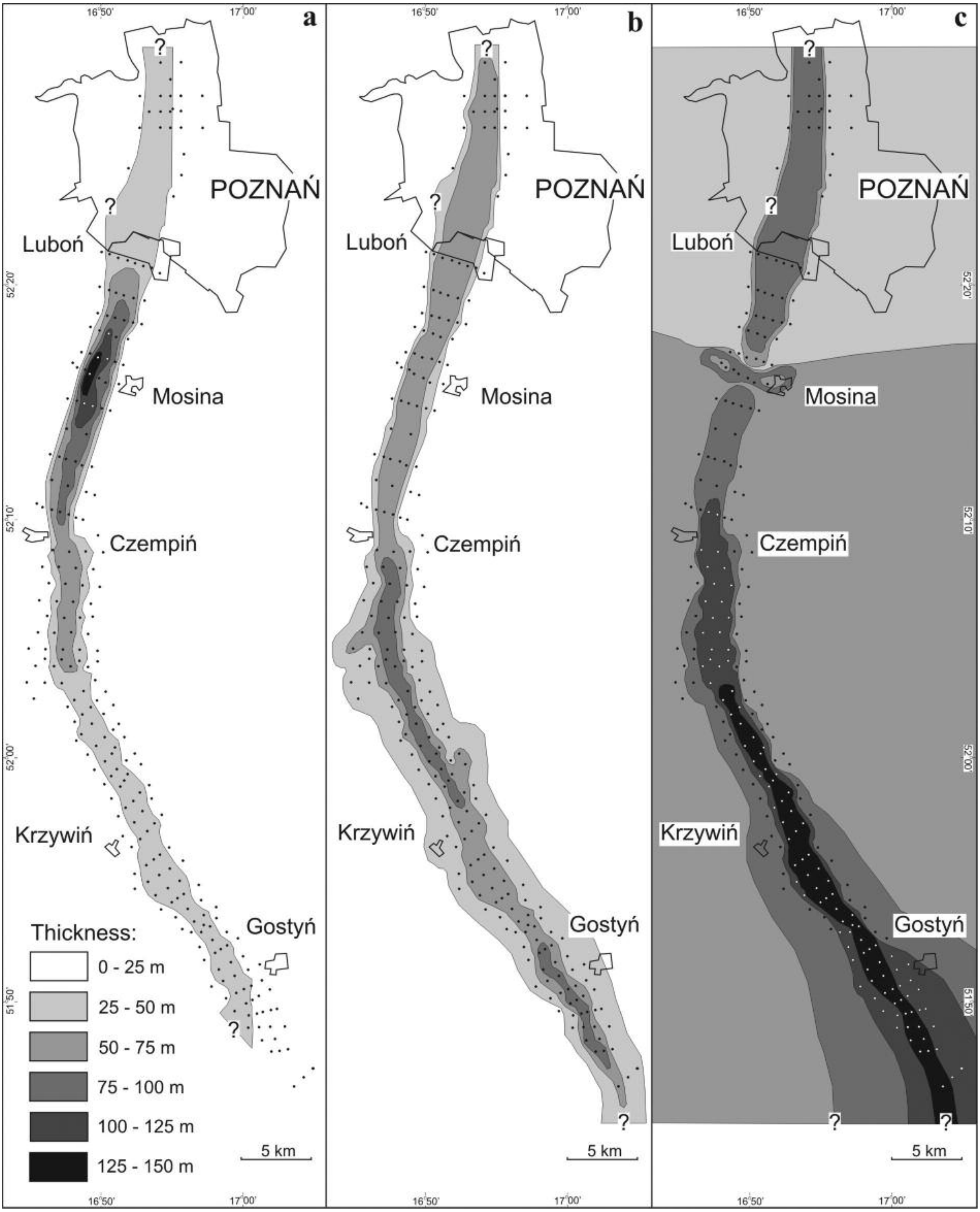

Fig. 6. Isopach maps: (a) Undifferentiated Paleogene; (b) Ścinawa Formation; (c) Poznań Formation

Formation. The total Paleogene succession accounts for an *AC* > 169% (Table 2). The next subsidence phase coincided with the deposition of the Ścinawa Formation, which accounts for an *AC* = 345%. The last subsidence phase occurred after the deposition of the Middle-Polish Member, as evidenced by its offset across the eastern border fault (Text-fig. 7a). This fault activity may have occurred during the deposition of the Wielkopolska Member and/or during the Early Pleistocene, i.e. prior to glacial sedimentation.

THE MOSINA GRABEN is located south of Poznań between Luboń and Czempiń and trends roughly NNE–SSW. It is about 30 km long and ranges in width between 2 and 2.5 km (Text-fig. 2). The Mosina Graben is the deepest segment of the entire P-OFZ, with the top of the Mesozoic being downthrown across the well defined western and eastern border-faults by over 200 m with respect to the graben flanks (WALKIEWICZ 1984, WIDERA & *al.* 2004, WIDERA 2007, WIDERA & KARMAN 2007). The cross-section M–M', used for palaeotectonic analysis, shows two main faults between the axial part of the Mosina Graben and its fault sides (Text-fig. 7b). Upward, the throw on these faults decreases to less than 50 m at the base of the Middle-Polish Member (Text-fig. 7b). Both border-faults were active throughout all stages of the graben evolution, while minor faults in the graben were only active during the early extensional phases. Development of the Mosina Graben commenced during the deposition of the Lower Mosina Formation (*AC* = 543%), with subsidence peaking during the deposition of the Upper Mosina Formation (*AC* = 3510%). The combined Paleogene units account for an average AC

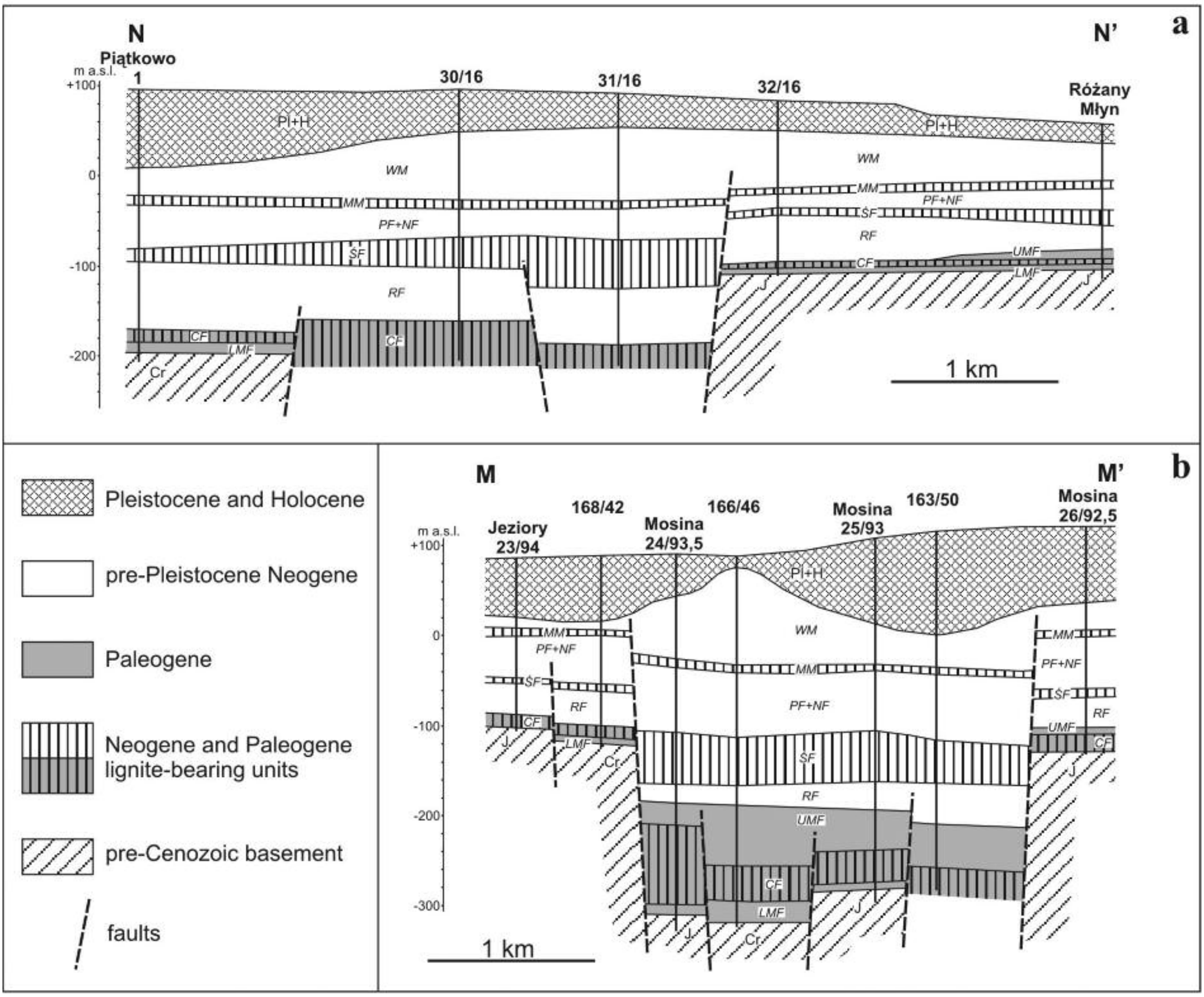

Fig. 7a-b. Simplified cross-sections through: **(a)** Naramowice Graben; **(b)** Mosina Graben. Chronostratigraphic units: Pl+H – Pleistocene and Holocene, Cr – Cretaceous, J – Jurassic, T – Triassic; Lithostratigraphic units: *LMF* – Lower Mosina Formation, *CF* – Czempiń Formation, *UMF* – Upper Mosina Formation, *RF* – Rawicz Formation, *ŚF* – Ścinawa Formation, *PF+NF* – Pawłowice and Naramowice formations, *MM* – Middle-Polish Member, *WM* – Wielkopolska Member; m a.s.l. metres above sea level; For location see Text-fig. 2 and for other explanations see Text-fig. 3 and the text

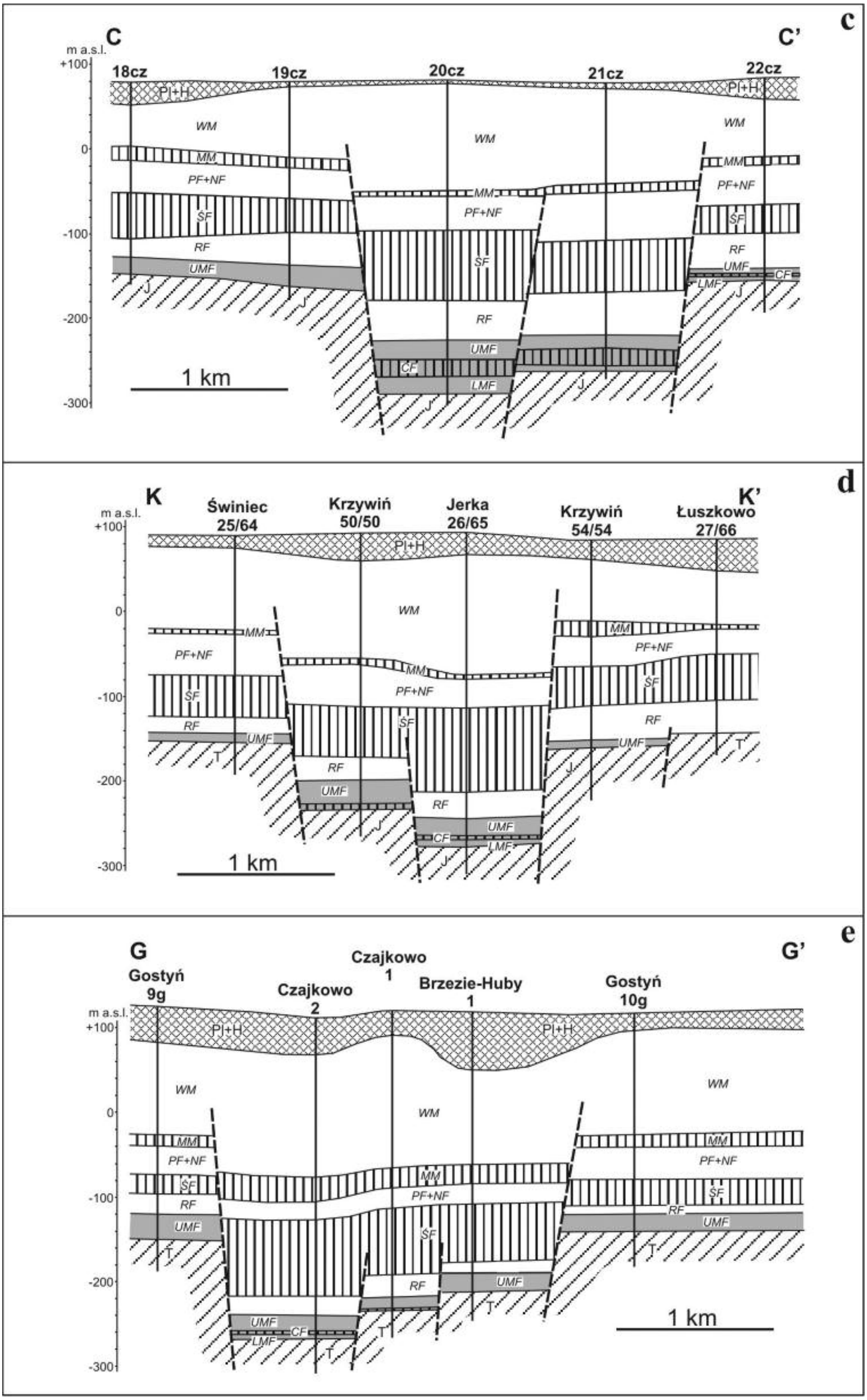

Fig. 7c-e. Simplified cross-sections through: **(c)** Czempiń Graben; **(d)** Krzywiń Graben; **(e)** Gostyń Graben. Chronostratigraphic units: Pl+H – Pleistocene and Holocene, Cr – Cretaceous, J – Jurassic, T – Triassic; Lithostratigraphic units: *LMF* – Lower Mosina Formation, *CF* – Czempiń Formation, *UMF* – Upper Mosina Formation, *RF* – Rawicz Formation, *ŚF* – Ścinawa Formation, *PF+NF* – Pawłowice and Naramowice formations, *MM* – Middle-Polish Member, *WM* – Wielkopolska Member; For location see Text-fig. 2 and for other explanations see Text-fig. 3 and the text

= 476% (Table 2). The second subsidence phase of the Mosina Graben occurred during the deposition of the Ścinawa Formation (*AC* = 800%). A third and last extensional pulse accounted for the vertical displacement of the Middle-Polish Member (Text-fig. 7b).

THE CZEMPIŃ GRABEN is about 8 km long and 2–2.5 km wide, trends approximately N–S, and is located in the area where the strike of the P-OFZ changes (Text-fig. 2). The top of the Mesozoic occurs in the central part of the Czempiń Graben at depths ranging between 250 and 320 m b.s.l. (WIDERA 2004, 2007). At the top Mesozoic level this graben is about 170–180 m deep (Text-fig. 7c). The throws on the border-faults of this graben exceed 120 m at the bottom and top of the Paleogene sequence, while at the base of the Middle-Polish Member they amount to 25–40 m only (Text-fig. 7c). These faults were active throughout all stages of the graben evolution whereas the fault between boreholes 20cz and 21cz became inactive during the deposition of the Middle Polish Member. Therefore, the outlines of the Czempiń Graben, formed during the Paleogene, did not change significantly during the Neogene. Subsidence of the Czempiń Graben commenced during the deposition of the Lower Mosina Formation. On the other hand, the last vertical dislocations occurred after the deposition of the Middle-Polish Member, but prior the glacial Pleistocene. On the basis of aggradation coefficients (Table 2), three tectonic subsidence phases of can be distinguished, namely during the deposition of the Lower Mosina Formation (*AC* = 543%), Czempiń Formation (*AC* = 2814%), Ścinawa Formation (*AC* = 183%) and Wielkopolska Member (*AC* = 169%). The relatively high AC value for the Wielkopolska Member may be the effect of late Neogene and even early Pleistocene tectonic movements.

THE KRZYWIŃ GRABEN trends NNW–SSE, is about 12 km long and 1.5–2.5 km wide (Text-fig. 2). In the axial parts of this narrow, up to 140 m deep graben the depths of the top of the Mesozoic increases northward from 280 to 300 m b.s.l. (KASIŃSKI 1984, 1985; WALKIEWICZ 1984; WIDERA 2007). Close borehole control within the graben and on its flanks enable its evolution to be constrained (Text-fig. 7d). The Paleogene initial subsidence phase of the Krzywiń Graben was not as intense as in the above-described segments of the P-OFZ, except during the deposition of the Upper Mosina Formation, which accounts for an *AC* = 370% (Table 2). Similarly the second subsidence phase, during the deposition of the Ścinawa Formation, accounts for a relatively low *AC* = 160%. The effects of the third and last extensional phase are clearly evident in the architecture of the Middle-Polish Member, the base and top of which are offset across the border-faults by 40 to 50 m.

THE GOSTYŃ GRABEN strikes NNW–SSW and represents the southernmost segment of the P-OFZ (Text-fig. 2). It is about 23 km long, 1–3 km wide and 110–125 m deep, with the top of the Mesozoic occurring at 265 m b.s.l. in the graben and between 140 and 150 m b.s.l. on the graben shoulders (Text-figs 5a, 7e; WIDERA 2007). As the Lower Mosina and Czempiń formations are missing on the graben shoulders, an aggradation coefficient cannot be calculated for the initial subsidence phase of the Gostyń Graben. Nevertheless, these formations are locally developed within the graben (Table 1). Moreover, during the deposition of the Upper Mosina Formation, the graben area subsided more slowly than its flanks *AC* = 70% (Table 2). This suggests that at these times the Gostyń Graben was uplifted. During the deposition of the Ścinawa Formation, the Gostyń Graben subsided rapidly, as reflected by an *AC* = 300% (Table 2). Following the deposition of the Pawłowice and Naramowice formations and the Middle-Polish Member, subsidence of the graben resumed but obviously ceased prior to the glacial Pleistocene. This is evidenced by 40–60 m offsets of the Middle-Polish Member across the boundary faults of the Gostyń Graben (Text-fig. 7e).

CONCLUSIONS

The Poznań-Oleśnica Fault Zone (P-OFZ) consists of six aligned Cenozoic graben segments that are referred to as the Naramowice, City of Poznań, Mosina, Czempiń, Krzywiń and Gostyń grabens (Text-fig. 2). Apart from the City of Poznań Graben, we analyzed the subsidence of these graben segments, taking into consideration the consolidation coefficients *CC* (WIDERA 2002, WIDERA & *al*. 2007) and the aggradation coefficients *AC* (KWOLEK 2000; WIDERA 2004, 2007; WIDERA & *al*. 2004). The P-OFZ area was affected by three major tectonic phases of extensional subsidence. These can be readily correlated with major tectonic events evident in various parts of Poland and Europe.

During the Cenozoic evolution of the P-OFZ, its depocentre migrated from north during the Paleogene to south during the Neogene. It is marked by a clearly visible change in the thickness of several individual lithostratigraphic units (Text-fig. 6). The undifferentiated Paleogene (Lower Oligocene) formations are a few times thicker in the north, but two of the Neogene formations, the Ścinawa Formation (uppermost Lower Miocene–lowermost Middle Miocene) and the Poznań Formation (uppermost Middle Miocene–lowermost Lower Pliocene), are thicker in the south of the study area (Text-fig. 6).

FIRST DEFORMATIONAL STAGE. Early Oligocene deposition of the Lower Mosina, Czempiń and Upper Mosina formations marked the initial extensional subsidence phase of almost the entire P-OFZ except for its southernmost part, the Gostyń Graben area, that was probably uplifted or the uplift and erosion took place before the Neogene sedimentation. During the Early Oligocene, subsidence exceeding 130 m was centred on the Mosina Graben that crosses the major Variscan Dolsk Fault (Text-fig. 1b). At the same time, a number of additional grabens in the Polish Lowlands came to existence: Szamotuły, Chróścina-Nowa Wieś, Chobienia-Rawicz, Lubstów, Bilczew-Drzewce, Adamów grabens *etc.* (Deczkowski & Gajewska 1980; Karnkowski 1980; Walkiewicz 1984; Kasiński 1984, 1985; Widera 2007; and references therein). This phase played a significant role in the evolution of the European Cenozoic Rift System (Ziegler 1990, 1992a; Sissingh 1998; Michon & *al*. 2003; Dèzes & *al*. 2004; Ziegler & Dèzes 2005, 2007). Of relevance to the Polish area is the Late Eocene–Early Oligocene, with a maximum in the Early Oligocene, development of the Eger volcano-tectonic zone on the Bohemian Massif (Malkovski 1987; Peterek & *al.* 1997; Ziegler & Dèzes 2007; and references therein). Correspondingly, the investigated P-OFZ subsided for the first time in its Cenozoic tectonic evolution during the Early Oligocene.

SECOND DEFORMATIONAL STAGE. This extensional subsidence phase of the P-OFZ occurred during the Early and Middle Miocene and affected all of its segments, as evidenced by the thickness of the lignite-bearing Ścinawa Formation (Test-figs 6, 7). Taking into account the lithology and thickness of these sediments and their compaction and/or consolidation, the grabens of the P-OFZ subsided during this time span by as much as 100 m (Text-fig. 4; Widera 2007). At the same time, a few grabens in the Sudetes, Carpathian Foredeep and Polish Lowlands had their Cenozoic maximum of development: Żytawa, Mokrzeszów-Roztoka, Paczków-Kędzierzyn, Nida, Kleszczów grabens *etc.* (Kasiński 1984, 1985; Dyjor 1995; Krysiak 2000; Gotowała & Hałuszczak 2002).

THIRD DEFORMATIONAL STAGE. The last extensional subsidence phase of the P-OFZ occurred some time after the deposition of the Middle-Polish Member, but before the glacial Pleistocene (Widera 2004, 2007; Widera & *al*. 2004; Widera & Karman 2007). Tectonic activity is evident in all of its graben segments, with the main faults offsetting the Middle-Polish Member by 20–60 m (Text-fig. 7). This deformation phase may have commenced during the Late Miocene, probably continued during the Pliocene but had ended prior to the deposition of the glaciogenic Pleistocene (Text-fig. 4). It coincided with the late stage uplift of the Bohemian Massif, entailing a reactivation of its border faults, reorganization of its drainage system and a resurgence of volcanic activity (Ziegler & Dèzes 2007; and references therein).

Acknowledgements

Our sincere thanks are due to Prof. Dr. P.A. Ziegler (University of Basel, Switzerland) for help in preparation of this paper: enlightening some regional tectonic problems, valuable comments and suggestions as well as improving linguistic mistakes. We gratefully acknowledge the critical but useful remarks by the reviewers Drs J.R. Kasiński and P. Krzywiec (Polish Geological Institute, Warsaw, Poland). Dr. A. Konon (University of Warsaw, Poland) is kindly thanked for his editorial comments and Christopher Wood (Scops Geological Services Ltd., United Kingdom) is also gratefully acknowledged for improving the English of the manuscript. Thanks are extended to the Ministry of the Treasury of Poland for enabling us to use the borehole data and to the Institute of Geology, Adam Mickiewicz University in Poznań (Poland) and Hebo Poznań Sp. z o.o. (Poland) for logistical support.

REFERENCES

Arthaud, F. & Matte, P. 1977. Late Paleozoic strike-slip faulting in southern Europe and northern Africa: result of a right-lateral shear zone between the Appalachians and the Urals. *Geological Society of America Bulletin*, **88**, 1305-1320.

Ahrens, H. & Lotsch, D. 1963. Tektonische Bewegungen im Tertiär der zentralen Niederlausitz. *Geologie*, **12**, 833-841.

Baldwin, B. & Butler, C.O. 1985. Compaction curves. *American Association of Petroleum Geologists Bulletin*, **69**, 622-626.

Ciuk, E. 1970. Lithostratigraphical Schemes of the Tertiary from Polish Lowland Area. *Kwartalnik Geologiczny*, **14**, 754-771. [*In Polish with English summary*]

— 1978. The present state of knowledge of brown coal deposits in Poland, recoverable resources covering their explotation to the year 2000, and trends in prospecting. *Przegląd Geologiczny*, **26**, 573-578. [*In Polish with English summary*]

CLOETINGH, S., MANCO, L., BADA, G., DINU, C. & MOCZANU, V. 2005. The evolution of the Carpathians–Pannonian system: Interaction between neotectonics, deep structure, polyphase orogeny and sedimentary basins in a source to sink natural laboratory. *Tectonophysics*, **410**, 1-14.

DADLEZ, R. 1997. Ogólne rysy tektoniczne bruzdy środkowopolskiej. *In*: MAREK, S., PAJCHLOWA, M. (*Eds*). The epicontinental Permian and Mesozoic in Poland. *Prace Instytutu Geologicznego*, **153**, 410-414. [*In Polish with English summary*]

— 2006. The Polish Basin – relationship between the crystalline, consolidated and sedimentary crust. *Geological Quarterly*, **50**, 43-58.

DADLEZ, R., NARKIEWICZ, M., STEPHENSON, R.A., VISSER, M.T. & WESS, J.D. 1995. Tectonic evolution of Mid-Polish Trough. Modelling implications and significance for central European geology. *Tectonophysics*, **252**, 179-195.

DANIELS, C.H., VON CICHA, I. & SPIEGLER, D. 1985. Correlation of Neogene regional stages between the boreal Tertiary of NW Germany and Paratethys using *Uvigerina* (forams). *In*: VIII Congress RCMNS, symposium European late Cenozoic mineral resources, Budapest, 131-169.

DĄBROWSKI, A. & KARASZEWSKI, W. 1957. Investigation on the presumed salt dome near Poznań. *Przegląd Geologiczny*, **5**, 472. [*In Polish with English summary*]

DECZKOWSKI, Z. & GAJEWSKA, I. 1977. The characteristics of Late Cimmerian and Laramide block structures of the Fore-Sudetic Monocline. *Kwartalnik Geologiczny*, **21**, 467-481. [*In Polish with English summary*]

— & — 1980. Mesozoic and Tertiary troughs in the Fore-Sudetic Monocline. *Przegląd Geologiczny*, **28**, 151-156. [*In Polish with English summary*]

DÈZES, P., SCHMID, S.M. & ZIEGLER, P.A. 2004. Evolution of the European Cenozoic Rift System: interaction of the Alpine and Pyrenean orogens with their foreland. *Tectonophysics*, **389**, 1-33.

DYJOR, S. 1995. Evolution of the Cainozoic on the Fore-Sudetic Block. Przewodnik LXVI Zjazdu Polskiego Towarzystwa Geologicznego, 29-40. [*In Polish with English summary*]

GOTOWAŁA, R. & HAŁUSZCZAK, A. 2002. The Late Alpine structural development of the Kleszczów Graben (Central Poland) as a result of a reactivation of the pre-existing, regional dislocation. European Geoscience Union, Stephan Mueller Special Publication Series, **1**, 137-150.

GRADSTEIN, F.M., OGG, J.G., SMITH, A.G., BLEEKER, W. & LOURENS, L.J. 2004. A new Geologic Time Scale, with special reference to Precambrian and Neogene. *Episodes*, **27**, 83-100.

GRIMM, K. (*Ed.*) 2002. Tertiary. *In*: German Stratigraphic Commission (*Ed.*), Stratigraphic Table of Germany 2002.

GUTERCH, A. & GRAD, M. 1996. Seismic structure of the Earth's crust between Precambrian and Variscan Europe in Poland. *Publication of the Institute of Geophysics, Polish Academy of Science*, **M-18 273**, 67-73.

GUTERCH, A., GRAD, M., THYBO, H., KELLER, R. & POLONAISE WORKING GROUP 1999. POLONAISE'97 – an international seismic experiment between Precambrian and Variscan Europe in Poland. *Tectonophysics*, **314**, 123-143.

HAGER, H., KOTHEN, H. & SPANN, R. 1981. Zur Setzung der Rheinischen Braunkohle und ihrer klastischen Begleitschichten. *Fortschritt in der Geologie von Rheinland und Westfalen*, **29**, 319-352.

HARDING, T.P. 1985. Seismic characteristics and identification of negative flower structure, positive flower structures and structural inversion. *American Association of Petroleum Geologists Bulletin*, **69**, 17-39.

HIPPOLYTE, J.-C. & SANDULESCU, H. 1996. Paleostress characterization of the "Wallachian phase" in its type area (southeastern Carpathians, Romania). *Tectonophysics*, **263**, 235-248.

JASKOWIAK-SCHOENEICHOWA, M. 1981. Upper Cretaceous sedimentation and stratigraphy in north-western Poland. *Prace Instytutu Geologicznego*, **98**, 91 p. [*In Polish with English summary*]

KARNKOWSKI, P.H. 1980. The paleotectonic of platform cover in the Wielkopolska. *Przegląd Geologiczny*, **28**, 146-151. [*In Polish with English summary*]

KASIŃSKI, J.R. 1984. Synsedimentary tectonics as the factor determining sedimentation of brown coal formation in tectonic depressions in western Poland. *Przegląd Geologiczny*, **32**, 260-268. [*In Polish with English summary*]

— 1985. Synsedimentary tectonics as a factor controlling sedimentation of brown-coal formations in tectonic depressions in western Poland. *In*: BORISOV (*Ed.*), Solid Fuel Mineral Deposits. Proceedings 27th International Geological Congress., Moscow, **14**, 247-279. *VNU Science Press*; Utrecht.

KRYSIAK, Z. 2000. Tectonic evolution of the Carpathian Foredeep and its influence on Miocene sedimentation. *Geological Quarterly*, **44**, 137-156.

KRZYWIEC, P. 2002. Mid-Polish Trough inversion – seismic examples, main mechanisms and its relationship to the Alpine-Carpathian collision. *In*: BERTOTTI, G., SCHULMANN, K. & CLOETHING, S. (*Eds*), Continental Collision and the Tectonosedimentary Evolution of Forelands. *European Geoscience Union Stephan Mueller Special Publication Series*, **1**, 151-165.

— 2006. Structural inversion of the Pomeranian and Kuiavian segments of the Mid-Polish Trough – Lateran variations in timing and structural style. *Geological Quarterly*, **50**, 151-168.

Kupetz, A., Kupetz, M. & Rascher, J. 2004. Der Muskauer Faltenbogen. Gesellschaft für Geowissenschaften e.V., Berlin, 36 pp.

Kwolek, K. 2000. The age of tectonic movements in the Poznań-Kalisz Dislocation Zone, Fore-Sudetic Monocline. *Przegląd Geologiczny*, **48**, 804-814. [*In Polish with English summary*]

Lamarche, J., Bergerat, F., Lewandowski, M., Mansy, J.L., Świdrowska, J. & Wieczorek, J. 2002. Variscan to Alpine heterogeneous palaeo-stress field above a major Palaeozoic suture in the Carpathian foreland (southeastern Poland). *Tectonophysics*, **257**, 55-80.

Malinowski, M., Żelaźniewicz, A., Grad, M., Guterch, A., Janik, T. & CELEBRATION Working Group 2005. Seismic and geological structure of the crust in the transition from Baltica to Palaeozoic Europe in SE Poland – CELEBRATION 2000 experiment, profile CEL02. *Tectonophysics*, **401**, 55-77.

Malkovsky, M. 1987. The Mesozoic and Tertiary basins of the Bohemian Massif and their evolution. *Tectonophysics*, **137**, 31-42.

Mazur, S., Aleksandrowski, P., Kryza R. & Oberc-Dziedzic, T. 2006. The Variscan Orogen in Poland. *Geological Quarterly*, **50**, 89-118.

Michon, L., Van Balen, R.T., Merle, O. & Pagnier, H. 2003. The Cenozoic evolution of the Roer Valley Rift System integrated at a European scale. *Tectonophysics*, **367**, 101-126.

Meulenkamp, J.E., Kovác, M. & Cicha, I. 1996. On Late Oligocene to Pliocene depocentre migration and the evolution of the Carpathian–Pannonian system. *Tectonophysics*, **266**, 301-317.

Oszczypko, N. 1999. The Miocene subsidence of the Polish Carpathian Foredeep. *Prace Państwowego Instytutu Geologicznego*, **168**, 209-230.

— 2001. The Miocene development of the Polish Carpathian Foredeep. *Przegląd Geologiczny*, **49**, 717-723. [*In Polish with English summary*]

Peterek, A., Rauche, H., Schroder, B., Franze, H.-J., Bankwitz, P. & Bankwitz, E. 1997. The late and post-Variscan tectonic evolution of the Western Border fault zone of the Bohemian Massif (BBZ). *Geologische Rundschau*, **86**, 191-202.

Pharaoh, T. 1999. Palaeozoic terranes and their lithospheric boundaries within the Trans-European Suture Zone, a review. *Tectonophysics*, **314**, 17-41.

Piwocki, M. 1998. An outline of the palaeogeographic and palaeoclimatic developments. *In*: Ważyńska H. (*Ed.*), Palynology and palaeogeography of the Neogene in the Polish Lowlands. *Prace Państwowego Instytutu Geologicznego*, **160**, 8-12.

Piwocki, M. & Ziembińska-Tworzydło, M. 1997. Neogene of the Polish Lowlands – lithostratigraphy and pollen-spore zones. *Geological Quarterly*, **41**, 21-40.

Schäfer, A., Utescher, T., Klett, M. & Valdivia-Manchego, M. 2005. The Cenozoic Lower Rhine Basin – rifting, sedimentation, and cyclic stratigraphy. *International Journal of Earth Sciences*, **94**, 621-639.

Schindewolf, O.W. 1960. Stratigraphische Methodik und Terminologie. *Geologische Rundschau*, **49**, 1-35.

Sclater, J.G. & Christie, P.A.F. 1980. Continental stretching: an explanation the post-mid-Cretaceous subsidence of the Central North Sea Basin. *Journal of Geophysical Research*, **85**, 3711-3739.

Sheldon, N.D. & Retallack, G.J. 2001. Equation for compaction of paleosols due to burial. *Geology*, **29**, 247-250.

Sissingh, W. 1998. Comparative Tertiary stratigraphy of the Rhine Graben, Bresse Graben and Molasse Basin: correlation of Alpine foreland events. *Tectonophysics*, **300**, 249-284.

Sokołowski, J. 1967. Geology and structure of the Sudetic foreland. *Geologia Sudetica*, **3**, 197-367. [*In Polish with English summary*]

Stackenbrandt, W. & Franzke, H.J. 1989. Alpidic reactivation of the Variscan consolidated lithosphere – the activity of some fracture zones in central Europe. *Zeitschrift für Geologische Wissenschaften*, **17**, 699-712.

Standke, G., Rascher, J. & Strauss, C. 1993. Relative sea-level fluctuations and brown coal formations around the Early-Middle Miocene boundary in the Lusatian Brown Coal District. *Geologische Rundschau*, **82**, 295-305.

Steininger, F. & Rögl, F. 1983. Stratigraphic correlation of the Tethys-Paratethys Neogene. *In*: Project 25 IGCP, Paris, pp. 65-66.

Steininger, F., Rögl, F. & Dermitznkis, M. 1987. Report of the round table discussion "Mediterrean and Paratethys correlation". *Annales Instituti Geologici Hungarici*, **70**, 397-421.

ten Veen, J.H. & Kleinspehn, K.L 2000. Quantifying the timing and sense of fault dip slip: New application of biostratigraphy and geohistory analysis. *Geology*, **28**, 471-474.

Van Hinte, J.E. 1978. Geohistory analysis – Application of micropaleontology in exploration geology. *American Association of Petroleum Geologists Bulletin*, **62**, 210-222.

Vinken, R. (*Ed.*) 1988. The Northwest European Tertiary Basin, Results of the IGCP, Project No 124. *Geologisches Jahrbuch Reihe A*, **100**, 512 p.

Walkiewicz, Z. 1984. The Tertiary in Wielkopolska. Wydawnictwo Naukowe UAM, Seria Geologia, **10**, 96 p. [*In Polish with English summary*]

WIDERA, M. 2002. An attempt to determine consolidation coefficient of peat for lignite seams. *Przegląd Geologiczny*, **50**, 42-48. [*In Polish with English summary*]

— 2004. Phases of Paleogene and Neogene tectonic evolution of selected grabens in the Wielkopolska area, central-western Poland. *Annales Societatis Geologorum Poloniae*, **74**, 295-310.

— 2007. Lithostratigraphy and palaeotectonics of the sub-Pleistocene Cenozoic of Wielkopolska. Wydawnictwo Naukowe UAM, Seria Geologia, **18**, 224 pp. [*In Polish with English summary*]

WIDERA, M., BANASZAK, J., CEPIŃSKA, S. & DERDOWSKI, R. 2004. Paleotectonic analysis of the Paleogene and Neogene activity of the northern parts of the Poznań-Oleśnica Dislocation Zone. *Przegląd Geologiczny*, **52**, 665-674. [*In Polish with English summary*]

WIDERA, M., JACHNA-FILIPCZUK, G., KOZULA, R. & MAZUREK, S. 2007. From peat bog to lignite seam: a new method to calculate the consolidation coefficient of lignite seams, Wielkopolska region in central Poland. *International Journal of Earth Sciences*, **96**, 947-955.

WIDERA, M. & KARMAN, R. 2007. Location of the major eastern fault in the Mesozoic substratum of the City of Poznań. *Przegląd Geologiczny*, **55**, 965-970. [*In Polish with English summary*]

WIDERA, M. & KITA, A. 2007. Paleogene marginal marine sedimentation in central-western Poland. *Geological Quarterly*, **51**, 79-90.

ZAGWIJN, W. & HAGER, H. 1987. Correlation of continental and marine Neogene deposits in South-Western Netherlands and the Lower Rhine district. *Mededelingen van de Werkgroep voor Tertiaire en Kwartaire Geologie (Contributions to Tertiary and Quaternary Geology)*, **24**, 59-78.

ZIEGLER, P.A. 1990. Geological Atlas of Western and Central Europe. 239 p. Shell International Petroleum Maatschappij, distr. Geological Society Publishing House; Bath.

— 1992a. European Cenozoic rift system. *In*: ZIEGLER, P.A. (*Ed.*), Geodynamics of Rifting. *Tectonophysics*, **208**, 91-111.

— 1992b. North Sea rift system. *In*: ZIEGLER, P.A. (*Ed.*). Geodynamics of Rifting. *Tectonophysics*, **208**, 55-75.

ZIEGLER, P.A., CLOETINGH, S. & VAN WEES, J.-D. 1995. Dynamics of intra-plate compressional deformation: the Alpine foreland and other examples. *Tectonophysics*, **252**, 7-59.

ZIEGLER, P.A. & DÈZES, P., 2005. Evolution of the lithosphere in the area of the Rhine Rift System. *International Journal of Earth Sciences*, **94**, 594-614.

— & — 2007. Cenozoic uplift of Variscan Massifs in the Alpine foreland: Timing and controlling mechanisms. *Global and Planetary Change*, **58**, 237-269

Manuscript submitted:
Revised version accepted: