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Late Cretaceous inversion and salt tectonics in the Koszalin-Chojnice and Drawno-Człopa-Szamotuły zones, Pomeranian sector of the Mid-Polish Trough

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Late Cretaceous inversion processes and their relation to salt movements in the Pomeranian sector of the Mid-Polish Trough are described, based on deep boreholes. Two tectonic zones, inverted in the Late Cretaceous, located in the Mid-Polish Trough, were selected for study: the Koszalin-Chojnice Zone situated NE of the present-day Mid-Polish Swell in the Pomeranian Trough, within an area of non-salt anticlines, and the Drawno-Człopa-Szamotuły Zone located in the Szczecin Trough, SW of the Mid-Polish Swell, in an area of strong salt tectonics. The stratigraphic gaps present indicate that the first pulse of Late Cretaceous inversion might have occurred in the Coniacian-early Santonian in this area. Another pulse can be dated at late Campanian-early Maastrichtian. Intra-Cretaceous stratigraphic gaps reached their maximum areal extent in the Coniacian (*Inoceramus involutus* Zone) and Upper Campanian (Koszalin-Chojnice Zone). Over large areas, Santonian (mostly upper Santonian) deposits rest upon Turonian (including *Inoceramus schloenbachi* Zone), and locally on older rocks. The lithofacies maps show that thickness and lithofacies distribution in the Cenomanian was independent of the strike of the Koszalin-Chojnice Zone. Such a dependence began and was accentuated in the Coniacian. Santonian and Campanian clastic deposits, extending along the SW boundary of the Mid-Polish Swell and absent in the SW part of the Pomeranian Trough, suggest local tectonic inversion within the central part of the Mid-Polish Trough.

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Key words: Mid-Polish Trough, Upper Cretaceous, salt structures, inversion, palaeogeography, facies and thickness analysis.

INTRODUCTION

In this study, Late Cretaceous inversion processes and their relation to salt movements in the eastern part of the Pomeranian sector of the Mid-Polish Trough are described (Fig. 1). In this area, salt movements were initiated in the Late Triassic, and were periodically accentuated later during the Jurassic and Early Cretaceous (Dadlez and Marek, 1974). Stronger salt tectonic activity occurred in the Late Cretaceous and Early Tertiary, resulting in the formation of a system of salt structures (Fig. 2).

Two tectonic zones, located in the Mid-Polish Trough and inverted in the Late Cretaceous, were selected for study (Fig. 2). The first is the Koszalin-Chojnice Zone situated NE of the present-day Mid-Polish Swell in the Pomeranian Trough, within an area of non-salt anticlines (Dadlez ed., 1998). The second is the Drawno-Człopa-Szamotuły Zone located in the Szczecin Trough, SW of the Mid-Polish Swell, in an area of salt tectonics which resulted in the formation of salt diapirs, partly piercing Mesozoic deposits. Both the zones are well illustrated on geological cross-sections across the Mid-Polish Trough (Dadlez, 2001).

The research focused mainly on facies and thickness analyses and identifications of stratigraphic and sedimentary gaps in Upper Cretaceous profiles (Tables 1 and 2) that allow the reconstruction of Late Cretaceous tectonic events in this area.

GEOLOGICAL DATA AND RESEARCH METHODS

Stratigraphical records of over 200 boreholes have been analysed (Fig. 1), including data from Jaskowiak-Schoeneichowa (1976, 1981) and Jaskowiak-Schoeneichowa and Krassowska (1988). The stratigraphy of Upper Cretaceous deposits from boreholes drilled before 1987, i.e. most of them, was studied by Jaskowiak-Schoeneichowa. Boreholes drilled after 1987 were studied in terms of their stratigraphy and sedimentology by me, by means of lithological descriptions of drillcores and cuttings (rock-type determination, chemical

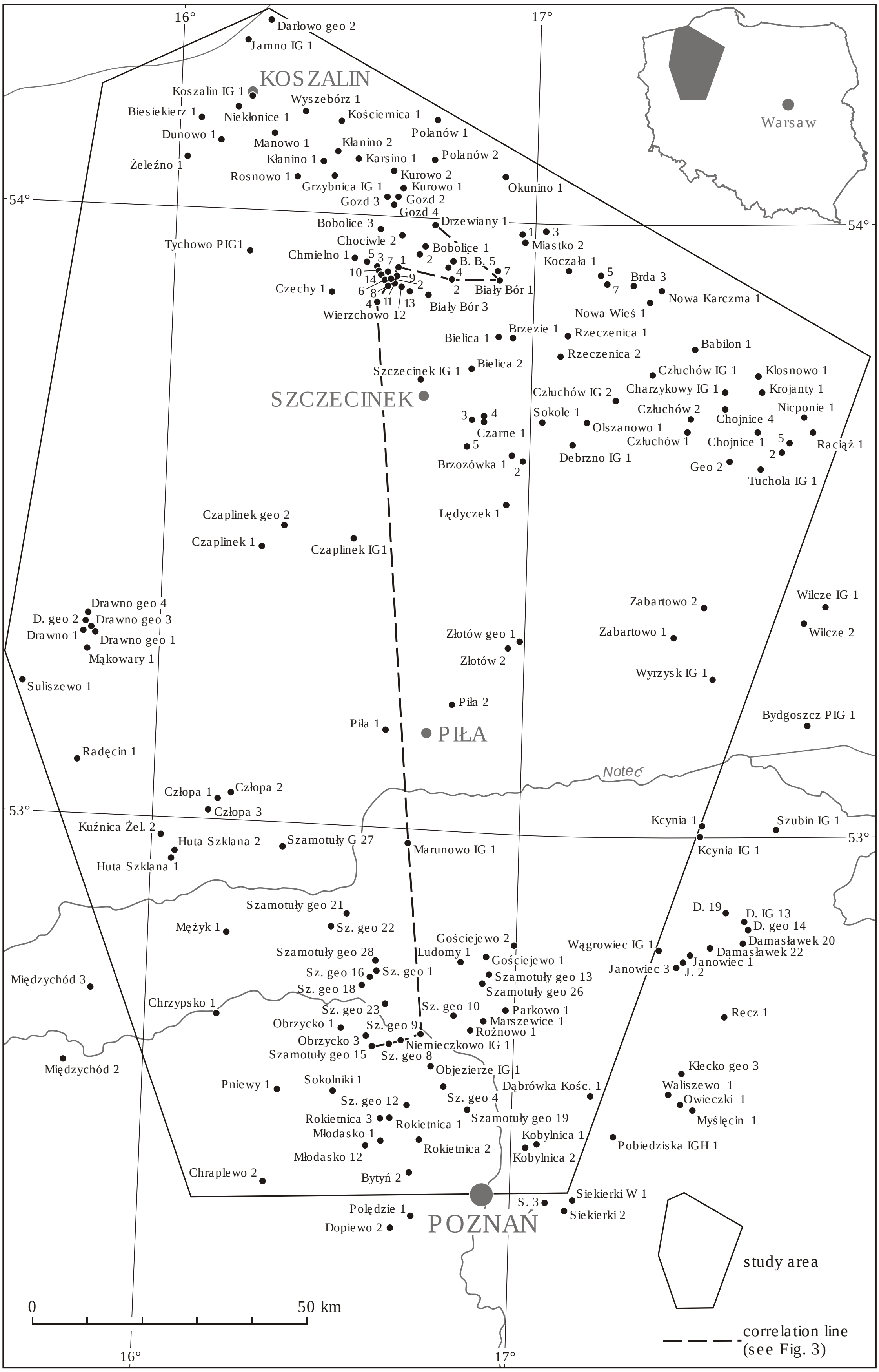

Fig. 1. Location of boreholes

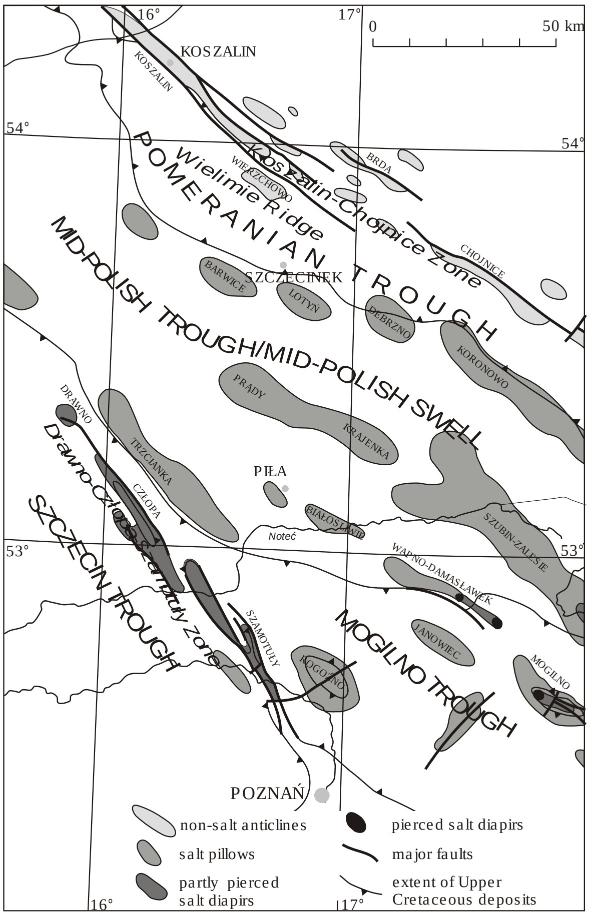

Fig. 2. Major tectonic units and salt structures of northwestern Poland (after Dadlez and Marek, 1998, modified)

analyses), sedimentological observations and well-log analysis and correlation, with supplementary data from reflection seismic profiles. Some boreholes were entirely cored; the majority, though, yielded scarce core data of variable, mostly poor, quality, or were uncored, with only cuttings available for study. Boreholes are distributed unevenly across the study area with concentrations mainly over anticlinal structures. Therefore, data reliability varies from area to area and from borehole to borehole, being locally poor. This applies in particular to the Koszalin-Chojnice Zone where the Coniacian-Campanian stratigraphy should be regarded as approximate.

Many core samples were investigated as regards their fossil content. Macrofaunal specimens were identified by Błaszkiewicz and Cieśliński (unpubl. reports). Microfaunal analyses (foraminifers) were made by Gawor-Biedowa, Natusiewicz-Dudziakowa, Pieniążek and Dudziak (unpubl. reports). For the Cenomanian, Turonian and Maastrichtian, palaeontological data are reasonably good. Campanian and Santonian deposits are also fairly well documented. Most uncertainties refer to the Coniacian interval which, in the Koszalin-Chojnice Zone, is devoid of guide fossils. Chemical analyses of rock samples were performed at the Chemical Laboratory of the Polish Geological Institute yielding information on calcium carbonate content.

Thickness were calculated by calculating gradients using data available from neighbouring boreholes, while taking into account regional tectonic patterns and subsurface geological structures and facies distributions. I have interpreted lithofacies and thickness patterns across the Mid-Polish Swell and in other areas without Cretaceous deposits.

Maps were constructed qualitatively, indicating the dominant lithological and subordinate lithological components. This was done because the Upper Cretaceous lithologies comprise a variety of rock types of mostly similar chemical composition, with transitions between the rock types being gradual and oscillatory (e.g. marly limestones, marls, opokas/siliceous marl, gaizes).

GENERAL TECTONIC SETTING

The Koszalin-Chojnice Zone is located in the Pomeranian Trough, NE of the present-day Mid-Polish Swell, within an area of non-salt anticlines (Dadlez ed., 1998) (Fig. 2). The zone developed along a major, NW–SE-trending, fault zone (Dadlez ed., 1998). In Mesozoic times, it separated the Mid-Polish Trough, extending to the south-west, from the uplifted stable East European Craton located to the north-east. A synsedimentary graben with considerably increased thicknesses of Lower Jurassic and Lower Cretaceous deposits was periodically active in this zone (Dadlez, 1983). To the south-west, within the Mid-Polish Trough, there was a periodically uplifting zone with a thinner stratigraphic succession, the Wielimie Ridge (Dadlez, 1983, 2001). Therefore, moving from the SW, i.e. from the axis of the Mid-Polish Trough, towards the NE, we cross the following Mesozoic tectonic zones: (1) the Wielimie Ridge characterised by a low subsidence rate and periodic uplift during latest Triassic-Early Cretaceous times, (2) a synsedimentary graben, associated with the Koszalin-Chojnice tectonic zone, and showing periodically increased subsidence rates at that time, and (3) an outer area of low subsidence rate, situated on the craton.

The tectonic activity of the Wielimie Ridge and synsedimentary graben, and the resulting prominent zonation of the area with distinct thickness variations, were strongly accentuated, mainly in the Late Triassic, Jurassic and Early Cretaceous (Dadlez, 1983).

Starting with the late Albian, the zonation was becoming less and less distinct. In the Cenomanian and Turonian the subsidence rate became more uniform. The general trend seemed to change in the Coniacian. The zones of synsedimentary grabens were subjected to gradual inversion, as shown by stratigraphic gaps and decreased stratal thicknesses in the Upper Cretaceous. Slightly thicker successions, thinning towards both NE and SW, were deposited on the Wielimie Ridge at that time. This trend continued until the end of Late Cretaceous times.

Regional synsedimentary faults are prominent in the Koszalin-Chojnice Zone (Dadlez, 2001). Inversion processes and compressional/transpressional stresses caused the formation of anticlinal structures such as the Koszalin-Chojnice Anticline (Krzywiec, 2002) which is bounded by synsedimentary faults.

The NW–SE-stretching Drawno-Człopa-Szamotuły Fault Zone developed in the eastern part of the Szczecin Trough, south-west of the Mid-Polish Trough (Fig. 2). This elongate zone was characterised by periodic strong tectonic activity dur-

Upper Cretaceous stratigraphy and thicknesses (in metres) in selected boreholes of the Koszalin-Chojnice Zone

Stratigraphy		Biały Bór 1	Biały Bór 2	Biały Bór 7	Bobolice 3	Chociwle 2	Rzeczenica 1	Wierzchowo 1	Wierzchowo 2	Wierzchowo 3	Wierzchowo 5	Wierzchowo 6	Wierzchowo 7	Wierzchowo 8	Wierzchowo 9	Wierzchowo 10
Maastrichtian	U			45.0		27.0	51.0	104.0	74.0	56.0	144.5	56.0	92.5	172.0	152.0	78.5
	L	101.0	35.5	72.0	48.0		74.0?	98.0								
Campanian	U			114.5												
	L	56.0														
Santonian	U	67.5		69.5			66.0?									
	L															
Coniacian*																
Turonian	U**	178.5		211.5												
	M+L		75.0			63.0	168.0	81.5	124.5	108.0	134.0	121.0	35.0	155.5	78.0	43.0
Cenomanian		22.0	21.0	26.5	7.5	35.5	16.0	25.5	35.5	42.0	62.0	37.0	34.0	50.5	35.0	42.0
Upper Albian		3.0	3.0	3.0	2.0	1.5	2.0	1.5	3.0	2.0	2.0	2.0	1.5	2.5	2.0	1.5
Basement		middle Albian-Barremian														

U — upper; M — middle; L — lower; grey — stratigraphic gap; * *Inoceramus involutus* Zone; **including *Inoceramus schloenbachi* Zone

ing the Mesozoic. Synsedimentary grabens, with increased thicknesses of deposits, began to form along the zone in the latest Triassic and Early Jurassic (Dadlez and Marek, 1974; Feldman-Olszewska, 1997; Dadlez *et al*., 1998). Their activity was strongly accentuated also in the Middle and Late Jurassic and Early Cretaceous.

In the Late Cretaceous, the Drawno-Człopa-Szamotuły Zone was subject to inversion. The present-day image of this area shows a long anticlinal zone with salt structures and neighbouring synclinal zones on either side. A complicated pattern of NW–SE-trending and transverse (SW–NE) faults underlines a complex geological structure in this area (Jaskowiak-Schoeneichowa, 1981).

STRATIGRAPHY, LITHOLOGY, PALAEOGEOGRAPHY AND LITHOFACIES DISTRIBUTION

Facies and thicknesses relationships between individual Upper Cretaceous stages are shown in a correlation of Upper Cretaceous sections across the Szamotuły and Koszalin anticlines (Fig. 3). Based on stratigraphical, lithological and thickness data, a series of maps (Figs. 4–9), showing distributions of dominant lithofacies and thicknesses of individual Upper Cretaceous stages, have been constructed. The following lithofacies are mapped:

— carbonate lithofacies (**organodetrital limestones** and **marly limestones**, locally marls),

— marly lithofacies (**marls**, locally marly limestone interbeds),

— carbonate-siliceous lithofacies (**opokas**, clayey and silty opokas, locally gaize and marl interbeds),

— muddy-marly lithofacies (**marly claystones, mudstones** and **siltstones**, locally marl interbeds),

— silty-marly lithofacies (**marly siltstones** and **silty marls**),

— silty-sandy-marly lithofacies (**marly** and **sandy siltstones**, sandy and silty marls, locally sandy-marly limestones and sandy gaizes),

— carbonate-sandy lithofacies (**sandy limestones**, gaizes, sandy gaizes),

— sandy lithofacies (**sandstones, marly sandstones**, locally marly siltstone interbeds).

Stratigraphical and lithological data which form the basis for the construction of the maps are given below. The lithofacies and thickness pattern across the Mid-Polish Swell and in other areas without Cretaceous deposits (wholly or partly) is my interpretation and takes into account the regional tectonic pattern and subsurface geological structures, as well as facies distributions on either side of the Mid-Polish Swell.

Cenomanian deposits cover the greatest area of all the Upper Cretaceous stages. South-west of the Mid-Polish Swell they are absent only locally on the Drawno structure (Drawno 4 borehole; Turonian on Hauterivian) and east of the Szamotuły Anticline (boreholes Szamotuły geo 4, 9 and 21; Santonian on Lower Cretaceous — Fig. 3). The Cenomanian sequence is monotonous in its lithology with predominant limestones and marly limestones, locally marls (Fig. 4). In the Koszalin-Chojnice Zone Cenomanian deposits occur over most of the area except on crests of the Koszalin Anticline. The sequence commonly consists of two lithological successions. The lower one is composed of limestones and marly limestones, commonly sandy, with local phosphatic concretions and an admixture of glauconite, as well as silty marls. The upper succession is represented by marls, silty marls and marly siltstones (the latter occur e.g. around Biały Bór and Bobolice — Figs. 1 and 3). The clastic content of Cenomanian deposits increases northeastwards (Fig. 4). Faunal content is commonly abundant and represented mostly by: *Inoceramus crippsi* Mantell, *I. virgatus* Schlüter, *I. etheridgei* Woods, *I. pictus* Sowerby, *I.*

Table 1

(based on data by Jaskowiak-Schoeneichowa and Leszczyński)

Wierzchowo 11	Wierzchowo 12	Wierzchowo 13	Wierzchowo 14	Chmielno 1	Chojnice 1	Chojnice 2	Chojnice 4	Człuchów IG 1	Niekłonice 1	Gozd 2	Czechy 1	Wierzchowo 4	Tychowo PIG 1	Bielica 2	Człuchów 1	Tuchola IG 1
75.5	173.5	186.5	109.0	116.0	121.0	43.0	91.5	95.0	186.0	129.5	239.5	234.0	55.5	256.0	164.5	56.5 / 60.0
		83.0?									83.0	92.0	92.5	56.5	171.5	137.0
		32.5?							42.0	27.0	66.0	68.0	63.0	70.0	80.0	57.0
									13.0	6.0	28.0	22.0	22.0	38.0	31.0	18.0
152.5	158.0	157.5	47.5	250.0	159.5		206.0	221.0	180.0	159.0	238.5	296.0	268.0	212.0	287.0	250.0
41.5	41.0	41.0	51.0	73.5	42.5	17.0	43.5	45.0	76.5	52.5	76.5	67.0	92.0	50.5	48.0	40.0
3.5	2.5	3.0	2.5	3.5	2.0	2.0	2.5	2.0	2.0		3.5	4.0	2.0	3.0	2.0	3.5
middle Albian-Barremian										U.Jurassic	middle Albian-Barremian					

bohemicus Leonhard, *Neohibolites ultimus* (d'Orbigny), and numerous foraminifers (Jaskowiak-Schoeneichowa, 1976, 1981). The distribution of the **Cenomanian lithofacies** shows a very simple regional pattern (Fig. 4). The Mid-Polish Trough area was occupied by carbonates. A marly lithofacies occurs to the north-east of the carbonate area. The northeasternmost position was occupied by marly-silty and marly-silty-sandy sedimentation. The northeastward increase in clastic content was associated with proximity to the Baltic Shield.

South-west of the Mid-Polish Swell, the **Turonian** (including the *Inoceramus schloenbachi* Zone) occurs all over the area except in the Człopa, Szamotuły and Rogoźno anticlines due to removal by post-Cretaceous erosion. In some boreholes of the Szamotuły Zone (e.g. Szamotuły geo 1, geo 4, geo 9, geo 21 and Niemieczkowo IG 1 — Fig. 3), there is a lack of Turonian and also of lower Upper Cretaceous deposits. Lower Cretaceous rocks are overlain there by the Santonian and Campanian. Elsewhere, lower Turonian rocks can be encountered beneath the Santonian and Campanian. Upper parts of the Turonian succession were removed from these areas as a result of intra-Cretaceous erosional events. In general, Turonian lithologies of the Drawno-Człopa-Szamotuły Zone are more varied than Cenomanian ones (Fig. 5). The Turonian starts with darkgrey marly claystones, distributed over the northern region. Over the remaining area, the Turonian begins with limestones or marls. Upper parts of the Turonian profile in the northern area are composed of marly siltstones, silty opokas and marls, with opokas at the top. In the Szamotuły area, the Turonian profile is represented by limestones and marls (Fig. 3). Opoka facies are predominant in the east, around the Rogoźno Anticline, whereas the Turonian section of the Marunowo IG 1 borehole is entirely represented by opokas (the drilling did not reach the base of the Turonian — Fig. 3). Turonian deposits of the Koszalin-Chojnice Zone also show a bipartite division with the lower succession represented by marly claystones, mudstones and siltstones, and the upper succession composed of marly and sandy siltstones (Chojnice Anticline) or opokas (siliceous marls) and silty opokas (Koszalin Anticline — Fig. 3). A general fining trend is observed towards the SW. Over large areas of the Koszalin-Chojnice Zone, the Turonian is erosionally truncated at the top and is overlain by various successions of Santonian (Biały Bór 1, 7, Wierzchowo 13), Upper Campanian (Rzeczenica 1) or Maastrichtian (Biały Bór 2 and 5, Chmielno 1, Chociwle 2, Wierzchowo 1–3, 5–12 and 14, Chojnice 2 and 4, Człuchów IG 1) deposits (Fig. 3). In the boreholes Bobolice 3 and Chojnice 2, the Maastrichtian is underlain by Cenomanian. It should also be emphasised that, in the standard division of the Upper Cretaceous, the uppermost part of the Turonian sequence probably corresponds already to the Coniacian (at least in part). Therefore, according to the standard division the Turonian sequence would have slightly smaller thicknesses. Turonian deposits have yielded numerous fossils including *Inoceramus labiatus* Schlotheim, *I. lamarcki* Parkinson, *I. inconstans* Woods, *I. apicalis* Woods, *I. cuvieri* Sowerby, *I. hercynicus* Petrascheck, *I. annulatus* Goldfuss, *Scaphites qeinitzi* d'Orbigny, *Pecten nilssoni* Goldfuss, and abundant foraminifera (Jaskowiak-Schoeneichowa, 1976, 1981). The regional pattern of **Turonian lithofacies** shows that the central part of the Mid-Polish Trough as far NE as the Noteć River was occupied by carbonate and carbonate-siliceous lithofacies (Fig. 5). A muddy-marly lithofacies is also widespread and, together with the carbonate-siliceous lithofacies, occurs north of the Noteć River. NE of the Koszalin-Chojnice Zone, carbonate-siliceous sedimentation was replaced by muddy-marly and silty-sandy-marly deposits, most probably associated with the Baltic Shield.

South-west of the Mid-Polish Swell, **Coniacian** (= *Inoceramus involutus* Zone) deposits are absent on the Drawno, Człopa, Szamotuły and Rogoźno structures. Turonian

Table 2

Upper Cretaceous stratigraphy and thicknesses (in metres) in selected boreholes of the Drawno-Człopa-Szamotuły Zone (based on data by Jaskowiak-Schoeneichowa and Leszczyński)

Stratigraphy		Drawno			Człopa		Niemie-czkowo IG 1	Szamotuły											Bytyń 2	Rokietnica		Młoda-sko 1	Chrap-lewo 2	Chrzyp-sko 1	Pnie-wy 1
		geo 1	geo 2	geo 3	2	3		geo 1	geo 4	geo 8	geo 9	geo 16	geo 18	geo 21	geo 12	geo 15	geo 10	geo 13		1	3				
Maastrichtian	U																								
	L																								
Campanian	U																								
	L				112.0			21.0			55.0			51.0		75.5	42.0	23.0	55.0	72.0	40.0	55.0	98.5	161.0	101.0
Santonian	U	199.0	179.0	83.0	150.0		92.0	1.5	70.0	213.0	157.5	17.5	156.0	196.0	283.0	355.5	253.0	140.0	37.0	183.0	184.0	53.5		100.0	76.0
	L					71.5					152.5			110.5		32.0									
Coniacian*																									
Turonian	U**	70.5?	75.0?	65.0?	43.0?										11.0	54.5	62.5	29.0	43.0						
	M+L	131.5	158.0	129.5	89.5	19.0				13.0		4.5	14.5		37.5	24.0	53.0	88.0		30.0	26.0	48.5	42.5	51.5	32.0
Cenomanian		21.0	26.0	15.5	3.5	6.0	1.0	1.0		17.0		16.5	19.0		9.5	18.5	13.0	5.5	25.5	20.5	21.0	31.5	18.5	34.0	29.0
Upper Albian					2.5	2.0	1.0	2.5		1.5	1.0	2.0	2.5		2.0	4.0	1.0	1.5	1.5	2.5	3.5	2.5	4.0	5.5	5.0
Basement		Upper Jurassic			middle Albian-Barremian									Haute-rivian	middle Albian-Barremian										

Explanations as in Table 1

rocks, or locally older ones, are overlain there by Santonian deposits (Fig. 3). The Coniacian is composed mostly of opokas and clay opokas, locally silty opokas (Gościejewo 2 and Marunowo IG 1 boreholes) (Figs. 3 and 6). Fossils are much rarer as compared with older Upper Cretaceous stages. North of the Mid-Polish Swell the Coniacian is absent over those areas of the Koszalin-Chojnice Zone where Turonian and Cenomanian sections are incomplete. Over the remaining area, the Coniacian was identified based on well-log correlations as an interval represented by more clayey deposits than beneath and above. In the southwestern area of the Koszalin-Chojnice Zone (Niekłonice 1, Tychowo PIG 1, Czechy 1, Wierzchowo 4, Szczecinek IG 1, Tuchola IG 1 boreholes), Coniacian deposits are composed of silty opokas (Fig. 3). To the north, marly mudstones and siltstones appear, locally with clay and sand admixture (e.g. Drzewiany 1 borehole — Fig. 3). Sandy siltstones and silty sandstones occur in the boreholes Brda 3, Nowa Karczma 1 and Nowa Wieś 1 (Fig. 6). Over the whole area of the Koszalin-Chojnice Zone Coniacian deposits have yielded no index fossils (Jaskowiak-Schoeneichowa, 1976). In some boreholes of the Szczecin Trough *Inoceramus involutus* Sowerby and other stratigraphically insignificant taxa were found (Jaskowiak-Schoeneichowa, 1981). The dominant **lithofacies of the Coniacian** (*Inoceramus involutus* Zone), occurring over most of the study area, is the carbonate-siliceous lithofacies (Fig. 6). In the Pomeranian Trough, the silty-marly lithofacies extends from the north-east, widening its area within the Koszalin-Chojnice Zone. Silty-sandy-marly deposits are known from the area around the Nowa Wieś and Nowa Karczma boreholes.

Many boreholes drilled in the Człopa-Szamotuły Zone and Rogoźno Anticline have documented the **Santonian** (upper, locally also lower Santonian) overlapping Turonian or older rocks. The upper Santonian overlies Turonian deposits also west of Poznań, in wide areas devoid of Coniacian deposits. Much of the Santonian profile is represented in this area by carbonate-clastic and clastic facies: marly mudstones and sandstones. Near the Pomeranian Swell (Marunowo IG 1 borehole), the Santonian is composed of opokas passing upwards into marly mudstones and siltstones with glauconite and silty sandstones (Figs. 3 and 7).

Drawno structure. Santonian (upper, locally also lower) deposits are underlain by Turonian opokas, and are represented (from bottom to top) by opokas, silty opokas, marly and sandy mudstones and siltstones with rare sandstone interbeds, and sandy marls. These rocks commonly contain glauconite.

Człopa-Szamotuły Zone. The upper Santonian (locally also part of the lower Santonian) commonly overlies Turonian deposits, but in some areas also older Cretaceous rocks: Cenomanian (Niemieczkowo IG 1 borehole), upper Albian (Szamotuły geo 9 borehole), middle Albian (Szamotuły geo 4 borehole) or Hauterivian (Szamotuły geo 21 borehole). Along the anticlinal axis, no Santonian and younger Upper Cretaceous deposits have been encountered. On the Człopa structure, the Turonian is overlain by opokas and clastic deposits, representing the upper Santonian or lower (partly) and upper Santonian (Człopa 3 borehole). A high contribution of opokas, and clay and silty opokas with marl interbeds, is observed in the Szamotuły Zone (Fig. 3). Marly mudstones and siltstones, as well as sandy gaizes are known locally from the Santonian profile of this area. In the Szamotuły geo 8 borehole (Fig. 3), sandstones of various grain sizes (with gravels and abundant glauconite) passing into quartz-glauconitic gritstones have been noted (Jaskowiak-Schoeneichowa, 1981). A hardground is also observed within the upper Santonian section of that borehole. The upper Santonian profile of the Szamotuły geo 4 borehole is composed of variable sandstones with interbeds of marls and opokas, containing glauconite and iron ooids.

Rogoźno Anticline. In this area, the Santonian profile is composed of opokas. NE of the anticline (Szamotuły geo 13 and Gościejewo 2 boreholes), occur sandy and silty marls, mudstones, siltstones and sandstones. The Santonian of the Szamotuły geo 13 borehole is represented by opokas with intercalations of silty marls with glauconite. The entire section of the Gościejewo 2 borehole is composed of marly mudstones and siltstones with sandstone interbeds. The Santonian rocks from the Gościejewo 1 borehole are represented by opokas. In the boreholes Szamotuły geo 13, geo 10, Ludomy 1 and Rożnowo 1, the upper or upper and lower Santonian overlies Turonian rocks (with a gap comprising part of the Turonian and Santonian and the whole of Coniacian). More complete Upper Cretaceous profiles are known from the boreholes Gościejewo 1 (Cenomanian to Campanian) and Gościejewo 2 (Cenomanian to Maastrichtian).

In the Koszalin-Chojnice Zone Santonian deposits are absent in areas of Coniacian gaps. The only exceptions are two boreholes: Biały Bór 1 and Wierzchowo 13, where the Turonian is overlain by ?upper Santonian and Campanian (Fig. 3). In the Biały Bór 7 borehole, the Turonian is overlain by Santonian (upper and partly ?lower) and younger Cretaceous deposits. Santonian lithologies resemble Coniacian ones, being represented along the Mid-Polish Swell (W and SW parts of the area) by opokas and silty opokas (but less clayey than Coniacian opokas), and in the east, by predominant marly siltstones with local sandy siltstones and silty sandstones (Nowa Wieś 1 and Nowa Karczma 1 boreholes) (Fig. 7). Over the Koszalin Anticline, the opoka facies occupies a slightly larger area at the expense of marly siltstones, as compared with the Coniacian (Figs. 3, 7 and 8). A fairly abundant and diverse fauna is represented by: *Inoceramus cycloides* Wegner, *I. lingua* Goldfuss, *I. patootensis* Loriol, *I. pachti* Arkhangelsky, *I. lobatus* Goldfuss, *I. fasciculatus* Heine, *I. cardissoides* Goldfuss, *Gonioteuthis* sp., *Paratexanites serratomarginatus* (Redtenbacher), *Actinocamax verus* Miller, and numerous foraminifers (Jaskowiak-Schoeneichowa, 1976, 1981).

The regional pattern of **Santonian lithofacies** is more variable (Fig. 7). Southwesternmost areas are occupied by carbonate, carbonate-siliceous and marly lithofacies. Locally, around the Szamotuły area (NW of Poznań), sandy lithofacies appear. Carbonate-siliceous and silty-sandy-marly lithofacies extend along the SW boundary of the Mid-Polish Swell; the latter can be associated with inversion processes of the Damasławek, Wapno, Człopa and Drawno structures, and probably also the Trzcianka Zone and other zones within the central part of the Mid-Polish Trough. NE of the area of clastic sedimentation a belt of carbonate-siliceous lithofacies (SW part of the Pomeranian Trough) surrounds the Koszalin Anticline in the north. The Koszalin-Chojnice Zone is occupied by silty-marly

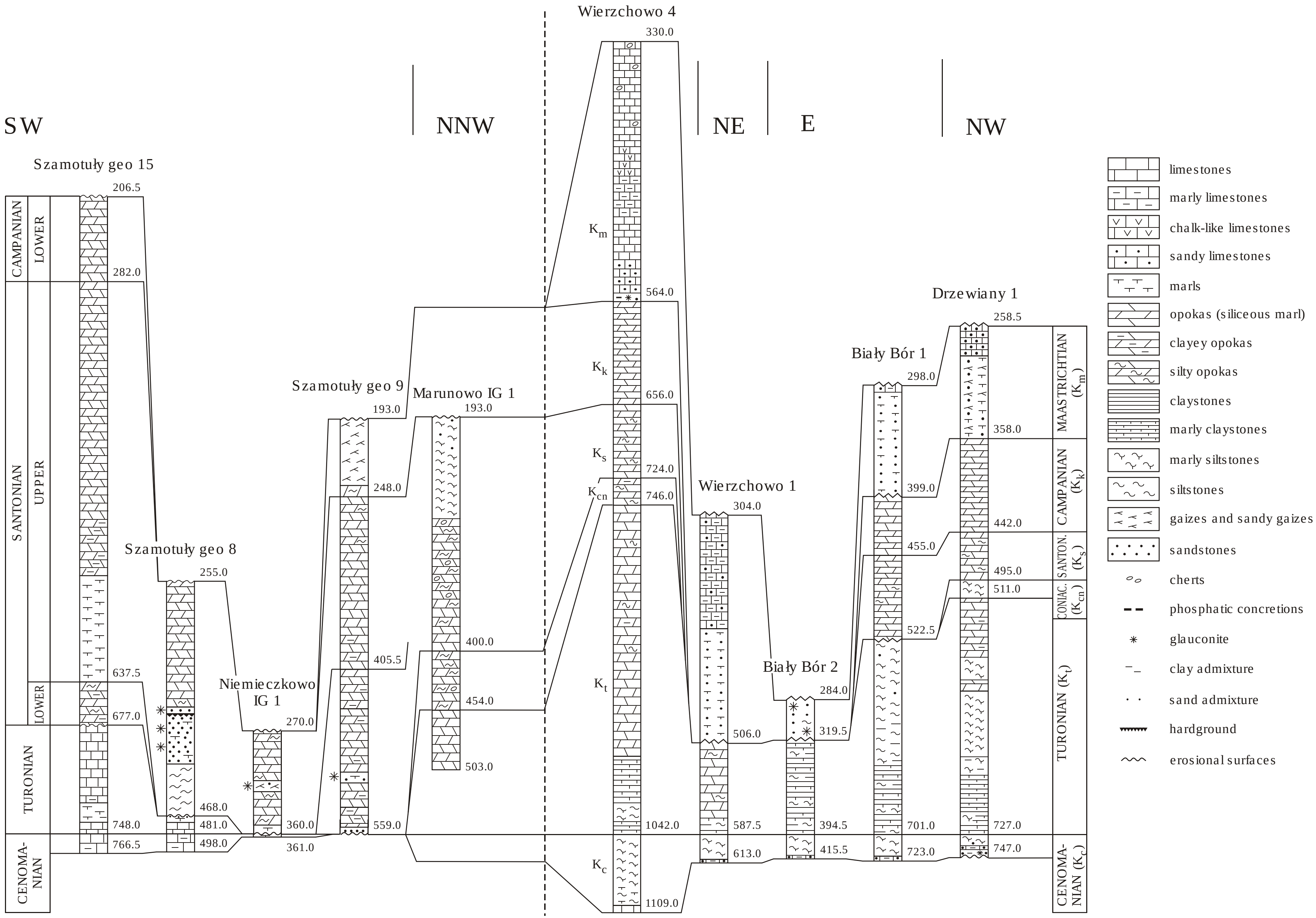

Fig. 3. Correlation of Upper Cretaceous sections across the Szamotuły and Koszalin anticlines

lithofacies, passing to the north-east into silty-sandy-marly deposits. Clastic material deposited in this area in the Coniacian and Santonian might have originated from both the Koszalin-Chojnice Zone being inverted during that time (eroded Turonian rocks) and the Baltic Shield in the north.

South-west of the Mid-Polish Swell the extent of **Campanian** deposits is smaller than that of older deposits. No Campanian rocks occur along the Drawno, Człopa, Szamotuły and Rogoźno structures due to post-Cretaceous (and possibly late Campanian-early Maastrichtian) erosion (Fig. 3). Over most of the area, the Campanian is represented by opokas with local interbeds of marls and marly limestones (Fig. 8). Around the Człopa structure, sandy and silty-marly facies have been encountered in the Człopa 2 borehole. Gaize interbeds are known from some boreholes. Lower parts of the Campanian profile in the Gościejewo 1 and 2 boreholes are composed of calcareous sandstones and sandstones, whereas upper parts are represented mostly by silty opokas. In the Koszalin-Chojnice Zone no Campanian deposits occur over areas of Coniacian and Santonian gaps, except in the Biały Bór 1 and Wierzchowo 13 boreholes. There is also a hiatus spanning the upper Campanian. The Biały Bór 7 borehole section is probably represented by the complete upper Santonian-upper Maastrichtian sequence. The Campanian is dominated by opokas and silty opokas, occupying almost the whole area investigated (Figs. 3 and 8). Upper parts of the Campanian sequence in the boreholes Kościernica 1, Karsino 1 and Kurowo 2 contain interbeds of gaizes. In the Biały Bór 3 borehole there is a marly limestone interbed. Around the Nowa Wieś 1 and Nowa Karczma 1 boreholes, sandstones and siltstones, which compose the Coniacian and Santonian sequence, are replaced in the Campanian by opokas. The fauna is represented by *Inoceramus balticus* Böhm, *Gonioteuthis quadrata* (Blainville), *G. granulata granulata* (Blainville), *Emperoceras* sp., *Belemnitella* sp., *Baculites* cf. *anceps* Lamarck, *Turitella multilineata* Müller and abundant foraminifers (Jaskowiak-Schoeneichowa, 1976, 1981). The regional distribution of **Campanian lithofacies** is more or less similar to that of Santonian lithofacies, although clastic sedimentation of the Pomeranian Trough retreated to the north (Fig. 8). Most of the Trough (including the Koszalin-Chojnice Zone) is occupied by carbonate-siliceous lithofacies, whereas carbonate-sandy lithofacies occurs only NE of Koszalin.

South-west of the Mid-Polish Swell **Maastrichtian** deposits show a much smaller extent, as compared with the older Cretaceous stages, due to post-Cretaceous erosion. They are represented mostly by the lower Maastrichtian, and occur only west of the Drawno-Człopa-Szamotuły Zone, and NE of the Szamotuły and Rogoźno anticlines (Jaskowiak-Schoeneichowa, 1981). South-west of the Człopa and Szamotuły structures, Maastrichtian deposits are represented mostly by opokas and silty opokas (Fig. 9). North-east of the Rogoźno Anticline (Gościejewo 2 borehole), gaizes and calcareous sandstones compose the Maastrichtian profile. Both the lower and upper Maastrichtian is represented in the Koszalin-Chojnice Zone (Jaskowiak-Schoeneichowa, 1976). Over areas where gaps within the Upper Cretaceous sequence are present, Maastrichtian deposits unconformably rest on older series, most commonly on the Turonian. The Maastrichtian sequence often begins with friable calcareous quartz-glauconitic sandstones (Figs. 3 and 9). They are overlain by sandy marls with glauconite and opokas with local gaizes. The uppermost Maastrichtian complex is represented by marly-sandy limestones. Chalk-like limestones have been locally noted from cores of the Niekłonice 1 and Wierzchowo 4 boreholes (Fig. 3).

Maastrichtian fossils are represented mainly by *Carneithyris carnea* Sowerby and *Belemnitella* sp. and numerous foraminifers. In boreholes drilled further to the W and NW (in the Szczecin Trough) numerous belemnites, gastropods and other fossils (Jaskowiak-Schoeneichowa, 1976, 1981) were found .

The regional pattern of **Maastrichtian lithofacies** (Fig. 9) shows that the carbonate and carbonate-siliceous facies of the Szczecin and Mogilno troughs pass into predominant carbonate-sandy facies close to the SW boundary of the present-day Mid-Polish Swell. These, in turn, pass northeastwards into more sandy facies with sandstones, calcareous sandstones, sandy gaizes and interbeds of sandy-marly limestones, with local carbonate and carbonate-siliceous rocks.

The present-day structure of the Mid-Polish Trough reveals a number of elongate anticlinal and synclinal structures (e.g. Dadlez ed., 1998). The thickness analysis performed for all boreholes shows that the Upper Cretaceous stages, beginning with the upper Albian, show smaller thicknesses within anticlinal structures (Jaskowiak-Schoeneichowa and Krassowska, 1988). This is particularly distinct in the Coniacian and later. In many areas, the formation of synclines and anticlines was probably, to a large extent, associated with salt movements.

RELATIONSHIPS BETWEEN INVERSION AND SALT TECTONICS

Stratigraphical, lithofacies and thickness analyses and tectonic evidence show that the Koszalin-Chojnice Zone was a non-salt structure, tectonically active and subjected to inversion during the Late Cretaceous. Along a zone where increased thicknesses and periodically developing synsedimentary grabens are observed in the Upper Triassic-Lower Cretaceous (Dadlez, 1976, 1983), stratigraphic gaps and thickness reductions occur within the Upper Cretaceous section. Similar inversion zones are known to the south-west of the Mid-Polish Swell, in the Szczecin and Mogilno-Uniejów troughs. These are the Drawno-Człopa-Szamotuły and Gopło-Ponętów-Wartkowice zones, where synsedimentary grabens with increased thicknesses of deposits also existed earlier in the Mesozoic (Marek ed., 1977; Jaskowiak-Schoeneichowa, 1981). Similarly, stratigraphic gaps are observed there within the Upper Cretaceous section (Marek ed., 1977; Jaskowiak-Schoeneichowa, 1979 ed., 1981; Leszczyński, 2000*a*, *b*). The major difference is that the Drawno-Człopa-Szamotuły and Gopło-Ponętów-Wartkowice zones are related to salt tectonics manifested by the occurrence of salt diapirs (Dadlez ed., 1998), whereas the Koszalin-Chojnice Zone is a non-salt inversion structure without a salt movement factor.

There are also strong similarities. One of them is the approximate time range of stratigraphic gaps interpreted in the Upper Cretaceous section of the Drawno-Człopa-Szamotuły

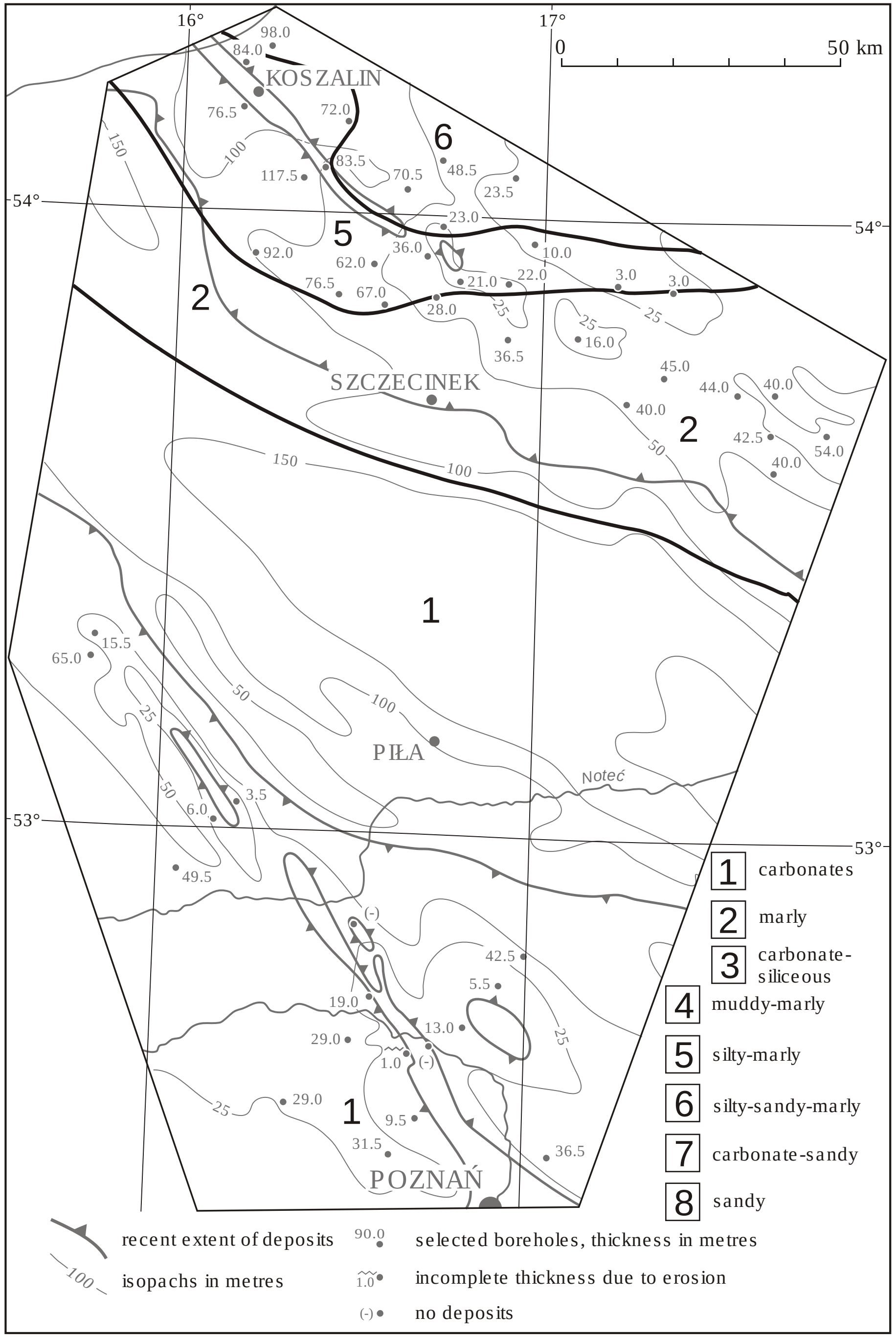

Fig. 4. Cenomanian; thickness and lithofacies

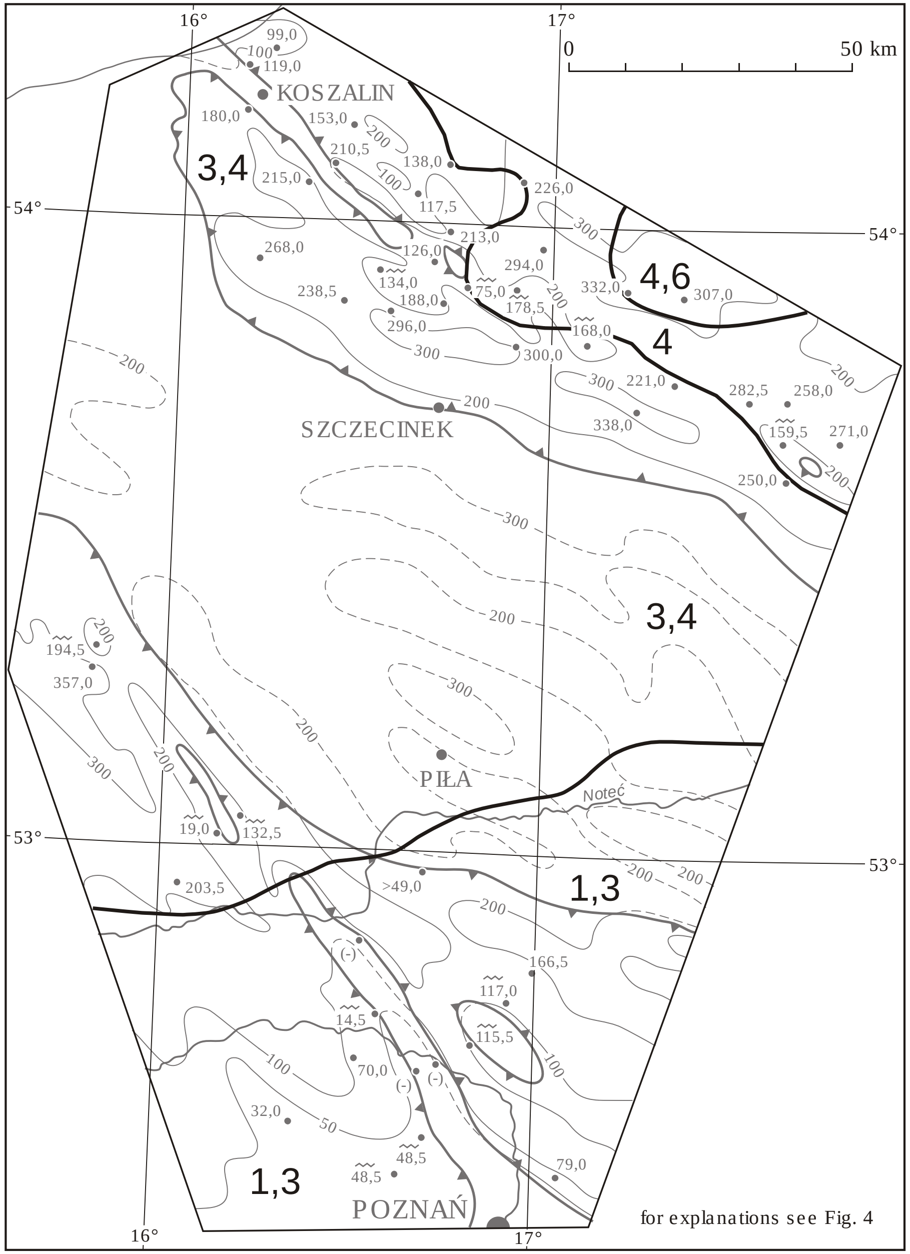

Fig. 5. Turonian (including *Inoceramus schloenbachi* Zone); thickness and lithofacies

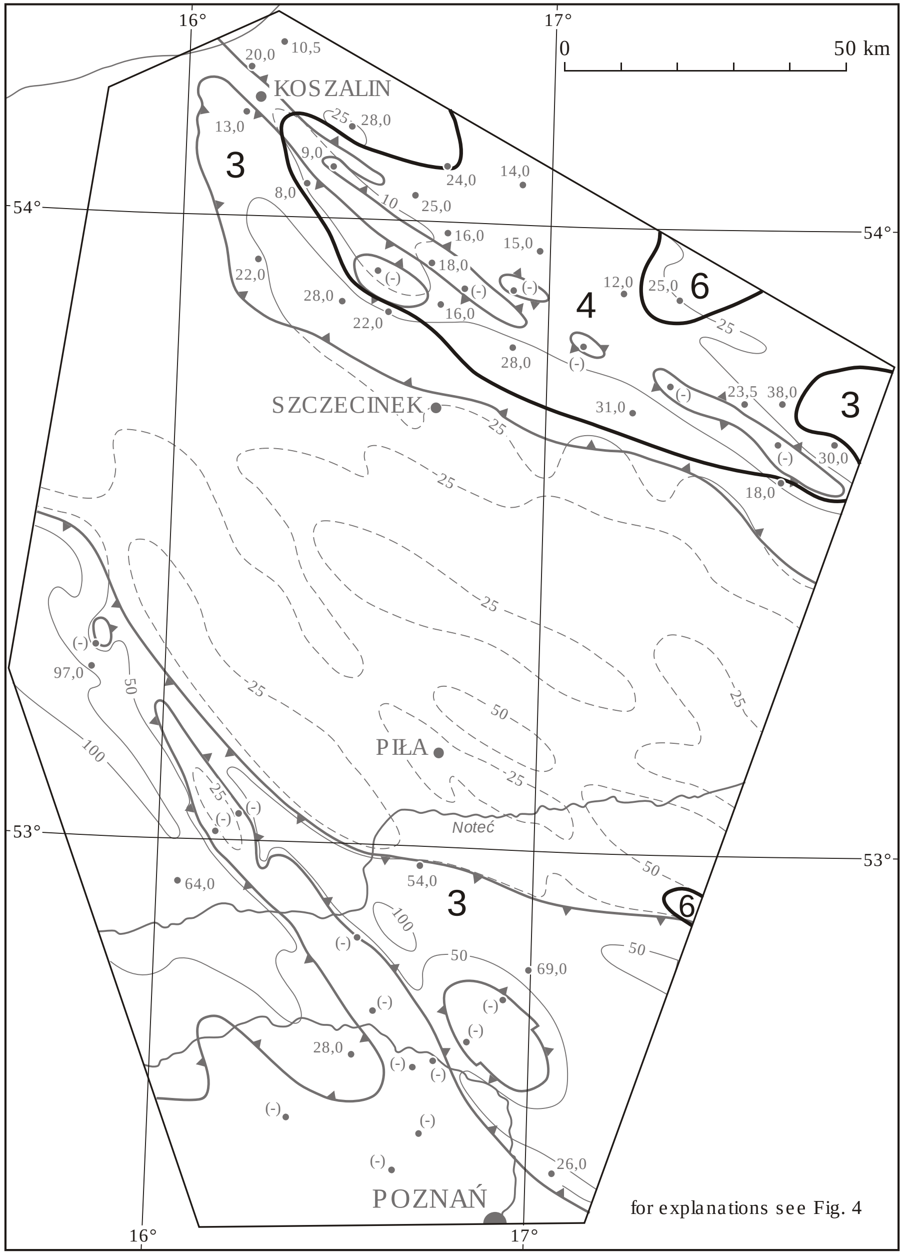

Fig. 6. Coniacian (*Inoceramus involutus* Zone); thickness and lithofacies

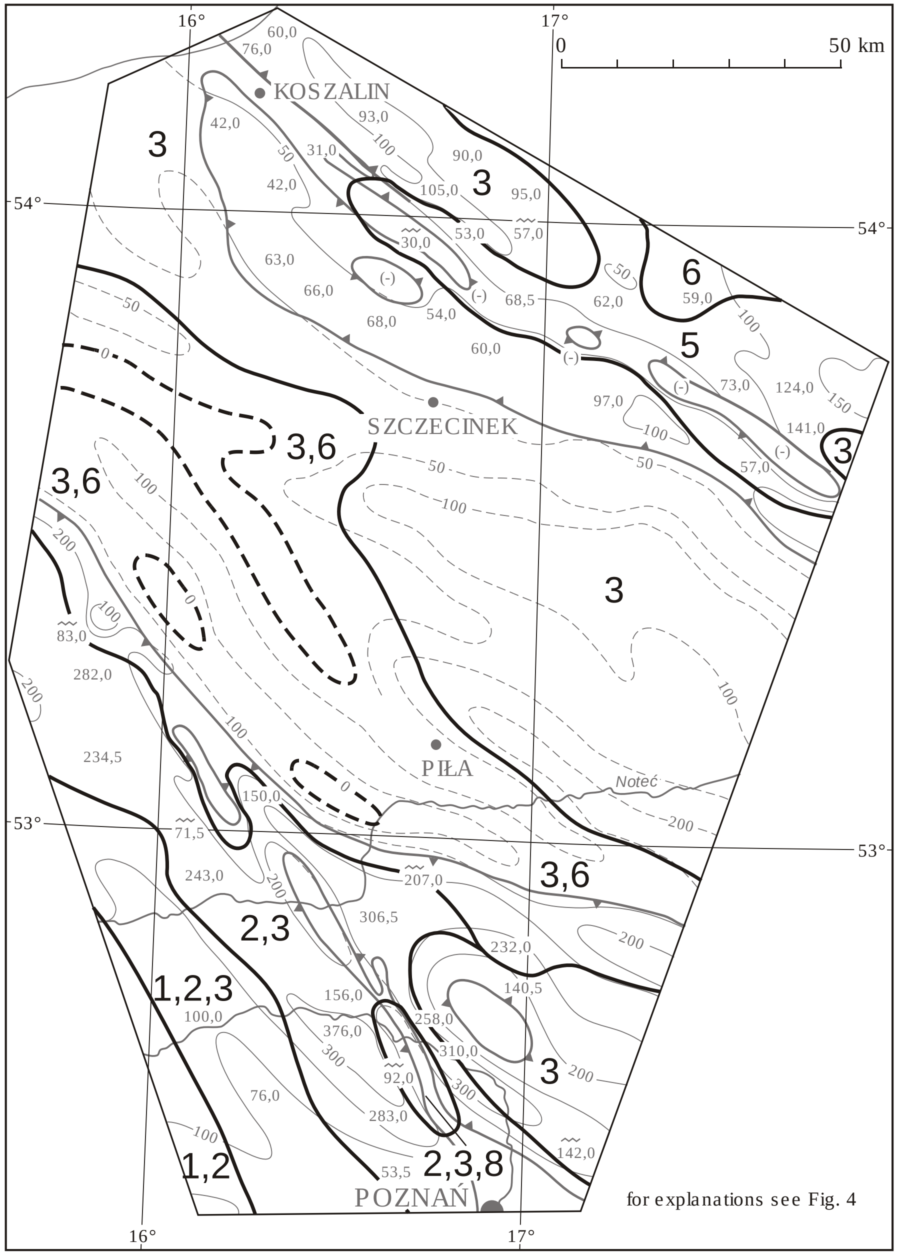

Fig. 7. Santonian; thickness and lithofacies

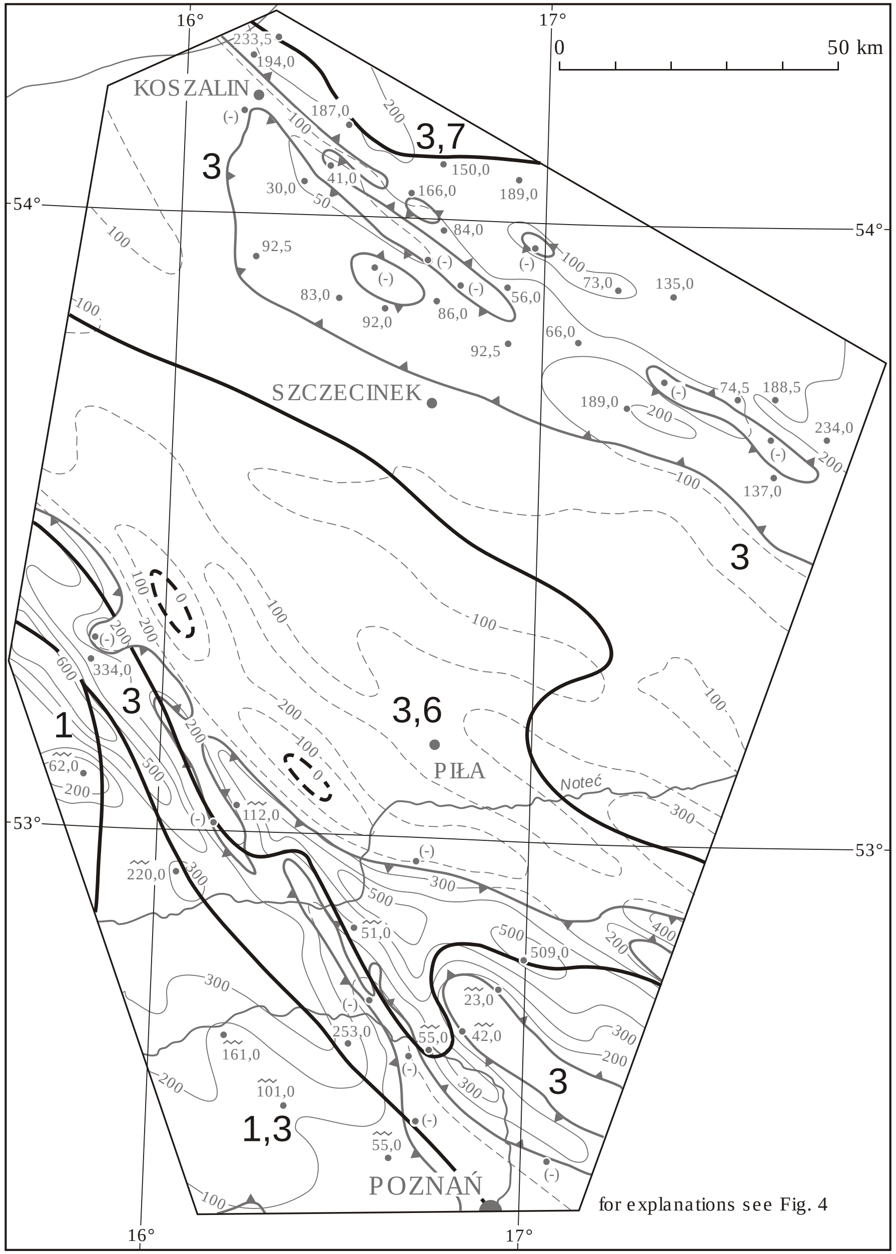

Fig. 8. Campanian; thickness and lithofacies

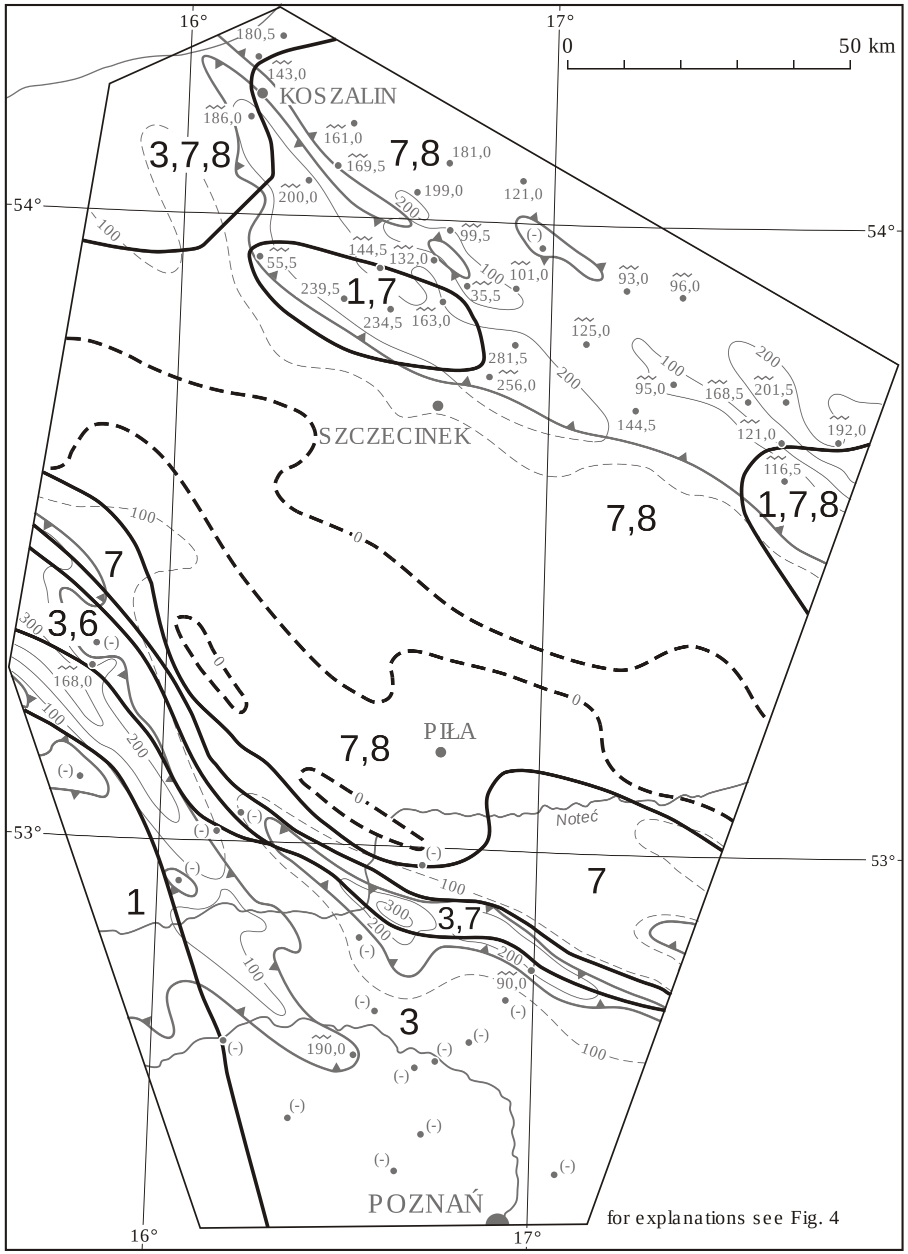

Fig. 9. Maastrichtian; thickness and lithofacies

and Koszalin-Chojnice zones (Tables 1 and 2). The gaps have been identified on the basis of palaeontological investigations, well-log analysis and thickness analysis of the reduced borehole profiles. The gaps are particularly well documented palaeontologically in the Drawno-Człopa-Szamotuły Zone (Jaskowiak-Schoeneichowa, 1981) in boreholes: Drawno geo 2, Człopa 3, Szamotuły geo 4, geo 12, and in the Biały Bór 1 borehole from the Koszalin-Chojnice Zone, where Turonian and Santonian deposits are dated by inoceramids and foraminifers. Geological evidence for the gaps in the Koszalin-Chojnice Zone is poorer and the dates are only approximate. The gaps may represent non-depositional periods and erosional events, as shown by the fact that Cenomanian or Turonian deposits, well documented palaeontologically, are eroded to a variable extent, and differ in thicknesses.

The main categories of gaps recognised in the tectonic zones analysed span the following intervals:

1. Campanian (?and lowermost Maastrichtian)-Coniacian (*Inoceramus involutus* Zone) + uppermost Turonian (including *Inoceramus schloenbachi* Zone). The upper (or locally lower) Maastrichtian rests upon Turonian: in the Koszalin-Chojnice Zone only.

2. Upper Campanian (+ possibly lowermost Maastrichtian), and lower Santonian-Coniacian (+ presumably uppermost Turonian): in the Koszalin-Chojnice Zone only.

3. Campanian (all or almost all) + possibly lowermost Maastrichtian: in the Koszalin-Chojnice Zone only.

4. Coniacian (*Inoceramus involutus* Zone) + most probably all the Turonian (including the *Inoceramus schloenbachi* Zone) or its upper part, + all the lower Santonian or its lowermost part.

5. Lower Santonian (or only its lower part) to Cenomanian or older stages: in the Szamotuły area only.

6. Total lack of Upper Cretaceous deposits due to post-Cretaceous erosion.

7. Maastrichtian to Santonian, Coniacian, Turonian or Cenomanian. Upper Cretaceous deposits are overlain by Tertiary or Quaternary rocks: in the Koszalin-Chojnice Zone only.

The two last categories may be a result of either post-Cretaceous erosion or combined intra- and post-Cretaceous erosion.

Interpretation of the extent of stratigraphic gaps suggests that the first pulse of Late Cretaceous inversion might have occurred in the Coniacian and early Santonian. Another pulse can be dated at the late Campanian-early Maastrichtian. These two pulses were interrupted by a period (late Santonian-earliest Campanian) of tectonic quiescence over most of the areas. The intra-Cretaceous stratigraphic gaps reached their maximum areal extent in the Coniacian (*Inoceramus involutus* Zone) and upper Campanian (Koszalin-Chojnice Zone). In the area where Maastrichtian deposits overlie Turonian (category 1; Table 1), stronger late Campanian-early Maastrichtian erosion could have removed presumed upper Santonian-lower Campanian strata. Over large areas of the Drawno-Człopa-Szamotuły area, Santonian (mostly upper Santonian) deposits rest upon the Turonian (including the *Inoceramus schloenbachi* Zone), locally on older rocks (Table 2). The occurrence of Santonian or lower Campanian deposits beneath the Cenozoic (lack of Maastrichtian) in this area can be interpreted as a result of both late Campanian-early Maastrichtian and post-Cretaceous erosion. Furthermore, the duration of inversion processes (causing erosion or non-deposition) may have differed slightly from area to area. The magnitude of intra-Cretaceous and post-Cretaceous erosion was also variable on individual tectonic structures.

The lithofacies maps (Figs. 4–9) show that, in the Pomeranian Trough, the thicknesses and lithofacies distribution in the Cenomanian was independent of the strike of the Koszalin-Chojnice Zone. Such a dependence began to be accentuated in the uppermost part of the Turonian (including the *Inoceramus schloenbachi* Zone). However, because the uppermost part of the Turonian (*sensu* Błaszkiewicz, 1997) belongs, according to the standard division, to the Coniacian stage, we can assume that the relationship between the thickness and lithofacies distribution, and the strike of the Koszalin-Chojnice Zone started to be marked in the Coniacian.

A slightly different situation occurred in the Szczecin and Mogilno troughs, in the area of salt tectonics. A slow process of formation of anticlinal and synclinal structures is observed in that area as early as the Cenomanian, as shown by thickness analyses in anticlinal and synclinal zones.

The conclusion is that flow of salt from synclines towards anticlines accelerated due to inversion processes.The magnitude of inversion of local structures (including the halokinetic component) can be illustrated by differences in thickness variations of individual Upper Cretaceous stages recorded between anticlinal and synclinal zones. For example, along the Drawno-Człopa-Szamotuły Zone, the thickness of Santonian deposits ranges from 150 (or even less) to 300 m. On either side of the structure, the thicknesses increase to almost 400 m. Therefore, in this area the magnitude of inversion (including the halokinetic component) can be estimated at approximately 100–250 m. Thickness variations are also observed in the Campanian.

DISCUSSION

The Late Cretaceous was a period of marked worldwide eustatic transgression, initiated in the middle Albian and accelerated during the late Albian and Cenomanian (Hancock and Kauffman, 1979; Ziegler, 1982, 1990; Hancock, 1989). Large areas of the Polish Lowlands were inundated by the sea with successively developing carbonate and carbonate-siliceous sedimentation (Cieśliński, 1959, 1960, 1976; Pożaryski, 1962; Marcinowski, 1974; Marcinowski and Radwański, 1983, 1989; Jaskowiak-Schoeneichowa and Krassowska, 1988; Krassowska, 1997).

Since the Coniacian, the evolution of the Mid-Polish Trough had been partly controlled by tectonic processes related to plate collision and the beginning of the Alpine orogeny (Dadlez *et al*., 1995; Ziegler *et al*., 1995). Studies of various tectonic zones within the Mid-Polish Trough (e.g. Jaskowiak-Schoeneichowa, 1976, 1979, 1981; Leszczyński, 2000*a*) suggest that inversion processes of local structures, corresponding most probably to the beginning of the inversion of the axial part of the Mid-Polish Trough, strongly accelerated at that time. However, the timing and mechanisms of the regional inversion has been widely disputed and discussed (*cf*. Dadlez, 1980; Świdrowska and Hakenberg, 1999; Leszczyński and

Dadlez, 1999; Krzywiec, 2000). According to Świdrowska and Hakenberg (1999) there is no evidence for inversion of the Mid-Polish Trough before the Campanian. A similar opinion was earlier expressed by Kutek and Głazek (1972) who postulated that inversion began during the Maastrichtian. According to other opinions inversion of the Mid-Polish Trough started in the Coniacian or even as early as in the late Turonian (e.g. Dadlez, 1976, 1980; Dadlez *et al*., 1995, 1997; Jaskowiak-Schoeneichowa, 1981; Krassowska, 1997; Dadlez and Marek, 1997; Leszczyński, 1997; Leszczyński and Dadlez, 1999). This is in agreement with neighbouring parts of the European Late Cretaceous basin where inversion effects are observed after the Turonian (Ziegler, 1990). In Scania they are dated as Santonian (e.g. Norling and Bergström, 1987; Erlström *et al*., 1997), and in the Kattegat area, as Coniacian (e.g. Liboriusen *et al*., 1987). Thick clastic successions, formed as a result of erosion on uplifted blocks close to morphological gradients and near fault escarpments, are well known from the Santonian, Campanian and Maastrichtian of Scania (Lund Sandstone and Hansa Sandstone; Erlström, 1990; Erlström *et al*., 1997) and from the Kattegat area, Denmark (Liboriusen *et al*., 1987). The latter are manifested on seismic sections as chaotic and "hummocky" seismic reflection facies within ordered chalk deposits. They are interpreted as representing "debris flows" originating from crests of rising anticlinal axes. Uplift of these anticlines started in the Coniacian and accelerated rapidly during Santonian-Campanian time (Liboriusen *et al*., 1987). In the Danish Basin, which is a NW prolongation of the Mid-Polish Trough, axial zones were uplifted above sea level during the late Cretaceous and early Tertiary, forming islands or peninsulas parallel to the border of the Fennoscandian Shield (Liboriusen *et al*., *op. cit.*). This is evidenced by a local influx of clastic deposits around Bornholm (Surlyk, 1980), in Oresund (Larsen *et al*., 1968) and in Scania (Erlström, 1990; Erlström *et al*., 1997). During the early Late Cretaceous, the tectonic regime within the Fennoscandian Border Zone changed from transtentional to transpressional, and faults were reactivated, displaying generally a reverse throw during inversion (Liboriusen *et al*., *op. cit.*).

In Scania a change in the tectonic regime and the beginning of inversion occurred in the Santonian (Norling and Bergström, 1987). Tectonic activity was also observed in Germany (Thiermann and Arnold, 1964; Voigt, 1977; Betz *et al*., 1987). In southern parts of the Lower Saxony Basin Upper Cretaceous submarine slides and slumps were noted in the Turonian and Coniacian (Thiermann and Arnold, 1964; Voigt, 1977). Such deposits formed close to rising anticlines. Inversion processes culminated in that area during the Campanian when the anticlinal crests became uplifted above sea level and subjected to erosion.

The subsidence rate in the troughs situated on either side of the present-day Mid-Polish Swell increased in the Coniacian-Santonian (Leszczyński, 1997, 2000*b*), and was more differentiated from area to area than before. It could have accompanied regional inversion of the axial part of the Mid-Polish Trough. Increased subsidence caused a diversified palaeobathymetry and palaeotopography of the basin floor. Salt movements and the formation of salt structures, already active earlier, also became stronger from Coniacian to Campanian times (e.g. Jaskowiak-Schoeneichowa, 1977, 1981; Jaskowiak-Schoeneichowa and Krassowska, 1983). As a consequence of these events, stronger facies variability is observed in the sedimentary basin.

Late Cretaceous sedimentation continued until the end of Maastrichtian (Jaskowiak-Schoeneichowa, 1977). At the Cretaceous/Tertiary transition, the main phase of inversion occurred together with strong structural-palaeogeographic restructuring of the whole area, accompanied by another stage of salt structure formation. This phase of inversion resulted in a marine regression in the Szczecin-Mogilno Trough. The relict Early Paleocene basin persisted only north-east of the Mid-Polish Swell. Over large areas of the former Mid-Polish Trough and to the south-west, erosion and denudation processes dominated (Jaskowiak-Schoeneichowa and Krassowska, 1988; Krassowska, 1997). NW–SE-trending faults were reactivated, as well as perpendicular strike-slip fault zones (trending SW–NE and inherited from the syn-Variscan fault system), which mark the transverse segmentation of the Mid-Polish Trough (Dadlez, 1994).

Lithological and stratigraphical data from boreholes seem to confirm the results of interpretation of seismic data from the Pomeranian area (Krzywiec, 2002). Krzywiec (*op. cit.*) interprets inversion structures of the Koszalin-Chojnice Zone as reverse faults and uplifted basement blocks, suggesting that inversion was associated with strike-slip movements. Major basement normal faults were reactivated and could have acted as reverse faults at that time. That author identified two phases of inversion on seismic sections: the first phase dated as Turonian and pre-Maastrichtian, and the second phase dated as middle Maastrichtian.

Inferring from data available from boreholes drilled in the Koszalin-Chojnice and Drawno-Człopa-Szamotuły zones, Late Cretaceous inversion phases can be dated as Coniacian-?early Santonian and late Campanian-early Maastrichtian. These dates more or less correspond to those postulated by Krzywiec (2002), although there is some uncertainty about the mid-Maastrichtian phase which cannot be reliably verified from lithological and stratigraphical data. Another discrepancy results from the position of the Turonian/Coniacian boundary which, in boreholes from the Polish Lowlands, does not correspond to that of the standard scheme and should be shifted downwards in the sections (*cf.* Błaszkiewicz and Cieśliński, 1979; Walaszczyk, 1992; Bengtson, 1996; Kaufman *et al*., 1996; Błaszkiewicz, 1997). As a result, the Coniacian section spans a longer interval at the expense of the Turonian. Therefore, no signs of inversion are recorded before the Coniacian (according to the standard scheme) and inversion might have started after the Turonian.

CONCLUSIONS

Studies of the Upper Cretaceous succession in the Pomeranian sector of the Mid-Polish Trough, in particular in the

Koszalin-Chojnice and Drawno-Człopa-Szamotuły zones, show that the intra-Cretaceous stratigraphic gaps reached their maximum areal extent in the Coniacian (*Inoceramus involutus* Zone) and upper Campanian (Koszalin-Chojnice Zone). Over large areas, Santonian (mostly upper Santonian) deposits rest upon Turonian strata (including the *Inoceramus schloenbachi* Zone), locally on older rocks. The main categories of gaps span the following intervals:

1. Campanian (?and lowermost Maastrichtian)-Coniacian (*Inoceramus involutus* Zone) + uppermost Turonian (including the *Inoceramus schloenbachi* Zone). The Upper (or locally Lower) Maastrichtian rests upon the Turonian in the Koszalin-Chojnice Zone only.

2. Upper Campanian (+ possibly lowermost Maastrichtian), and lower Santonian-Coniacian (+ presumably uppermost Turonian).

3. Campanian (all or almost all) + possibly lowermost Maastrichtian.

4. Coniacian (*Inoceramus involutus* Zone) + most probably all the Turonian (including the *Inoceramus schloenbachi* Zone) or its upper part, + all the lower Santonian or its lowermost part.

5. Lower Santonian (or only its lower part) to Cenomanian or older stages.

6. A total lack of Upper Cretaceous deposits due to post-Cretaceous erosion.

7. Maastrichtian to Santonian, Coniacian, Turonian or Cenomanian. Upper Cretaceous deposits are overlain by Tertiary or Quaternary rocks.

The first pulse of Late Cretaceous inversion might have occurred in the Coniacian and early Santonian. Another pulse can be dated at late Campanian-early Maastrichtian. These two pulses were interrupted by a period of tectonic quiescence (late Santonian-earliest Campanian).

The lithofacies maps show that thickness and lithofacies distribution in the Cenomanian was independent of the strike of the Koszalin-Chojnice Zone. Such a dependence began and was accentuated in the Coniacian. In the Santonian, silty-sandy-marly lithofacies extend along the SW boundary of the Mid-Polish Swell; they can be associated with inversion of the Damasławek, Wapno, Człopa, Drawno structures, and probably also the of Trzcianka Zone and other zones within the central part of the Mid-Polish Trough. NE of the area of clastic sedimentation (SW part of the Pomeranian Trough), there extends a further belt of carbonate-siliceous lithofacies. A similar lithofacies distribution pattern is observed in the Campanian, although clastic sedimentation of the Pomeranian Trough retreated to the north. In Maastrichtian, sandy and carbonate-sandy sedimentation occupied over larger areas, with carbonate and carbonate-siliceous deposition in the Szczecin and Mogilno troughs.

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