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The Late Cretaceous sedimentation and subsidence south-west of the Kłodawa Salt Diapir, central Poland

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The Upper Cretaceous sequence in the area located between Uniejów, Kłodawa and Ozorków, Central Poland, is dominated by carbonate and carbonate-siliceous deposits. They are represented by limestones, marly limestones, marls and opokas with local gaize intercalations in the uppermost part of the sequence. There is also a complex of Santonian-Campanian clastics immediately adjoining the present-day Mid-Polish Swell near the Kłodawa Salt Diapir. The clastics may represent gravity flow deposits associated with a strong uplift of the Izbica–Kłodawa–Łęczyca Zone due to salt movements during inversion of this structure related to the incipient phase of the Late Cretaceous inversion of the whole Mid-Polish Swell. These processes caused increasing morphological gradients when passing south-westwards to the neighbouring subsiding trough. Detailed sedimentological studies of the clastic series cannot be made due to insufficient material and poor core condition. Investigations of the regional facies distribution and sedimentation, performed both along the areas adjoining the present-day Mid-Polish Swell and in local inversion structures, may help in the elucidation of timing of the incipient tectonic inversion phase of the Mid-Polish Trough which was ultimately transformed into the Mid-Polish Swell during the Early Tertiary.

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Key words: Mid-Polish Trough, Late Cretaceous, sedimentation, subsidence, tectonic inversion.

INTRODUCTION

The area of interest is located within the Uniejów Trough, Central Poland, close to the Mid-Polish Swell, near the Kłodawa Salt Diapir piercing itself along the SW edge of the swell, between the towns of Uniejów, Kłodawa and Ozorków (Fig. 1). Geology of this region is fairly well known by a number of boreholes and seismic profiles. Thicknesses of Upper Cretaceous deposits (including Upper Albian) range from around 1000–1500 m along the axis of the Ponętów and Wartkowice Anticlines up to > 2700 m in the synclines on both their sides (Fig. 2). Towards the Mid-Polish Swell, Upper Cretaceous deposits are truncated due to post-Cretaceous erosion, and older formations crop out at the sub-Cenozoic surface (Fig. 1).

The stratigraphy of the Upper Cretaceous has been established from correlations of well logs between boreholes from the Uniejów Trough supported by comprehensive palaeontological studies conducted by Gawor-Biedowa (1984, 1990, 1997), Gaździcka (1994) and Błaszkiewicz (1997). Difficulties in drawing stratigraphic boundaries between individual stages refer mainly to the upper part of the Cretaceous sequence, and appear to be due largely to both poor core material and monotonous lithologies in most boreholes. Therefore, some of the boundaries are established with slight uncertainty.

All the Upper Cretaceous stages are represented in this area, from the Cenomanian through Maastrichtian. Because Upper Albian deposits commence the great Late Cretaceous transgressive-regressive cycle, they are usually included into the Upper Cretaceous sequence. Maastrichtian deposits are slightly limited in their extent due to epigenetic erosion that affected this area during the main phase of tectonic inversion. Their more complete sections occur in the synclines on both sides of the Ponętów and Wartkowice Anticlines.

SEDIMENTATION

The Upper Cretaceous sequence (including Upper Albian) is underlain by the Kruszwica Member deposits of Early?-Middle Albian age (Marek ed., 1977; Raczyńska, 1979; Marek and Raczyńska, 1979). They are represented by a complex, up to

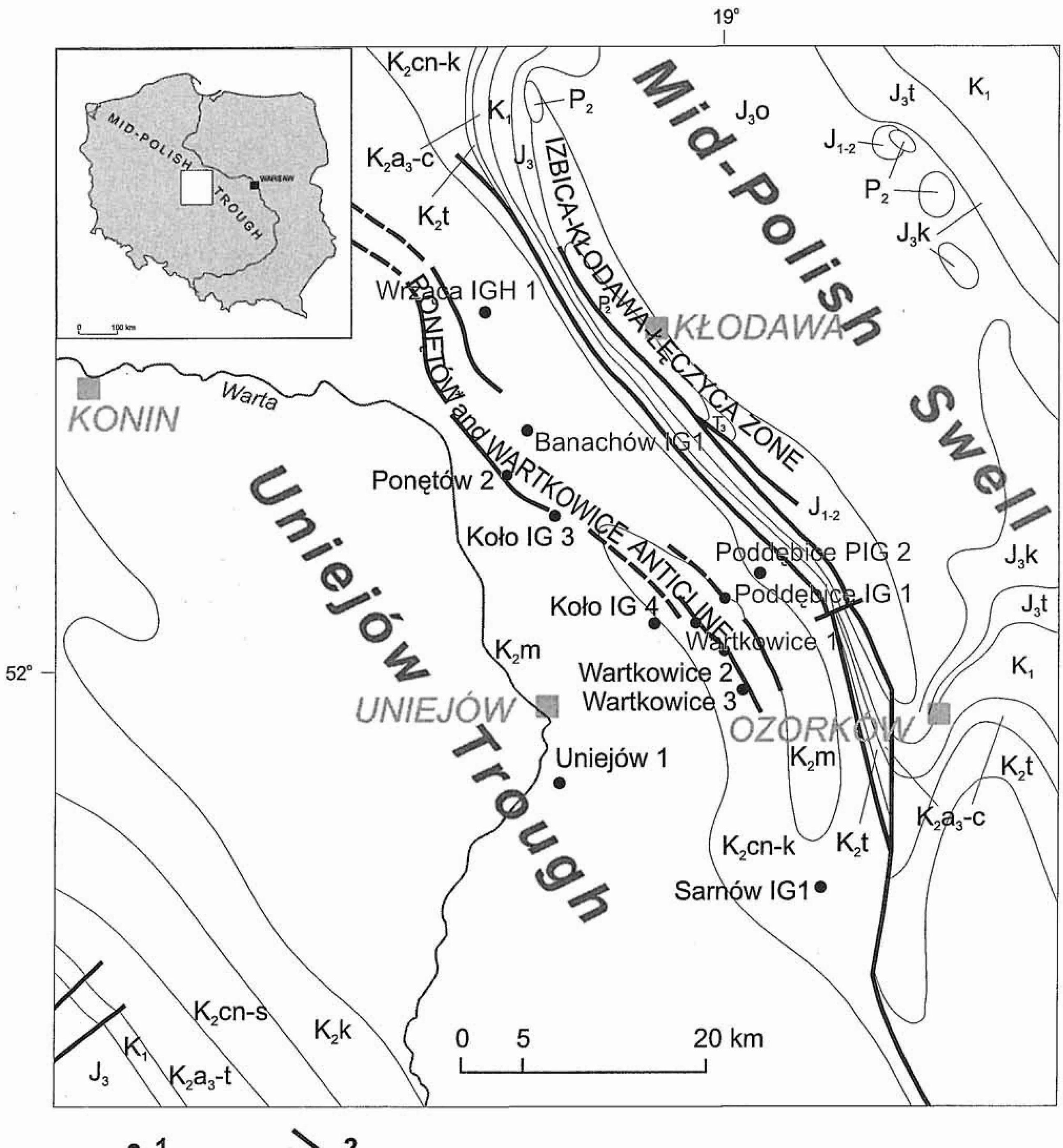

Fig. 1. Geological map of Central Poland (without Cenozoic), after Marek and Leszczyński

1 — boreholes of major importance; 2 — faults; K_2m — Maastrichtian; K_2k — Campanian; K_2cn-k — Coniacian-Campanian; K_2cn-s — Coniacian-Santonian; K_2t — Turonian; K_2a_3-t — Upper Albian-Turonian; K_2a_3-c — Upper Albian-Cenomanian; K_1 — Lower Cretaceous; J_3 — Upper Jurassic; J_3t — Tithonian, J_3k — Kimmeridgian; J_3o — Oxfordian; J_{1-2} — Middle and Lower Jurassic; T_3 — Upper Triassic; P_2 — Upper Permian-Zechstein

124 m thick, of shallow-marine sandstones with gravelly horizons.

The Late Albian marine expansion resulted in a deposition of a thin, up to 1.1 m thick, layer of quartz-glauconitic sandstones with a horizon of phosphatic nodules, which pass upwards into sandy marls and marls with marly limestone interbeds (Fig. 3) containing abundant marine fauna. The Upper Albian deposits thicken towards the north-east, and in the borehole Poddębice PIG 2 they attain a thickness of 53 m.

A decrease in clastic material supply into this part of the Cretaceous basin took place in the Cenomanian. A pelagic carbonate deposition developed all over the area, with dominant

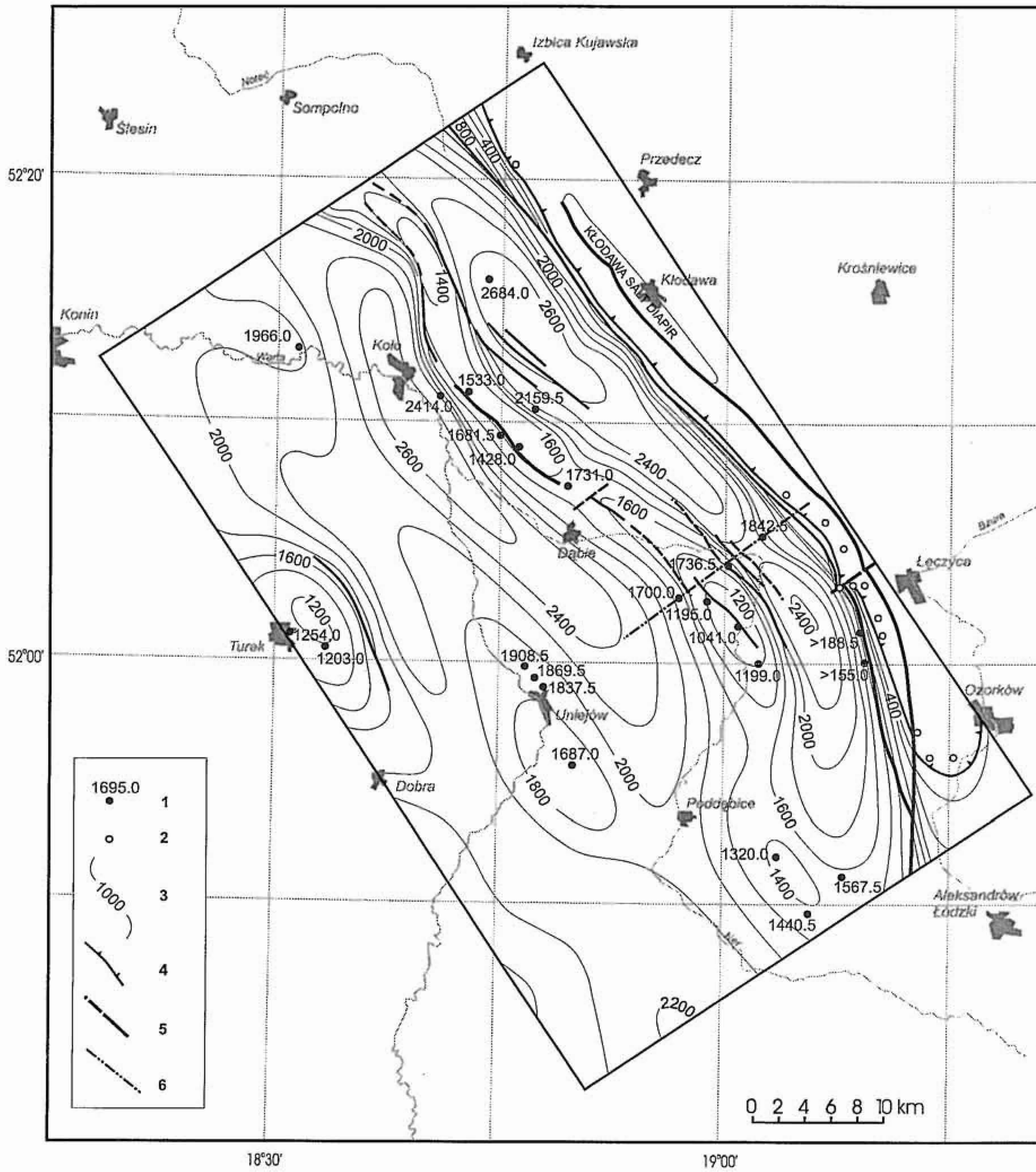

Fig. 2. Thickness of Upper Cretaceous deposits (including Upper Albian)

1 — boreholes with Upper Cretaceous deposits drilled; 2 — boreholes without Upper Cretaceous deposits; 3 — isopachs of Upper Cretaceous; 4 — extent of total epigenetic erosion of Upper Cretaceous deposits (including Upper Albian); 5 — faults; 6 — seismic section 3-II-77 line (Fig. 7)

limestones and marly limestones (mudstones and wackestones with foraminifer and inoceramid bioclasts) of high $CaCO_3$ content ranging from 70 to 86% (Fig. 3). The carbonates contain numerous inoceramids which are present throughout the whole Upper Cretaceous section. Thicknesses of the Cenomanian deposits range from 70 m in the south-west to 105 m in the north-east.

A short break in carbonate deposition took place at the beginning of the Turonian. Dark grey and black claystones, slightly calcareous, were deposited at that time (Fig. 3). Later in the Turonian pelagic carbonate sedimentation resumed with marly limestones, marls and limestones. In the upper part of the Turonian sequence (including *Inoceramus schloenbachi* Zone; Błaszkiewicz, 1997) sedimentation changed from carbonate-marly to carbonate-siliceous one (opokas and marly intercalations) with opokas becoming predominant up the section. Thicknesses of the Turonian are much higher compared with those of the Cenomanian and range from around 300 up to 475 m.

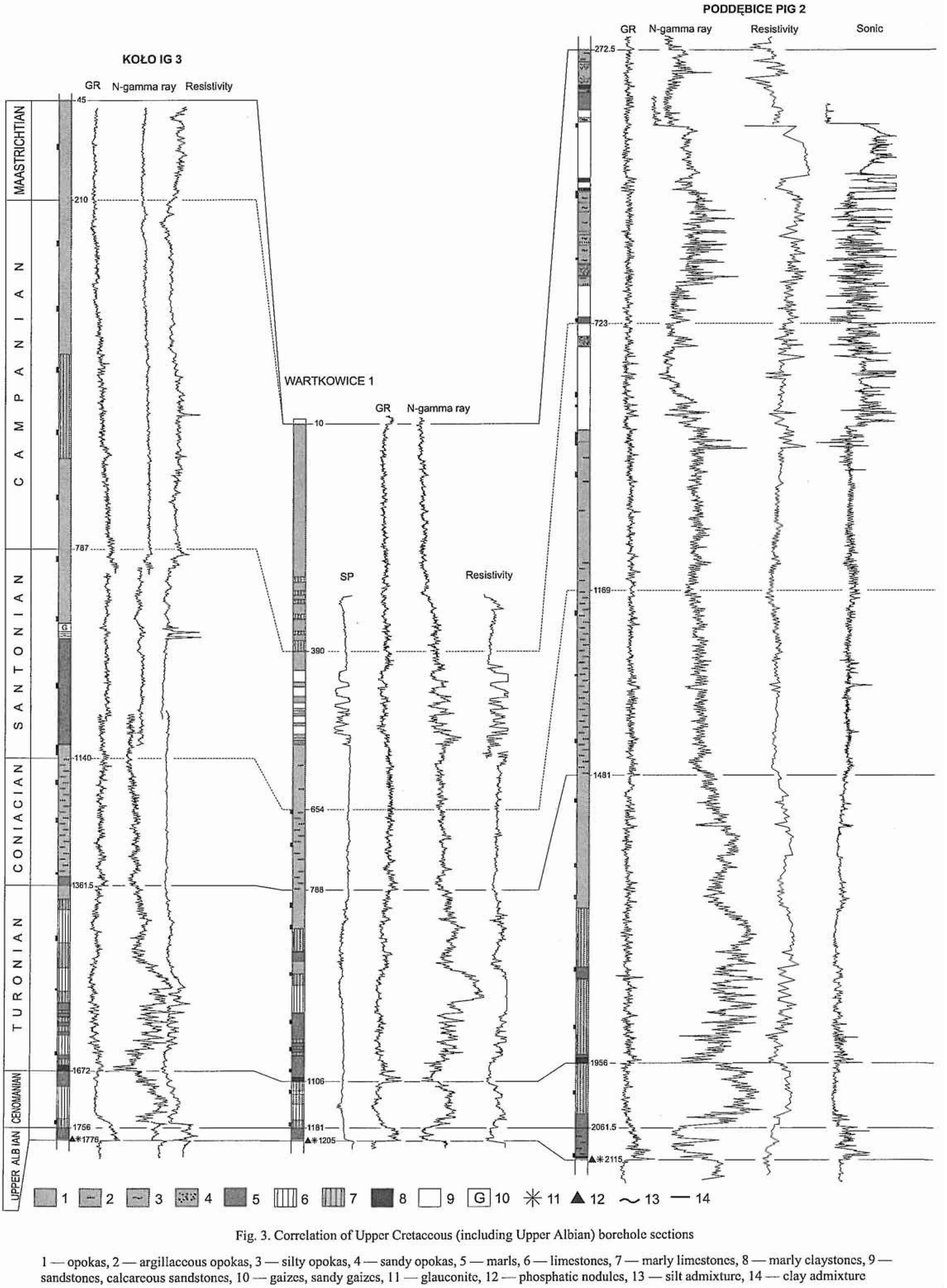

Fig. 3. Correlation of Upper Cretaceous (including Upper Albian) borehole sections

1 — opokas, 2 — argillaceous opokas, 3 — silty opokas, 4 — sandy opokas, 5 — marls, 6 — limestones, 7 — marly limestones, 8 — marly claystones, 9 — sandstones, calcareous sandstones, 10 — gaizes, sandy gaizes, 11 — glauconite, 12 — phosphatic nodules, 13 — silt admixture, 14 — clay admixture

The Coniacian (=*Inoceramus involutus* Zone, Błaszkiewicz, 1997) is represented by a uniform opoka complex (Fig. 3). Carbonate content (40–50% $CaCO_3$) is in general less when compared with the older deposits, whereas detrital quartz grains and clay material occur in slightly increased quantities in these rocks. Thicknesses of the Coniacian deposits are in excess of 200 m.

Earlier in the Santonian, sedimentation of opokas with interbeds of marls continued throughout the entire area. Later on, the facies pattern becomes more varied. Clastic deposits (mostly sandstones) occur in the northeastern part of the area immediately adjoining the present-day Mid-Polish Swell southwest and south of the Kłodawa Salt Diapir. They were penetrated by boreholes Koło IG 3, IG 4, Poddębice IG 1, PIG 2 and Wartkowice 1, 2 and 3 (Fig. 1). No clastic intercalations in the Santonian-Campanian section have been found in boreholes Wrząca IGH 1, Banachów IG 1, Ponętów 2, Uniejów 1 and Sarnów IG 1. There are two clastic complexes related to two pulses of stronger tectonic movements along the the Izbica–Kłodawa–Łęczyca Zone: the lower one is of Late Santonian (and possibly earliest Campanian) age, while the upper one represents the Late Campanian. They are separated by carbonate-siliceous deposits (largely opokas with subordinate marls). The upper complex is of a smaller extent and was encountered only by boreholes Poddębice IG 1 and PIG 2. The thickness of clastic deposits increases to the northeast towards the Kłodawa–Łęczyca structure, and their total thickness reaches 390 m (Fig. 4; borehole Poddębice PIG 2). Sandstone complexes in the borehole Poddębice PIG 2 are dated from nannoplankton data (Gaździcka, 1994). Insufficient material and poor core condition render a detailed sedimentological recognition of these deposits impossible. However, the palaeogeographic setting, cores available and well log analyses allow some remarks on the nature and origin of these deposits.

The complexes are composed of sandstone layers interbedded with opokas and marls, and locally with thin intercalations of mudstones and calcareous mudstones. The sandstones are fine- to coarse-grained. Individual sandstone beds have usually sharp basal surfaces, while in the upper parts the sandstones typically show gradual transitions into finer-grained deposits. Petrographical studies (Połońska, 1998) have shown that they are represented by moderately sorted quartz and subarcosic wackes, locally with infrequent glauconite. They contain scarce fauna of mostly foraminifers. A bimodal grain-size distribution (usually in coarser-grained sandstones), characteristic of gravity flow deposits (Gradziński *et al.*, 1986), and occasionally cross lamination have been observed in these sediments. Their mineral composition comprises quartz, feldspar, glauconite, muscovite and rare lithic fragments (siliceous rocks, metamorphic schists, quartzites). The grains are cemented by coarse-crystalline spar or occasionally calcite microspar, clay-ferruginous material and rare pyrite (Połońska, 1998). Scarce plant remains were found in the borehole Koło IG 4.

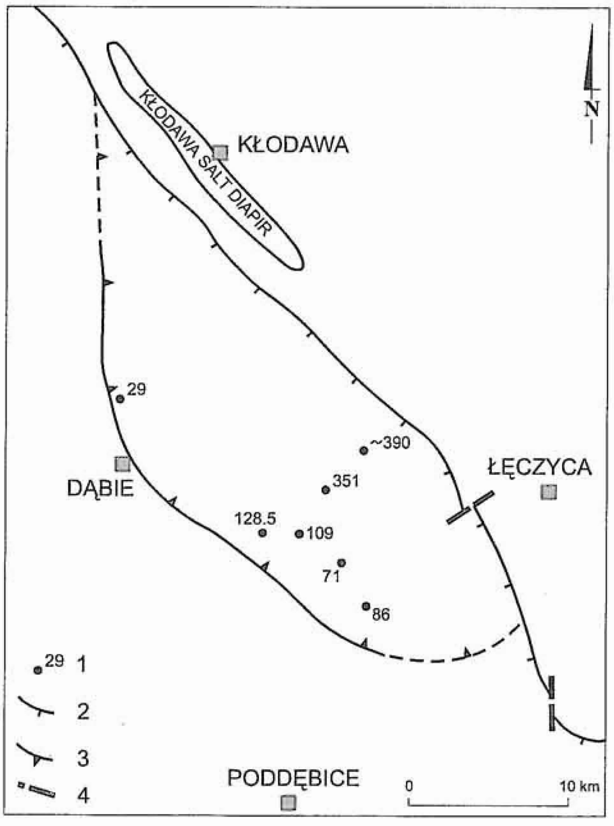

Fig. 4. The extent of Santonian-Campanian clastics south-west of the Kłodawa Salt Diapir

1 — boreholes, thickness of clastics in metres; 2 — recent extent of the Upper Cretaceous; 3 — extent of Santonian-Campanian clastics; 4 — faults

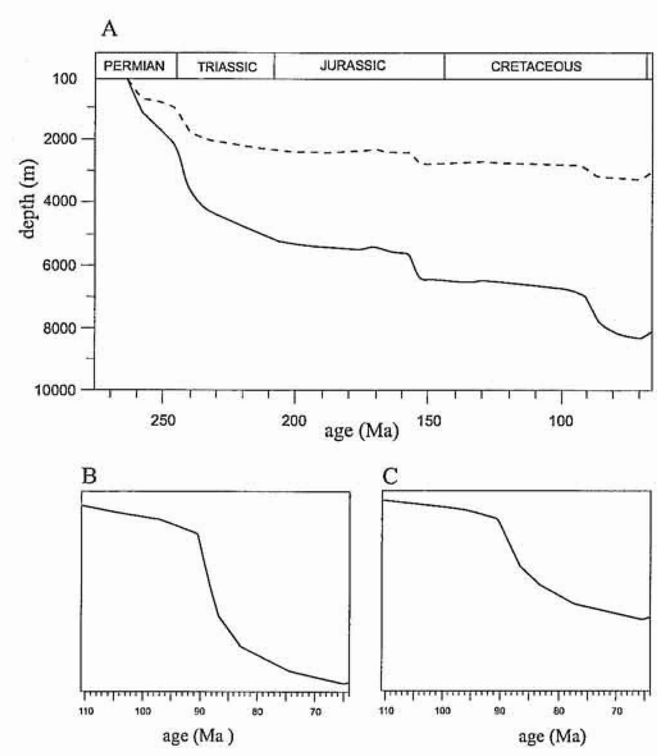

Fig. 5. Subsidence curves drawn for boreholes Poddębice PIG 2 and Wartkowice 2 (time scale after Harland *et al.*, 1989)

A — total subsidence (solid line) and tectonic subsidence (dashed line) curves drawn for borehole Poddębice PIG 2; **B** — tectonic subsidence curve drawn for borehole Poddębice PIG 2 (Late Cretaceous only); **C** — tectonic subsidence curve drawn for borehole Wartkowice 2 (Late Cretaceous only)

Table 1

Cretaceous time scale after Harland *et al.* (1989)

Period	Epoch	Stage	Age Ma	Duration Ma		
Tertiary		Danian				
Cretaceous	Late	Maastrichtian	65,0	9,0	32,0	80,6
		Campanian	74,0	9,0		
		Santonian	83,0	3,6		
		Coniacian	86,6	1,9		
		Turonian	88,5	1,9		
		Cenomanian	90,4	6,6		
	Early	Albian	97,0	15,0	48,6	
		Aptian	112,0	12,5		
		Barremian	124,5	7,3		
		Hauterivian	131,8	3,2		
		Valanginian	135,0	5,7		
		Berriasian	140,7	4,9		
Jurassic	Late	Tithonian	145,6			

Some of the sandstone beds display normal grading. In planar view the clastic complexes have a fan-like outline (Fig. 4). Therefore, they may be considered to represent gravity flow deposits associated with increased relief gradients near the Izbica–Kłodawa–Łęczyca Zone. Eroded detrital material (presumably Lower Cretaceous clastics and maybe even older) was transported down into the deeper neighbouring parts of the subsiding Uniejów Trough and deposited in the form of a submarine fan (Leszczyński, 1997). In the areas located beyond the extent of clastic sedimentation, carbonate-siliceous and carbonate deposition took place during Santonian and Campanian times. Thicknesses of the Santonian deposits are of up to 545 m, while the Campanian ones exceed 800 m (borehole Wrząca IGH 1).

The distribution of Maastrichtian deposits is more restricted than the older ones due to post-Cretaceous epigenetic erosion. They are absent along the Wartkowice Anticline (Fig. 1). The Maastrichtian sequence is represented by opokas (Fig. 3) locally with thin interbeds of gaizes and sandy gaizes. No clastic deposits similar to those from the Santonian and Campanian have been recorded in this area. However, the restricted extent of the Maastrichtian does not allow to preclude the possibility of the existence of the clastics in the past. Present-day thicknesses of the Maastrichtian deposits are in excess of 400 m. The highest values are observed on both sides of the Ponętów Anticline in the boreholes Dobrów IGH 1 and Wrząca IGH 1 (Fig. 1). The original thicknesses must have been by at least tens of metres greater.

Marine sedimentation in this part of the Polish basin may have persisted until the latest Maastrichtian and was followed by the main phase of tectonic inversion that resulted in a strong palaeogeographic rearrangement of vast areas in the Polish Lowlands (Jaskowiak-Schoeneichowa, 1977; Krassowska, 1997). The Upper Cretaceous sequence in the study area is overlain by a thin Cenozoic cover mostly composed of fluvial, glacial and glaciofluvial Quaternary deposits with local patchy occurrences of thin Tertiary deposits.

SUBSIDENCE AND TECTONICS

During the Late Albian and Cenomanian, the rate of subsidence in this part of the Polish basin was low. It rapidly increased in Turonian and Coniacian times, and from the Santonian until Maastrichtian it was continuously decreasing (see Dadlez *et al.*, 1994, 1995). This is shown in total and tectonic subsidence curves drawn for the boreholes Poddębice PIG 2 and Wartkowice 2 using the BasinMod computer software (Fig. 5), and applying the time scale of Harland *et al.* (1990) (Tab. 1). For the construction of subsidence curves, a global sea level of +100 – +350 m (*cf.* Hancock and Kauffman, 1979; Haq, 1988; Allen and Allen, 1990) in relation to the present-day level, and bathymetry of 100–400 m have been assumed for the Late Cretaceous time. A different shape of the tectonic subsidence curve from the borehole Wartkowice 2 (Fig. 5C) compared with that from Poddębice PIG 2 (Fig. 5B) reflects a differentiation in tectonic activity between the Ponętów–Wartkowice Zone and neighbouring areas, and the lower rate of subsidence within the former zone. It should be noted that these curves, in addition to regional tectonic subsidence, also contain a local salt movements component due to salt flow from synclines towards anticlines.

Likewise, the sedimentation rate (after decompaction) was very low during the Late Albian and Cenomanian (10–30 m/My) and increased considerably in the Turonian and Coniacian (270 m/My). Later, it was decreased to a few tens of metres per million years in the Maastrichtian (Fig. 6).

However, subsidence probably became increasingly differentiated in Coniacian, Santonian and Campanian times in particular zones. At those times, the synclines located on both sides of the Ponętów and Wartkowice Anticlines subsided more rapidly. Simultaneously, the Ponętów and Wartkowice Anticlines themselves were subjected to lower subsidence or movements.

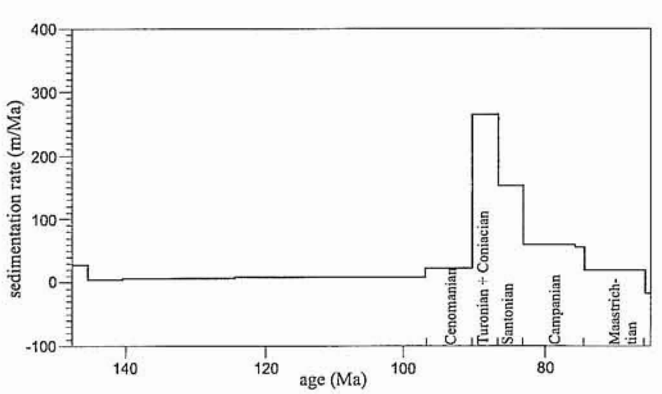

Fig. 6. Sedimentation rate of Cretaceous deposits (decompacted curve) drawn for borehole Poddębice PIG 2 (time scale after Harland *et al.*, 1989)

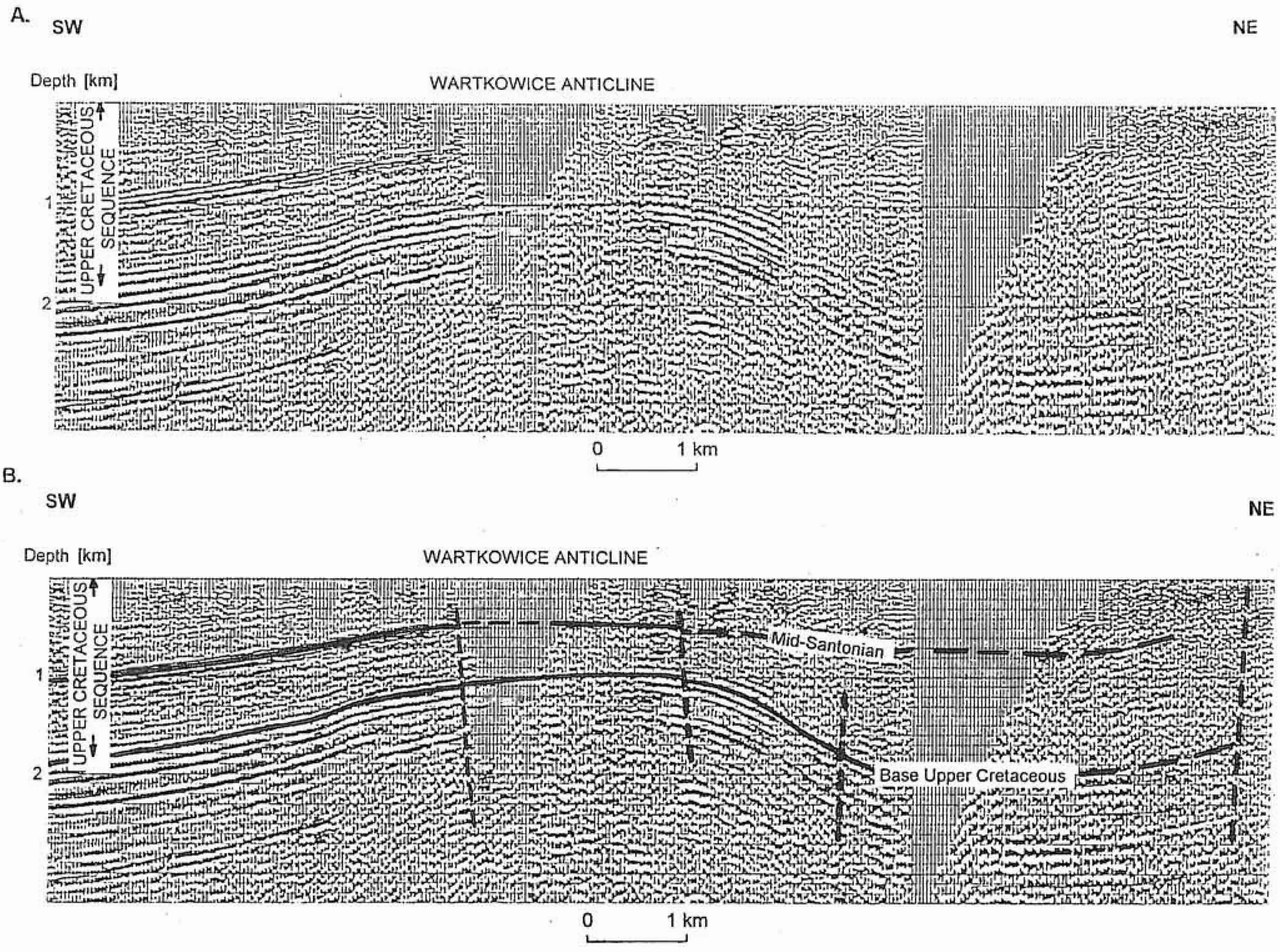

Fig. 7. Depth-converted seismic section 3-II-77 across the Wartkowice Anticline (A) and its interpretation (B) (for location see Fig. 2)

This is shown by a decreasing thickness of Upper Cretaceous deposits towards the axis of the structure (Fig. 2). The whole Upper Cretaceous sequence exhibits in the seismic section an internal thinning (in particular in the middle part) along the Ponętów and Wartkowice Anticlines crest (Fig. 7). From boreholes it is known that the most pronounced thickness differences refer to the Coniacian- Santonian (?and Campanian) (Fig. 3). The uppermost parts of the Upper Cretaceous sequence cannot be interpreted reliably due to shallow depths from the ground surface and poor seismic reflection record.

The Izbica–Kłodawa–Łęczyca Zone was probably being strongly uplifted in Coniacian through Campanian times. It seems that the strong uplift occurred due to a combination of regional inversion of the Kłodawa–Łęczyca structure as a part of the Mid-Polish Swell owing to a general tectonic inversion régime and mobilization of salts, recognised elsewhere in the Polish Late Cretaceous basin (Dadlez and Marek, 1969, 1974; Cieśliński and Jaskowiak, 1973), and the uplift took place along reactivated faults that were earlier probably active as normal faults during, for example, the Late Permian-Early Triassic extensional (or transtensional) event (Dadlez *et al.*, 1994, 1995). Therefore, these events may have been related to an incipient phase of tectonic inversion in the axial part of the Mid-Polish Trough (Leszczyński and Dadlez, 1999).

It is possible that sedimentation of the Santonian-Campanian clastics might have also been controlled to a certain extent by eustatic sea-level changes. This may be related to sea-level falls observed during both the Late Santonian-earliest Campanian and Late Campanian (Vail, Mitchum and Thompson, 1977; Hancock, 1989).

Gravity flow deposits originating from crests of rising anticlinal axis and structural relief, and related to a tectonic inversion régime, have been described from the areas located farther north-west within the inverted parts of Danish basins in Kattegat and the North Sea (Liboriusen *et al.*, 1987; Vejbaek and Andersen, 1987).

CONCLUSIONS

1. The Upper Cretaceous sequence in the area located between Uniejów, Kłodawa and Ozorków, Central Poland, is dominated by carbonate and carbonate-siliceous deposits.

2. A complex of Santonian-Campanian clastics immediately adjoining the present-day Mid-Polish Swell occurs southwest of the Kłodawa Salt Diapir.

3. The clastics may represent gravity flow deposits related to local inversion of the Izbica–Kłodawa–Łęczyca Zone within a regional tectonic inversion régime which caused mobilization of salts, as well as to increasing relief gradients when passing south-westwards to the neighbouring Uniejów Trough. Such movements might have been associated with an incipient phase of tectonic inversion in the axial part of the Mid-Polish Trough.

4. Eroded detrital material (presumably Lower Cretaceous clastics and maybe older) was transported down into deeper parts of the subsiding trough and deposited in a form of submarine fan.

5. No clastic deposits similar to those from the Santonian and Campanian have been recorded in this area in the Maastrichtian. However, later erosion may be responsible for the lack of any sedimentological evidence. The possibility of their existence in the past cannot be precluded.

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