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Evolution of the Holy Cross segment of the Mid-Polish Trough during the Cretaceous

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Facies and thickness patterns of consecutive Cretaceous stages have been interpreted in the Holy Cross segment of the Mid-Polish Trough. The study has been based on detailed analysis of available materials concerning stratigraphy and lithology of the Cretaceous deposits. Regions characterised by similar vertical lithofacies succession for each Cretaceous stage have been distinguished and can be related to different depositional environments. An axial part of the basin has been defined, the location and role of synsedimentary faults have been determined and variability of the basins transversal asymmetry has been characterised. The importance of the sandy material influx in the uppermost Cretaceous has been analysed. Main tectonic pulse, leading to an increase of subsidence rate and controlled by the fault activity, took place in the Turonian.

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Key words: Mid-Polish Trough, Cretaceous basin, basin analysis, thickness facies, bounding faults, synsedimentary faults, subsidence.

INTRODUCTION

The region described in the present paper slightly exceeds area bordered by Wisła and Pilica rivers (Fig. 1A). The Cretaceous deposits fill three synclines, evolved during the Laramide inversion: the Warsaw–Lublin Syncline in the north-east, Miechów Syncline in the south-west and Tomaszów Syncline in the north-west. During the Cretaceous depositional cycle, since the Late Albian, these areas have been included into a single depositional basin. Recently, due to the Laramide inversion and related epigenetic erosion, Tomaszów and Miechów synclines are separated from the Warsaw–Lublin Syncline by the Mid-Polish Swell with its Holy Cross segment.

The aim of this paper is to establish a depositional evolution and subsidence history of the mentioned area during the Cretaceous by means of thickness and facies analysis of particular stages. Input data on Cretaceous stratigraphy and lithology was derived from papers of the following authors: R. Chlebowski *et al.* (1977), S. Cieśliński (1959*a*, *b*, 1976), S. Cieśliński, W. Pożaryski (1970), B. Don (1973), S. Geroch *et al.* (1972), R. Gradziński (1960), M. Hakenberg (1969, 1978, 1986), I. Heller, W. Moryc (1984), M. Jaskowiak-Schoeneichowa (1972), M. Jaskowiak-Schoeneichowa, A. Krassowska (1983, 1988), A. Krassowska (1989, 1997), J. Kutek (1967, 1968, 1994*a*, *b*), J. Kutek *et al.* (1987), J. Kutek, R. Marcinowski (1996), W. Machej (1970), R. Marcinowski (1974), R. Marcinowski, S. Rudowski (1980), R. Marcinowski, A. Radwański (1983, 1989), R. Marcinowski, I. Walaszczyk (1985), S. Marek (1983, 1988, 1997), W. Moryc (1996), W. Moryc, J. Waśniowska (1965), K. Mrozek (1975), W. Pożaryski (1938, 1948, 1966), A. Raczyńska (1979), J. Rutkowski (1965, 1976), E. Senkowicz (1959), J. Uberna (1967), I. Walaszczyk (1992), and A. Witkowski (1969). Archival and published descriptions of deep well sections (*Profile głębokich otworów wiertniczych..*, 1973–1988) have been also used, as well as, for the area of the Miechów Syncline, explanations of 14. sheets of the *Detailed Geological Map of Poland* (scale of 1:50 000). The early history of studies of the Cretaceous deposits is presented in the paper by S. Cieśliński and W. Pożaryski (1970).

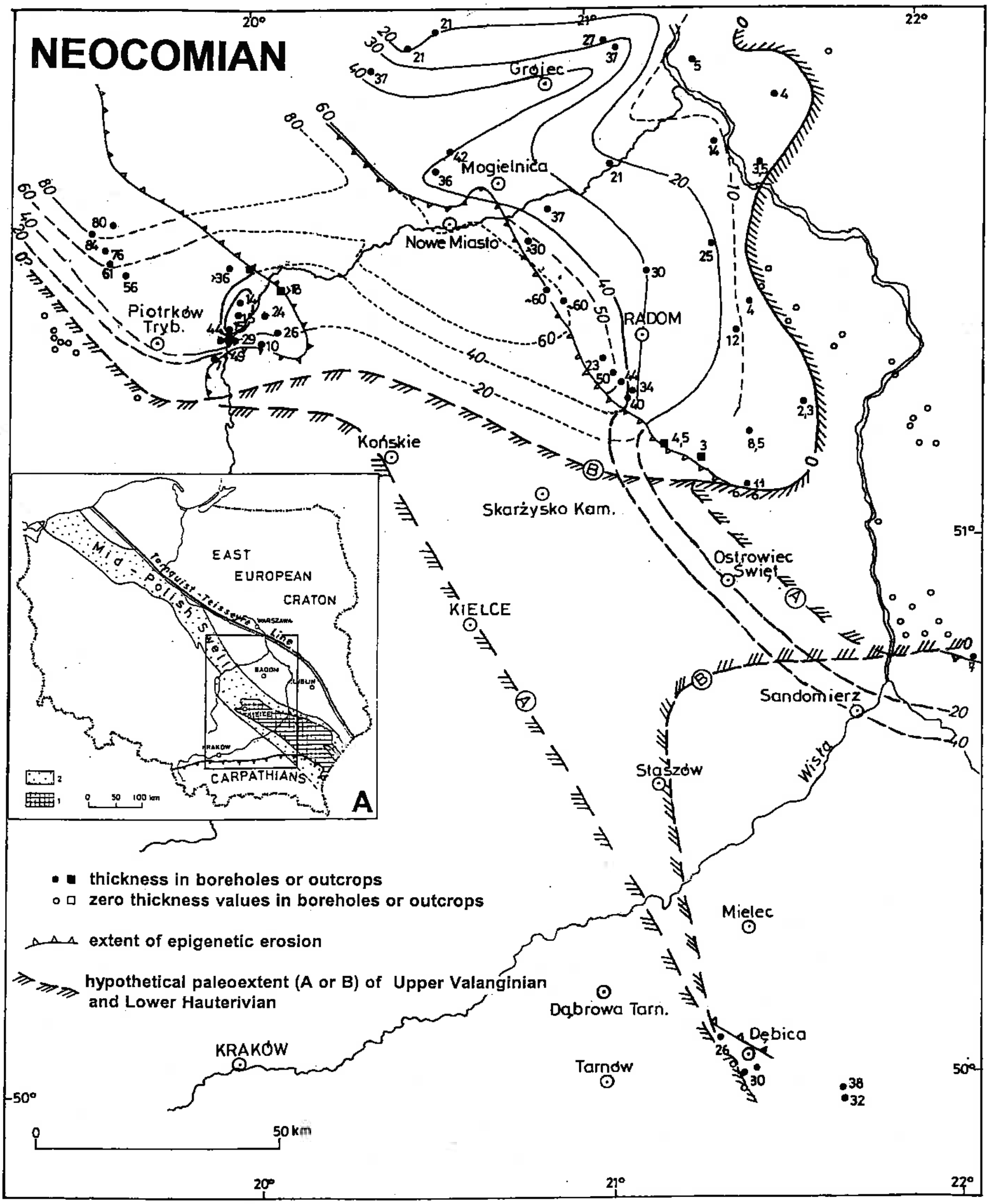

Fig. 1. Thickness pattern of Neocomian deposits (A — location of investigated area)
1 — Palaeozoic, 2 — Triassic and Jurassic

Rozkład miąższości osadów neokomu (A — lokalizacja obszaru badań)
1 — paleozoik, 2 — trias i jura

From the palaeotectonic point of view the discussed area was situated in three distinctly different regions. The first of them was connected with the south-east extension of axial and near-axial part of the Mid-Polish Trough. Here, both subsidence and sediment-thicknesses were considerable in the Permian and Mesozoic, and depositional breaks and erosional episodes were few and short-lasting. The two other zones were located on opposite flanks of the trough and recently they are occupied by the areas of the Miechów and Warsaw–Lublin synclines. They are both characterised by opposite tendency in terms of depositional conditions, when compared to the Mid-Polish Trough area (J. Głazek, J. Kutek, 1970; R. Dadlez, 1987, 1989; M. Hakenberg, J. Świdrowska, 1996; A. Morawska, 1996; M. Hakenberg, J. Świdrowska, 1997).

The above differences became pronounced i.a. near the Jurassic/Cretaceous boundary which is characterized by stratigraphic gaps of various magnitude. In the Miechów Syncline the gap may range from ca. 45 Ma near Przedbórz (Upper Albian on Upper Kimmeridgian — J. Kutek, 1968; M. Hakenberg, 1978) to ca. 60 Ma in some localities near Kraków (Santonian on Oxfordian — R. Gradziński, 1960). A considerably smaller stratigraphic gap has been identified on the area of Warsaw–Lublin Syncline. It can be estimated to span about 9 Ma in the Raducz IG 1 deep well (Upper Valanginian on Upper Volgian — S. Marek, 1983) to ca. 15 Ma in the Białobrzegi IG 1 deep well (Upper Valanginian on Lower Kimmeridgian — S. Marek, 1983). In the part of the investigated area situated closer to the axis of the Mid-Polish Trough (Tomaszów Syncline) the depositional gap between the Jurassic and Cretaceous is in the order of merely 5 Ma (Upper Berriasian on Middle Volgian — A. Witkowski, 1969; J. Kutek, 1994*b*; J. Kutek *et al.*, 1987).

NEOCOMIAN

Neocomian deposits crop out in the Tomaszów Syncline and in the northeastern margin of the Holy Cross Mountains between Nowe Miasto and Chwałowice near Iłża (S. Cieśliński, W. Pożaryski, 1970). North of this line Lower Cretaceous deposits were reached by wells in the Warsaw–Lublin Syncline (S. Marek, 1983). They have been also detected in wells in both flanks of the Upper San Anticlinorium in the vicinity of Dębica (S. Geroch *et al.*, 1972; W. Moryc, 1996) and Lubaczów (W. Moryc, J. Waśniowska, 1965).

Facies and thickness patterns in the Neocomian are difficult to characterise, due to a variable sequence of depositional and erosional processes, combined with a small subsidence and often with lack of biostratigraphic documentation. Upper Berriasian and Hauterivian (probably Lower) are represented by a highly discontinuous stratigraphic record with gaps detected at the following boundaries: (1) Middle Volgian–Upper Berriasian, (2) Upper Berriasian–Lower Valanginian (*Platylenticeras*), (3) Lower Valanginian (*Polyptichites*)–Upper Valanginian, (4) Hauterivian–Barremian (J. Kutek *et al.*, 1987). Transgressive pulses with increasing range are recorded in Upper Berriasian, Lower Valanginian, and Upper Valanginian. The duration of erosional episodes, changing the extent of Berriasian and Lower Valanginian, was relatively short, as it was limited by consecutive transgressions (Fig. 2). Only the extent of Upper Valanginian and Hauterivian between Radom and the Wisła river is mainly erosional, as undated Pagórki and Gopło Members, considered conventionally as Barremian and Aptian (S. Marek, 1983), have a considerably smaller extent (Fig. 3) and occur north of Pilica river. Lower and Middle Albian deposits are also missing in this region, which indicates a long-lasting period of erosion in a vast area.

Earliest Cretaceous deposits are of Late Berriasian age, as documented by fauna described by A. Witkowski (1969) in three wells in the northern and northeastern part of the Tomaszów Syncline (Dębniak 1, Łazisko 1 and Zarzęcin 2). In their lowermost part quartz pebbles occur sometimes accompanied by cemented coquinas overlain by clays with pyrite (non-calcareous and without sandy fraction). The upper part of the section is composed of mudstones with ferruginous oolites and sphaerosiderites (section **a** in Fig. 2). In three other wells clays with siderites were not documented biostratigraphically, but are similarly developed (Swolszowice, Wiaderno and Bronisławów). Deposits considered as Upper Berriasian have a thickness slightly exceeding 7 m, and rest on marine limestone-dolomitic mudstones without fossils, or on Volgian limestones belonging to the *Zaraiskites scyticus* Zone with commonly occurring reworked Jurassic fauna. Both top and bottom boundaries are erosional surfaces underlined by the occurrence of limestone pebbles documenting intraformational erosion (J. Kutek *et al.*, 1987).

Best documented Lower Valanginian section (*Platylenticeras*), with a thickness of about 4.3 m, occurs in Wąwał (J. Kutek *et al.*, 1987; J. Kutek, R. Marcinowski, 1996), south of the Pilica river in Tomaszów Syncline, in the area just affected by a transgression. The section is composed of: (1) limestone conglomerates, (2) sands and muds, (3) clays with sideritic concretions and ferruginous oolites (section **a** in Fig. 2). The aerial extent of the Lower Valanginian deposits seems to include also the Tuszyn region (see K. Mrozek, 1975), where sandstones constitute greater part of the section (section **b** in Fig. 2). Present area of occurrence of the Berriasian and Lower Valanginian deposits is similar and limited to a narrow and short strip in the northwestern part of the whole study area and its southwestern boundary is almost perpendicularly cut by the line limiting epigenetic post-Cretaceous erosion (Fig. 2). This suggests a possibility of palaeogeographic continuity of coeval deposits in the southeastern direction, which is further suggested by the fact, that occurrence of Tethys ammonites is connected with both Early Cretaceous transgressions, the later fauna missing in contemporaneous deposits in Germany (J. Kutek *et al.*, 1987).

Acceptance of the connection with the Tethys approximately along the subsidence axis of the Late Jurassic trough (*vide* J. Kutek *et al.*, 1987) leads to a conclusion, that the link must have been quite narrow, along the line Piotrków Trybunalski–Kielce–Mielec, in order not to exceed the zone of epigenetic erosion and not to embrace the area of Zagórze and Nawsie near Dębica, where Upper Valanginian deposits have been discovered (S. Geroch *et al.*, 1972; W. Moryc, 1996). Thus, an outline of a narrow and elongated graben emerges.

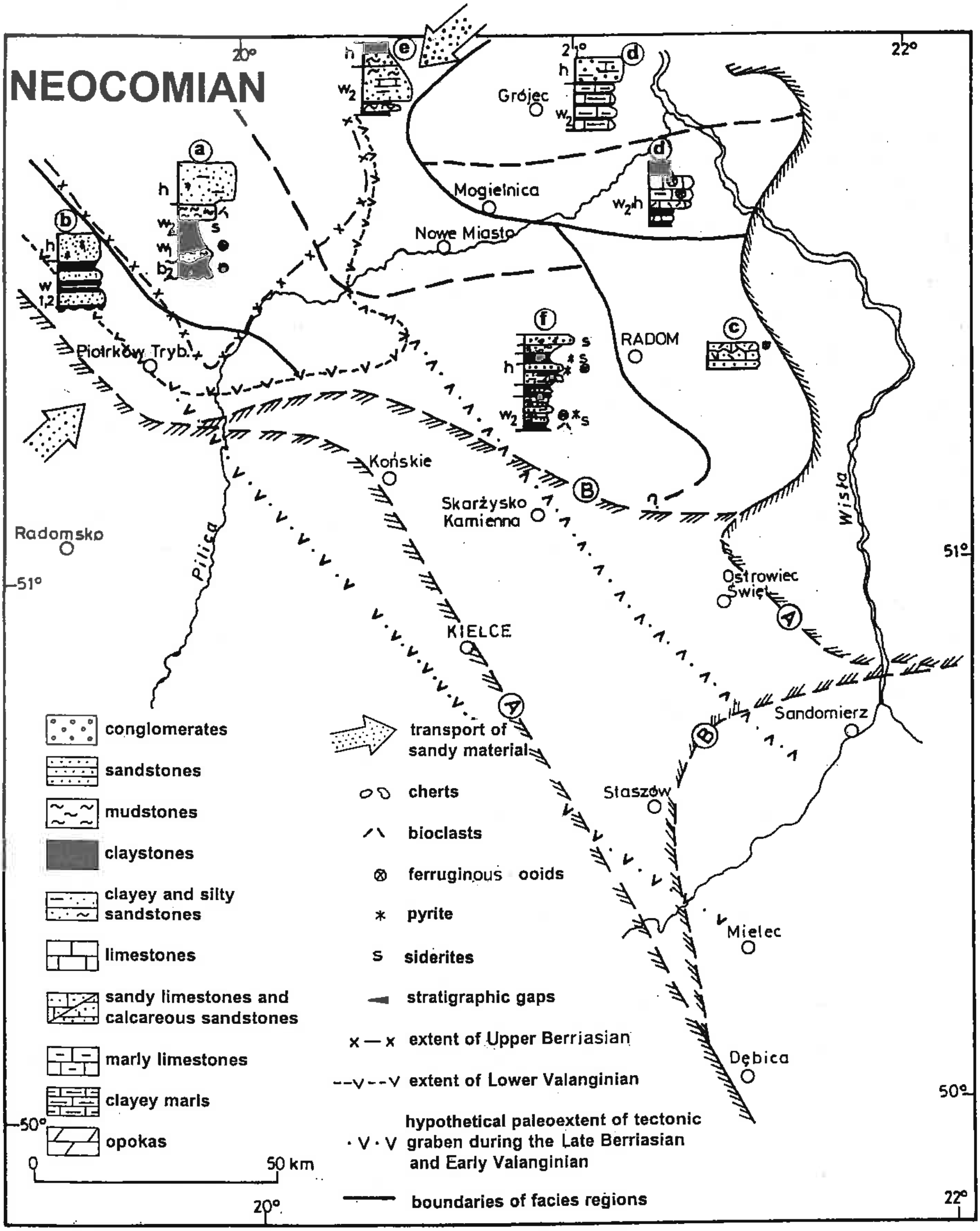

Fig. 2. Facies pattern of Neocomian deposits

b_2 — Upper Berriasian, w_1 — Lower Valanginian, w_2 — Upper Valanginian, h — Hauterivian; other explanations see Fig. 1

Wykształcenie facjalne osadów neokomu

b_2 — berias górny, w_1 — walanżyn dolny, w_2 — walanżyn górny, h — hoteryw; pozostałe objaśnienia na fig. 1

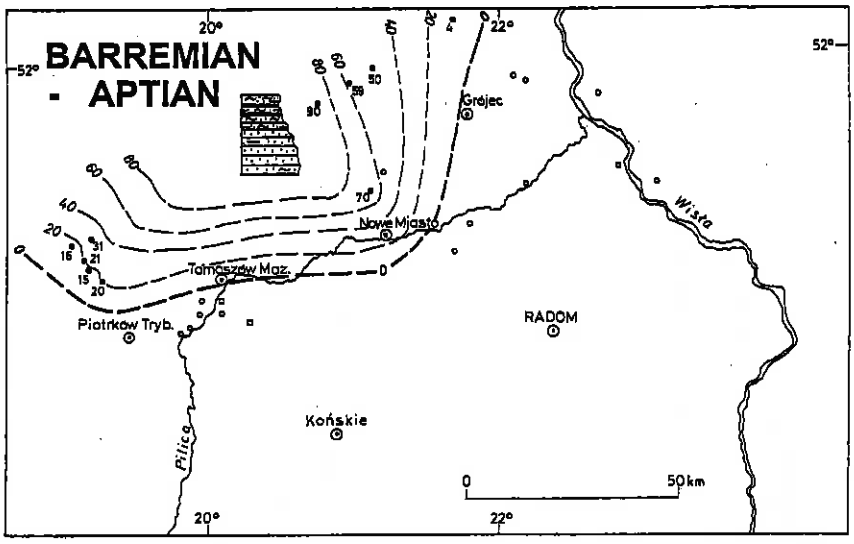

Fig. 3. Thickness and facies patterns of Barremian and Aptian deposits
Explanations see Figs. 1 and 2

Rozkład miąższości i wykształcenie facjalne osadów barremu i aptu
Objaśnienia na fig. 1 i 2

Occurrence of such structures trending NW–SE is known (M. Bac-Moszaszwili, A. Morawska, 1975; S. Marek, 1988) from the central part of the trough and from the area of the East European Craton (Płońsk, Żuromin and Dębe grabens)[1].

Upper Valanginian, developed similarly as underlying deposits, is found with a stratigraphic gap embracing the *Polyptichites* Zone. In the Tomaszów Syncline it is developed as clays with sideritic concretions, overlain by mudstones with limestone concretions and with skeletal detritus of bivalves and boreal ammonites (section **a** in Fig. 2). Hauterivian was poorly documented by J. Lewiński, and due to revision of the species *Dichotomites bidichotomus* (J. Kutek *et al.*, 1987) it lacks credible documentation. Hauterivian age is considered for mudstones and sandstones with glauconite, lying in continuity with the uppermost Valanginian and underlying the sandstones without glauconite and fragmented fauna.

Upper Valanginian and Lower Hauterivian display much greater extent towards the NE, where they rest on various Kimmeridgian deposits (S. Cieśliński, W. Pożaryski, 1970), and towards the SE in the Dębica region (S. Geroch *et al.*, 1972; W. Moryc, 1996). Erosion preceding the Late Valanginian have caused stronger denudation in the SE, and therefore evidencing probably more intensive uplift transverse to the trough's axis there. Similar tendencies have been noted towards the end of Jurassic (J. Kutek, 1994*a*). Facies pattern is quite complex (Fig. 2), which could result from the superimposed activity of two faults transverse to each other: Tomaszów Mazowiecki–Nowe Miasto Fault (downthrown northern limb) and Nowe Miasto–Radom–Iłża zone (downthrown SW limb). Earliest Lower Cretaceous transgressive deposits preserved between Grójec, Radom and Wisła river are of shallow-water type — they represent a zone of carbonate platform with more turbulent deposition in the south (winnowings, ooids, bioclasts, high clastic material contents — section **c** in Fig. 2). In the Grójec Fault area limestones lose their sandy admixture whereas clay material content increases (section **d** in Fig. 2). In the northern periphery strongly sandy facies occur, indicating existence of currents coming down from relatively elevated East European Craton into the Mid-Polish Trough in the Mszczonów region (section **e** in Fig. 2).

Siliciclastic fine-grained deposits (clays, mudstones) occur in the central part of the trough and approximately correspond to the areas of greater thickness (Tuszyn area, Tomaszów Syncline, area south and south-west of Radom). Sideritic concretions, ooids, cherts and spongiolitic interlayers occur there. On one hand such a pattern indicates the proximal occurrence of shallow-water areas, perhaps even land, on the other, is an evidence of relatively deeper depositional environment (fine-clastic facies, spongiolites, cherts).

Total thickness of Neocomian deposits is small, reaching 80 m in the Tomaszów Syncline (Fig. 1). South of Pilica river the main subsidence axis approaches the Nowe Miasto–Iłża

[1]It is characteristic, that within the grabens open marine fine-clastic facies occur: Berriasian clays in the Tomaszów Syncline, or even limestones with bivalve and gastropod faunas (in the Warsaw Syncline). In lower Valanginian finer deposit fraction is observed in grabens than on their flanks. Therefore, considering these grabens as strictly synsedimentary is difficult to be accepted, as with such a small width versus lenght ratio, facies pattern should be opposite: the grabens would be filled with coarser fractions, derived from the shoulders. High water turbulence of bottom currents in narrow depressions would also preclude deposition of low-energetic facies. Only assuming, that the troughs developed after Berriasian, during regression, we can explain such facies pattern. Development of grabens could save from erosion small fragments of originally very vastly spread depositional cover (M. Bac, pers. comm.). In early Valanginian higher subsidence existing over a buried tectonic trough could result in greater water-depth and in deposition of finer fractions.

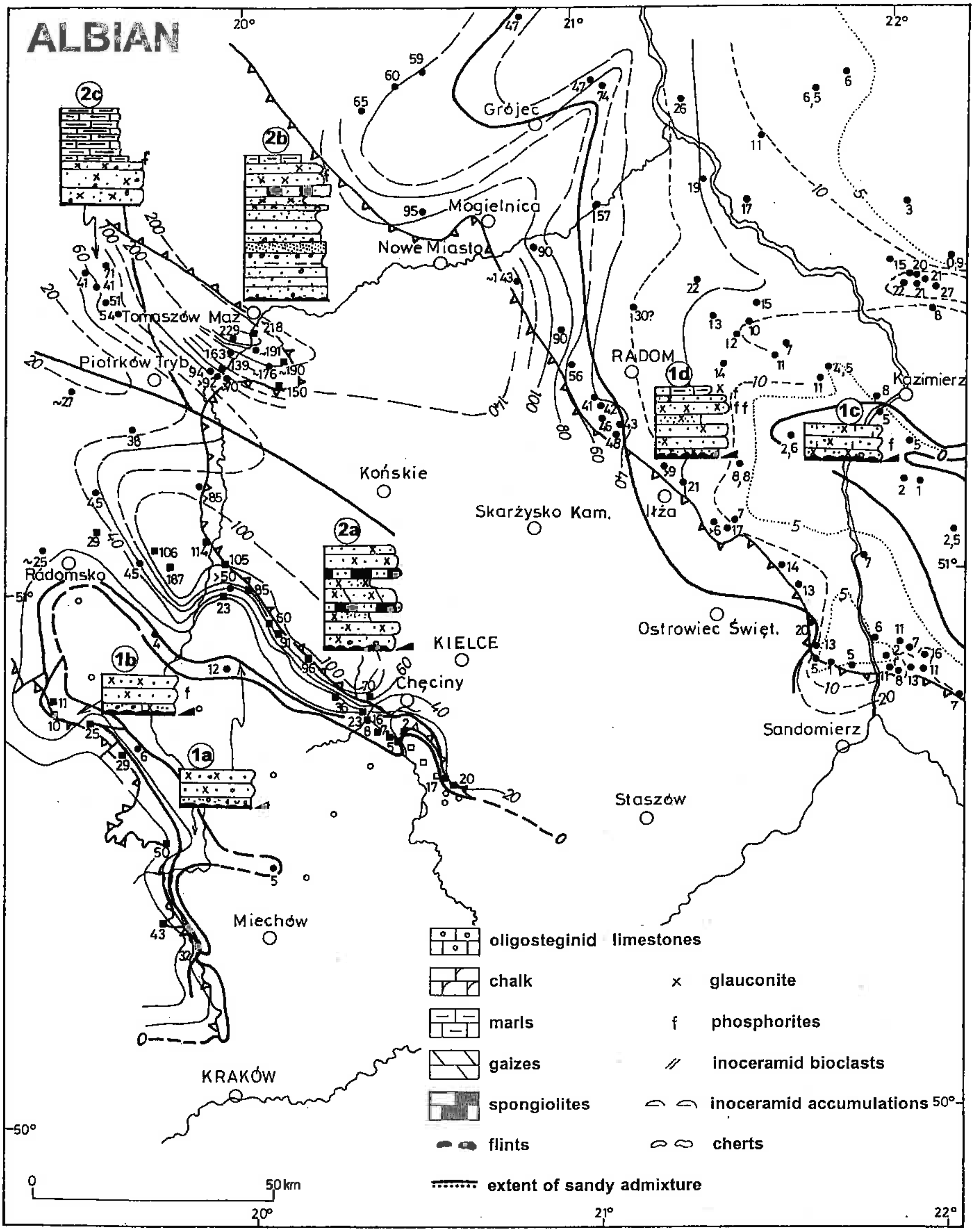

Fig. 4. Thickness and facies patterns of Albian deposits
Explanations see Figs. 1 and 2

Rozkład miąższości i wykształcenie facjalne osadów albu
Objaśnienia na fig. 1 i 2

line, suggesting activity of this tectonic zone (see M. Hakenberg, J. Świdrowska, 1997).

BARREMIAN–APTIAN

Hauterivian deposits constitute a regressive member of the Lower Cretaceous succession, preceding another period of denudation, which embraced most of the region in the Barremian and Aptian (Fig. 3). In the northern part of the investigated area, between presumed Hauterivian and Upper Albian rocks, stratigraphically undocumented clastic deposits were recognised (A. Witkowski, 1969; B. Don, 1973; K. Mrozek, 1975; A. Raczyńska, 1979; R. Marcinowski, S. Rudowski, 1980; S. Marek, 1983). In the Polish Lowlands, where these deposits occur in analogous position in the section, they have been ascribed to the Mogilno Formation. It is divided into following members (from the bottom): sands — Pagórki Member, mudstones and sands — Gopło Member, and sands — Kruszwica Member (A. Raczyńska, 1979; S. Marek, 1983). The age of whole formation is thought to be Barremian to Middle Albian (*op. cit.*).

In the investigated area all three members of the Mogilno Formation have been found only in few wells near Tuszyn and north of Mogielnica (K. Mrozek, 1975; S. Marek, 1983). In the Tomaszów Syncline, between probable Hauterivian and Upper Albian rocks, only sand series was recorded. These are so-called Biała Góra sands (A. Witkowski, 1969). According to R. Marcinowski and S. Rudowski (1980) they belong to the upper (Kruszwica) member of the Mogilno Formation and are of Middle Albian age, possibly ranging also to Lower and Upper Albian. According to this and to the opinion of A. Raczyńska (1979) the Pagórki and Gopło Members of the Mogilno Formation are in this paper considered to fall into the Barremian–Aptian age interval.

ALBIAN

Transgressive Albian deposition started in the investigated area in different time. The Middle Cretaceous transgression could have started in the Tomaszów Syncline area already in Early Albian (R. Marcinowski, S. Rudowski, 1980), and following an extension of the Mid-Polish Trough towards the south-east, they could spread simultaneously outwards towards the present Holy Cross Mountains on one side, and towards the Warsaw–Lublin Syncline on the other. In the northeastern margin of the Holy Cross Mountains there is evidence (Rachów section) of at least Middle Albian age of this transgression (J. Samsonowicz, 1925; S. Cieśliński, 1959*a*, *b*, 1976; S. Cieśliński, W. Pożaryski, 1970; R. Marcinowski, A. Radwański, 1983, 1989; R. Marcinowski, I. Walaszczyk, 1985).

Latest of all — in Late Albian and in some places even in Early Cenomanian, the transgression occurred in the southwestern margin of the Holy Cross Mountains (S. Cieśliński, 1959*a*; M. Hakenberg, 1969, 1978; R. Chlebowski *et al.*, 1977) and in the Kraków–Częstochowa flank of the Miechów Syncline (S. Z. Różycki, 1937, 1938; W. C. Kowalski, 1948; R. Marcinowski, 1974).

Albian deposits consist mainly of sands and non-calcareous sandstones. Only in the northeastern margin of the Holy Cross Mountains and in the Tomaszów and Warsaw synclines the sandstones are marly in the uppermost part of the Albian, and less commonly in the whole section. Other components are: common glauconite, interlayers of siliceous rocks (gaizes, spongiolites, sandstones with siliceous matrix) and phosphorites in upper part of the sections.

Distribution of these components, resulting from their spatial relationship with the source areas and regions of various subsidence, makes it possible to distinguish two major facies regions: 1 — shallower, situated nearer the shore-line, and 2 — deeper, located further seawards. When considering this problem, it must be remembered that the Albian deposits were sedimented during a transgressive cycle, which implies i.a. that all the sections contain near-shore sediments in their lower parts.

In the first of the distinguished regions proximal deposits were sedimented in a shallow-water area with a small subsidence. Their thickness is small (Fig. 4, section 1), which probably resulted among other factors from shorter period of deposition (end of Late Albian) in the near-shore part of the basin. In this region (the area of the present Miechów Syncline) subordinate facies zones can be distinguished with the sedimentation of: (1a) sands and non-calcareous sandstones with glauconite, deposited close to the shore-line, in a belt located around peninsular area without Albian deposits, in environmental conditions rather unsuitable for faunal development, and (1b) sands and non-calcareous sandstones with glauconite and phosphorites. The latter zone is also located near the shore-line, although conditions for faunal development were better than in the previous area.

Two further subregions characterised by the occurrence of admixture of calcium carbonate occur in the NE margin of the Holy Cross Mountains and in the Warsaw–Lublin Syncline. These are: (1c) marly sandstones with glauconite and phosphorites — facies surrounding a small area lacking Albian deposits south-east of Kazimierz, with small sediment thicknesses (up to 5 m) and with suitable conditions for faunal development, and (1d) sands and non-calcareous sandstones, with glauconite and phosphorites in the upper part of the section, and with sandy marls topped by phosphorites, deposited further from the shore, in an area with greater subsidence in the north-west part of the subregion (Fig. 4).

The second region (2) is characterised by the occurrence of silica within gaizes, spongiolites, siliceous sandstones and spicules of siliceous sponges. Abundant occurrence of sponges indicates greater distance from a shore-line and increased depth (J. Uberna, 1967; M. Hakenberg, 1969, 1978). Three subordinate facies zones have been distinguished here: (2a) in the outer fringe of a peninsula area, with sands and non-calcareous sandstones with (or rarely without) glauconite, with sponges and interlayers of gaizes, spongiolites and quartzitic sandstones, and (2b) in the NE margin of the Holy Cross Mountains and in the Warsaw Syncline, with sections similar

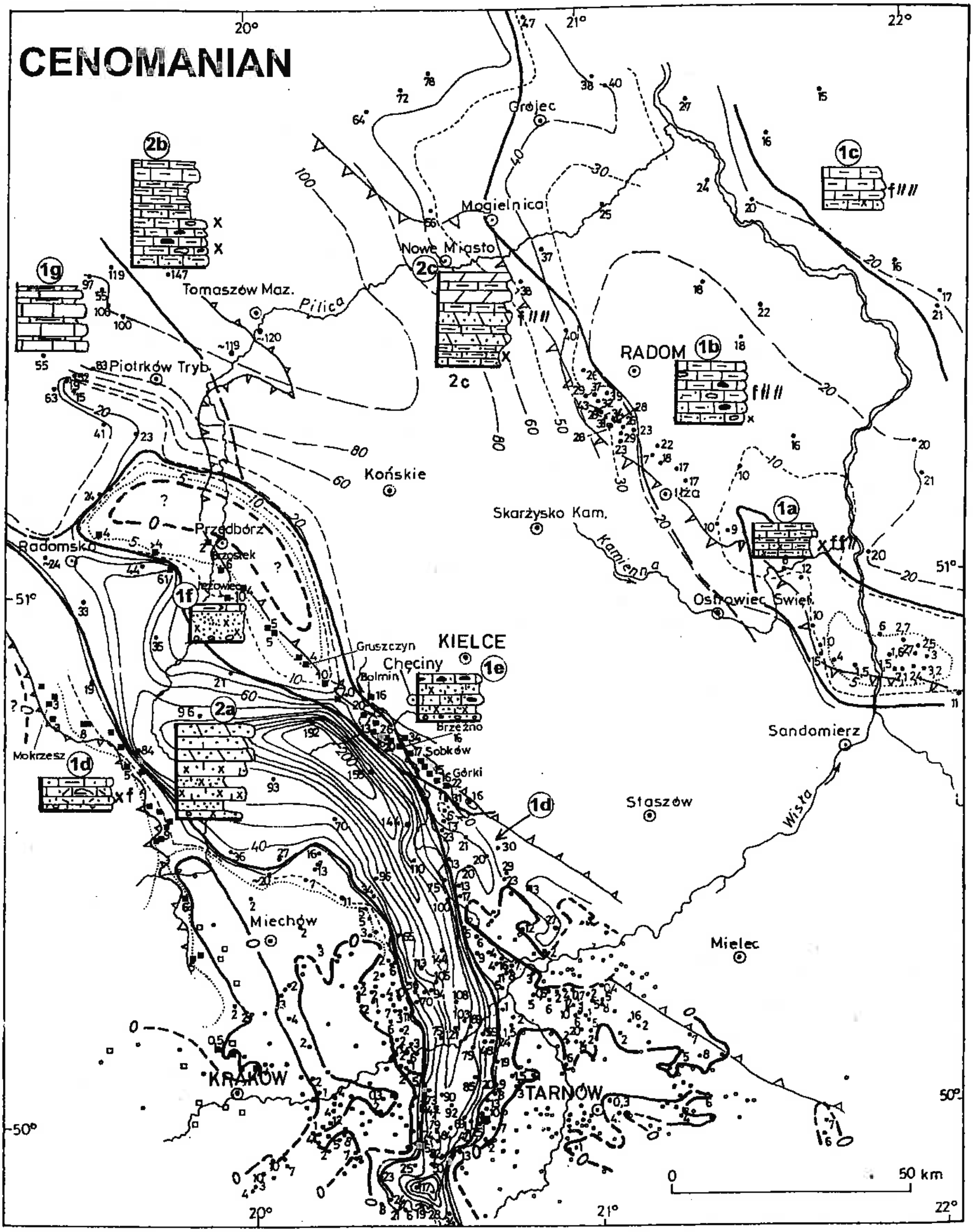

Fig. 5. Thickness and facies patterns of Cenomanian deposits
Explanations see Figs. 1, 2 and 4

Rozkład miąższości i wykształcenie facjalne osadów cenomanu
Objaśnienia na fig. 1, 2 i 4

to those in the subregion 2a, but additionally with phosphorites and sandy marls at the top (Fig. 4). An area of the Albian occurrence has been distinguished also in the Tomaszów Syncline (2c), with fine-grained, poorly cemented, horizontally or obliquely bedded sandstones with gravel horizons in the lowermost part of the section (so-called Biała Góra sands), overlain by spongiolitic sandstones with phosphorites, and — higher in the section — by gaizes and gaizy sandstones, with marly sandstones with glauconite at the top (A. Witkowski, 1969; S. Cieśliński, W. Pożaryski, 1970). Wells Tuszyn 1, 2, 3, 5 and 9 also belong to the 2c region. In the bottom part of the sections sandy deposits with small amount of glauconite (probably equivalent of the Biała Góra sands) occur, and the Upper Albian is developed as clayey marls with phosphorites in the bottom (K. Mrozek, 1975).

It can be assumed, that during the Albian initially a shallow, near-shore siliciclastic shelf environment prevailed, with periods of non-deposition (phosphorites), later followed by deeper siliciclastic shelf with gaizes and spongiolites.

CENOMANIAN

Near the Albian/Cenomanian boundary, uplifting movements took place, at least in the present outcrop areas on both flanks of the Miechów Syncline. They are indicated by the occurrence of conglomerate facies in the bottom part of the Cenomanian in numerous sections in this region (R. Marcinowski, 1974; M. Hakenberg, 1978, 1986). This pulse was relatively short-lived, and was followed by subsidence and resumed Middle Cretaceous transgression.

Cenomanian deposits have a sandy-calcareous development (only exceptionally non-calcareous), with glauconite and in places with phosphorites. The amount of sandy material, glauconite and phosphorites usually decreases towards the top. Interlayers and concentrations of siliceous rocks of biogenic origin, opokas, gaizes and flints, are common.

Comparison of thickness maps of Albian and Cenomanian deposits (Figs. 4 and 5) shows continuity of the general tendencies in the northeastern part of the investigated area (northeastern Mezozoic margin of the Holy Cross Mountains and the Warsaw–Lublin Syncline) and drastic, even opposite changes in the southeastern area (Miechów Syncline with its both flanks and the Radomsko Elevation) (M. Hakenberg, 1986).

The areas of the Warsaw–Lublin Syncline and the northeastern margin of the Holy Cross Mountains represented, similarly as during the Albian, a zone of smaller sediment-thicknesses (lower subsidence). A subordinate elevated structure emerges here, corresponding spatially to large extent to the northwestern part of the Radom–Kraśnik Elevation. In its southwestern flexural flank, gradient of a deposit-thickness increase is much more evident than in the north-east wing. An area of lowest subsidence (1a) has been distinguished here (Fig. 5), with relatively strong input of detrital quartz (S. Cieśliński, 1959*b*; I. Walaszczyk, 1987; R. Marcinowski, A. Radwański, 1989). It is a shallow-water area with numerous fauna (inoceramid shells and phosphorites) and slow sedimentation (phosphorites).

In another facies area (1b), surrounding the former one from the north, west and south, the deposition occurred in greater water-depths. Cherts and flints with sponge spicules commonly occur here in predominantly marly limestones with smaller input of detrital quartz (A. Krassowska, E. Witwicka, 1983; A. Krassowska, 1989). Sedimentation was not fast, with environmental conditions suitable for some organisms (numerous phosphorites and abundant debris of inoceramid shells).

Facies zone located northeasternmost (1c) was characterised by a low subsidence (Fig. 5) and (excluding the bottom part of the sections) almost completely lacking sandy material. Sedimentation was slow (occasionally appearing phosphorites) and accompanied by abundant occurrence of inoceramids. It took place in smaller water-depths than in the previously described zone (lack of sponge remains).

The area of the present Miechów Syncline was occupied in the end of Albian by a peninsula, whose northwestern extension reached Gidle and whose base hides beneath the marginal Carpathian Overthrust (M. Hakenberg, 1978, 1986). In the beginning of the Cenomanian this peninsula was relatively quickly cut along its axis by a narrow, but active S-shaped zone of subsidence with considerable thickness of Cenomanian deposits (M. Hakenberg, 1986). In the southern part of the former Albian peninsula four areas remained free from deposition also during the Cenomanian. Together with the zones of small sediment thicknesses they constitute two relatively close regions of low subsidence, separated by the above-mentioned zone of higher subsidence. Shallow-water conditions, favouring development of biotas, and low subsidence were characteristic for the region 1d, surrounding four southern areas devoid of sedimentation (Fig. 5).

Slightly increased water-depths, documented by the occurrence of gaizes and flints, can be ascribed to the facies region 1e (from Górki through Sobków to Bolmin), although the subsidence and rate of deposition were slightly higher then in the previously described region (1d), and the conditions of organic development, mainly inoceramids, echinoderms and foraminifers, were similar.

Common feature of the following facies region 1f is a lack of carbonate content and relatively monotonous sediment development. The section is composed of sands and poorly cemented sandstones with glauconite, often cross-bedded with traces of deposit-feeders activity (*Chondrites*), devoid of other faunal remains. These rocks have been recognised in outcrops along the southwestern margin of the Holy Cross Mountains between Brzeźno and Przedbórz and in the southern part of the Radomsko Elevation (M. Hakenberg, 1978). Completely non-calcareous development of the deposits in the described facies region is very unusual for the Cenomanian sediments not only in Poland but even in a broader scale. It may be related to some degree with the completely non-calcareous development of the Albian sandstones (and their substrate) on which the Cenomanian sands were deposited, but this is not a sole explanation. It seems, that some other factors must have been involved here, that created unsuitable

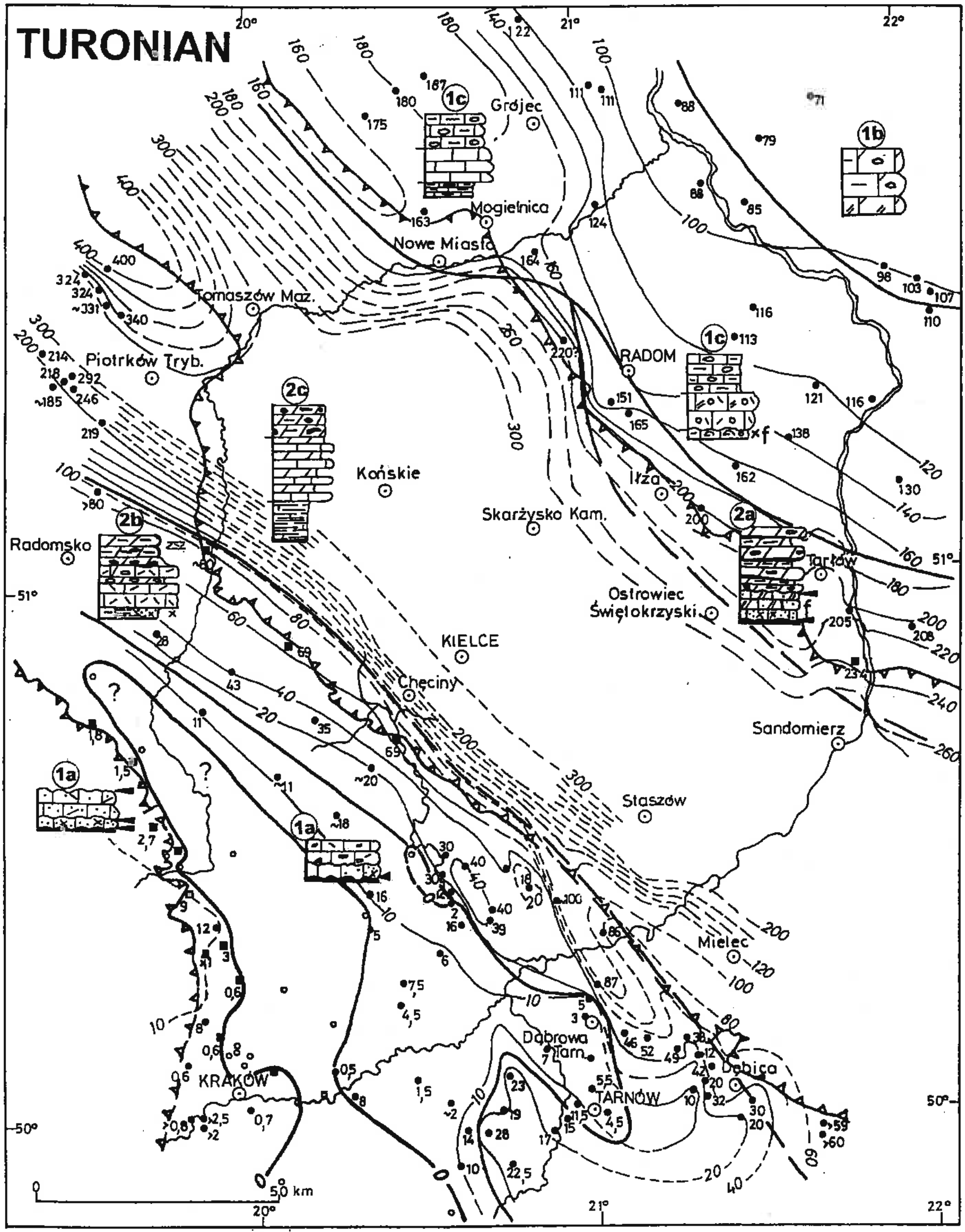

Fig. 6. Thickness and facies patterns of Turonian deposits
Explanations see Figs. 1, 2 and 4

Rozkład miąższości i wykształcenie facjalne osadów turonu
Objaśnienia na fig. 1, 2 i 4

conditions for development of organisms with calcareous shells, or prevented their fossilization.

Subsidence and resulting deposit thicknesses were rather low in the southeastern part of the investigated area, and very low (thicknesses between 2 and 6 m) in the zone north-west of Gruszczyn. Due to a clear decrease of sediment thickness towards the north in the last of the above listed sections (Jeżowiec — 10 m, Brzostek — 6 m, Góra Majowa near Przedbórz — 2 m) occurrence of a zone with zero thickness of the Cenomanian deposits is considered possible north of Przedbórz and west of Mokrzesz. A zone north of Przedbórz to a large extent would represent the highest known thickness of Albian deposits (exceeding 100 m). This phenomenon can be considered as another manifestation of the subsidence inversion in Cenomanian versus Albian, only with the opposite effect, than it was in the central part of the Miechów Syncline.

In the northwestern part of the investigated area, a facies zone 1g without sandy terrigenous material was recognised, where organodetrital limestones with interlayers of calcareous clays were deposited (K. Mrozek, 1975) in a relatively shallow-water basin (lack of sponge-derived silica) and in conditions of relatively slow subsidence.

Two of the above regions of relatively low subsidence (1d and 1f) were constituting relatively stable frames of a narrow S-shaped zone with higher subsidence, located in the central part of the present Miechów Syncline. In this zone (2a) the lithological development indicates, that the deposition occurred in a deeper marine environment (numerous gaize interbeds), in the conditions of rapid sedimentation, unsuitable for the development of benthic organisms with calcareous shells.

Two other zones of higher subsidence and faster sedimentation in deeper-water conditions are related to the peripheral areas of the Holy Cross segment of the Mid-Polish Trough (Fig. 5). The Cenomanian sections of the Tomaszów Syncline (2b) (vicinity of Zarzęcin and Swolszowice — A. Witkowski, 1969; Będków 1 well — K. Mrozek, 1975) indicate a relatively high subsidence (large sediment thickness) and an early stage of sedimentation in deeper-water conditions (cherts and flints), although initially with the supply of sandy material.

Second region, neighbouring from the north-east the hypothetical area of highest subsidence (with subsequently eroded Cenomanian deposits), is a facies zone 2c, ranging from north of Nowe Miasto to Ostrowiec Świętokrzyski (Fig. 5). In this region sedimentation took place in relatively deep environment, as indicated by large amounts of sponge-derived silica, forming one of components of gaizes and opokas (J. Uberna, 1967; S. Cieśliński, W. Pożaryski, 1970). Subsidence was here higher than in the area neighbouring from the NE. The conditions were suitable for development of some organisms, with a relatively slow deposition as evidenced by abundant debris of inoceramid shells and phosphorites.

When characterising the spatial pattern of sedimentary environments, it must be stressed, that the central part of the Miechów Syncline became an area of sedimentation as late as in the Cenomanian. The deposition began in an environment of a shallow siliciclastic-carbonate shelf with organodetrital material which changed due to a rapid subsidence into deep siliciclastic shelf with gaizes. The zone was limited from the NE and SW by shallow-shelf environments, spatially related to the four areas situated in the south and devoid of sedimentation during the Cenomanian. At the turn of the Albian/Cenomanian a short-lived regressive pulse occurred evidenced by conglomerate interbeds in the bottom part of the Cenomanian. These were siliciclastic-carbonate shelf systems with a considerable accumulation of organodetrital material. The only exception was a siliciclastic shelf between Nida and Pilica, located relatively close to the hypothetical area north of Przedbórz without sedimentation in the Cenomanian. Further towards the north-east, a deep siliciclastic-carbonate shelf was recognised. In the East European Craton area it passed into a carbonate shelf almost devoid of terrigenous quartz.

TURONIAN

The area of prevailing denudation (or perhaps only non-deposition) stretches as a narrow strip in the south-west, between Milianów and Niepołomice (Fig. 6). The facies pattern consists of clear belts trending NW–SE, controlled by the subsidence rate, which indicates, that it did not keep pace with the accumulation rate. Increased accomodation space is expressed by the development of deeper-water facies.

Shallower marine facies (1) were deposited in the vicinity of the afore-mentioned sediment-source area in the south-western part of the investigated region, and on the other side, in its northeastern part (Fig. 6). Deeper-water facies are located towards the centre of the Holy Cross segment of the trough, being there characterised by the occurrence of rocks of the opoka type (2). Turonian deposits display carbonate-siliceous development, in places with the admixture of detrital quartz in the bottom part of the sections.

The shallowest-water sequences (1a) surround the region originally devoid of deposits, and reach a thickness of a dozen or so metres. The sections most commonly are composed of sandy, biogenic (inoceramid remains) limestones, with stratigraphic gaps and often observed winnowing surfaces. At the boundary with the Cenomanian a hardground occurs. Stratigraphic gaps have been documented in the bottom of the Turonian, between the Turonian zones *labiatus* and *lamarcki* and in the top of the Turonian (I. Walaszczyk, 1992). The sections in the eastern and western slopes of the Turonian peninsula slightly differ. In the east the limestones are clearly biogenic and more commonly devoid of sandy admixture. In their upper part flints occur, possibly indicating deepening of the basin. It is the area named by I. Walaszczyk (1992) the Kraków Swell.

In the northeastern margin of the area located behind the line of the Wisła river another shallow-water zone stretches (1b), where the lithological variability in the section is relatively small. The sequence consists of limestones and chalk-like marly limestones with cherts in the bottom part containing scattered fibres of inoceramids (A. Krassowska, 1989). They were deposited in stable conditions of low subsidence (thickness up to 100 m).

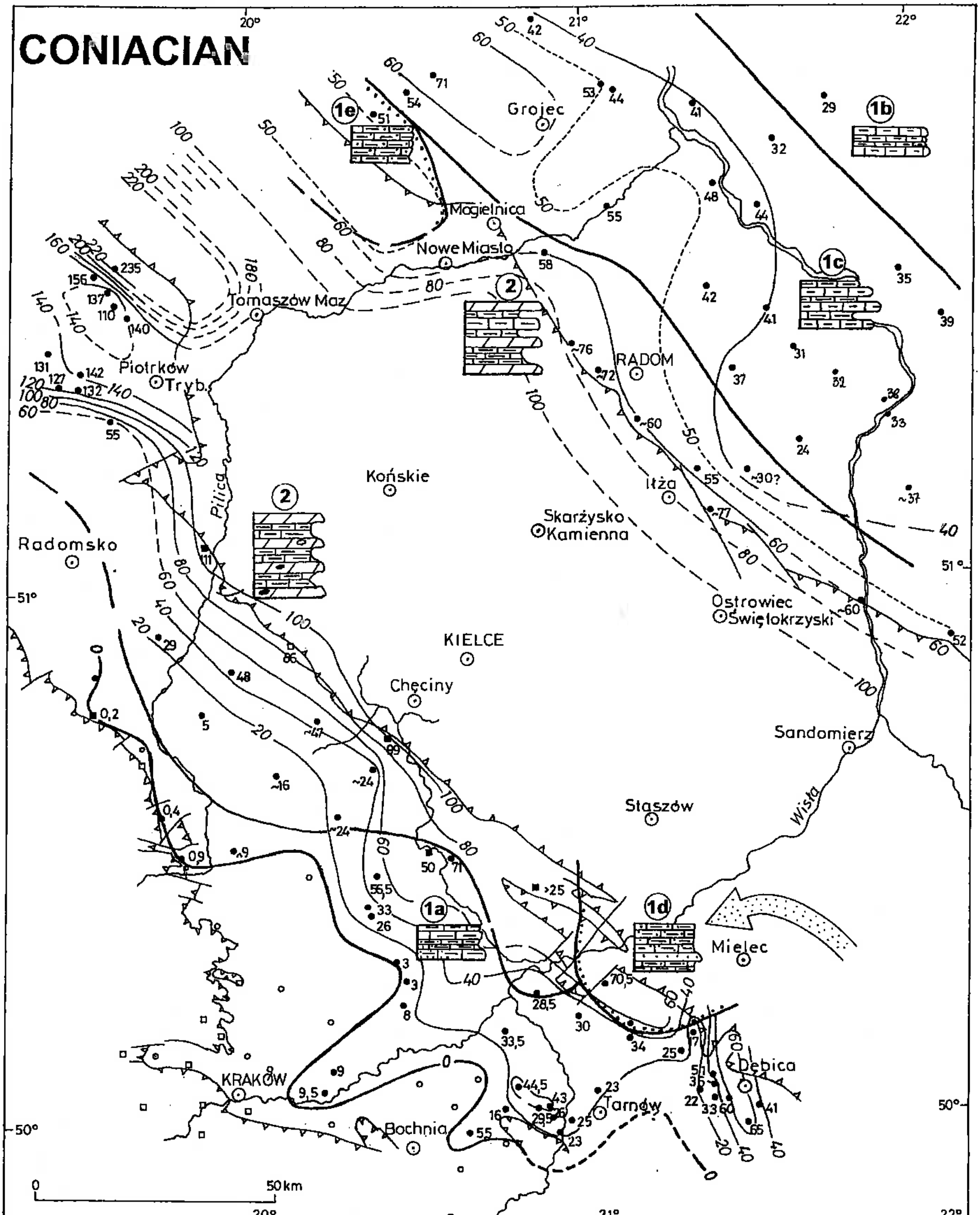

Fig. 7. Thickness and facies patterns of Coniacian deposits
Explanations see Figs. 1, 2 and 4

Rozkład miąższości i wykształcenie facjalne osadów koniaku
Objaśnienia na fig. 1, 2 i 4

The area stretching from Grójec to Puławy (1c) with the Turonian thickness of 100–150 m is characterised by a tri-partite section: Lower Turonian is developed as marly inoceramid-oligosteginid limestones (*labiatus* Zone) with abundant glauconite, phosphorite concretions and hardgrounds, overlain by oligosteginid-inoceramid limestones, passing towards the top into marly limestones with cherts (I. Walaszczyk, 1992).

It can be assumed, that in the successively distinguished facies zones (2) sedimentation took place in deeper-water conditions, which is indicated by the occurrence of opokas in the higher part of the sections. First of these zones (2a) represents the northeastern margin of the Holy Cross Mountains between Radom and Annopol, where the thickness of Turonian deposits changes between 150 and 300 m. The sequence begins with sands and calcareous sandstones with glauconite and phosphorite concretions, lying with a gap on the Cenomanian (hardground). Higher, with a gap between the zones *labiatus* and *lamarcki*, a series of opokas occur, more or less marly or silicified with cherts and well- or poorly-bedded chalcedonites. There is thus some similarity between this zone and zone 1a expressed in the occurrence of the same stratigraphic gaps (I. Walaszczyk, 1992) and in the occurrence of siliciclastic deposits and glauconite in the bottom part. The only differences consist in occurrence of limestones and phosphorites. The earlier trend of relatively low subsidence prevailing in the Albian and the Cenomanian was continuing during the Early Turonian.

For a long time the existence of synsedimentary Tarłów Graben (Fig. 6) has been noted in this region (J. Samsonowicz, 1934; W. Pożaryski, 1938, 1948), limited from the east by the Wisła dislocation, and from the west by the Ożarów flexure. The Tarłów Graben in Early and partly in Middle Turonian is characterised by continuous sedimentation, while on its shoulders stratigraphic gaps occur (I. Walaszczyk, 1992). Here, the opoka lithofacies appear at its earliest, as early as in the *labiatus* Zone. Later on, the facies are rather uniform, however, until the end of Turonian clear sediment-thickness differences are noted. The exception is an occurrence of a unique detrital bryozoan limestones in the eastern part of the graben in Middle and Upper Turonian (*op. cit.*).

Next zone of sedimentation (2b) embraces northeastern part of the present Miechów Syncline and the SW-margin of the Holy Cross Mountains, and is characterised by sediment-thickness of dozen to about 100 m. The transition from Cenomanian to Turonian is relatively continuous; within carbonate-sandy or clayey deposits (M. Hakenberg, 1978). The bottom part of the Turonian is commonly characterised by higher amount of sandy admixture and by glauconite grains (M. Hakenberg, 1978; I. Walaszczyk, 1992). These deposits are overlain by limestones without sand, commonly organodetrital (in Skotniki — inoceramid-crinoid) and by marls and opokas. In the middle part of the section layers with cherts and flints are common. Towards the top, marly opokas become more important component of the section, with less numerous flints; beds of detrital limestones are also present. Triplicity of the section is clear: limestones, limestones with marly opokas with cherts and flints, marly opokas.

The beginning of the Turonian sedimentation is represented by a large lithological variability across the discussed facies zone. Following lithofacies can be traced along the outcrop belt in the SW-margin of the Holy Cross Mountains (from NW): marly limestones (as far as Wola Świdzińska), clays, in places with flints (from Krasocin to Brzeźno), sands with glauconite or calcareous sandstones (between Brzeźno and Korytnica), clays (Pysk, Górki) and limestones (Skotniki) (M. Hakenberg, 1978). There is thus a subordinate transversal facies variability.

In the central part of the basin (2c), about which one can infer mainly on the base of data from the Piotrków Trybunalski region, thickness of Turonian deposits in the Holy Cross segment of the trough considerably exceeded 200 m (probably ranging to about 300 m), and in the Rawa segment could have exceeded even 400 m. Similarly as in the above described zone triplicity of the succession can be recognised, but with lesser proportion of limestones in favour of opokas and clayey material. The section is composed of marly clays, thin-bedded limestones interlaying with opokas and marly opokas with flints (K. Mrozek, 1975).

In the south, in the area of Dębica and Sędziszów, the triplicity disappears, with the occurrence of marly opokas with flints and marly intercalations, and slightly further to the north (in the Stefanów area) opokas with cherts (W. Moryc, 1996).

Summarising the sedimentation history in terms of presumable depositional environments it can be stated that in the southwestern part of the investigated region, areas of shallow carbonate shelf systems persisted, with predominant amount of organodetrital components, detrital quartz admixture decreasing towards the north-east and increasing content of biogenic silica. Similarly stable depositional environments occur in the northeastern part of the area, located on the East European Craton. The main differences are lack of sandy terrigenous material and increased content of biogenic silica towards the south-west. The middle part, located in the extension of the Mid-Polish Trough, with higher subsidence, is occupied by deeper-water pelagic depositional environments with substantial admixture of sponge-derived silica.

CONIACIAN

Area devoid of the Coniacian deposits extends in the southwestern part of the investigated region, between Bochnia and Radomsko (Fig. 7). Its occurrence and eastern limit were deduced mainly on the basis of papers by I. Heller and W. Moryc (1984) and I. Walaszczyk (1992). The western boundary of the area is not clear due to epigenetic erosion.

Thickness of the Coniacian deposits in the Holy Cross segment of the Mid-Polish Trough gradually increases towards its axis, up to about 100 m in both outcrop belts contacting with the area of epigenetic erosion (Fig. 7). In the Rawa part of the trough greatest thickness (about 220 m) is observed in the area north-west of Tomaszów Mazowiecki,

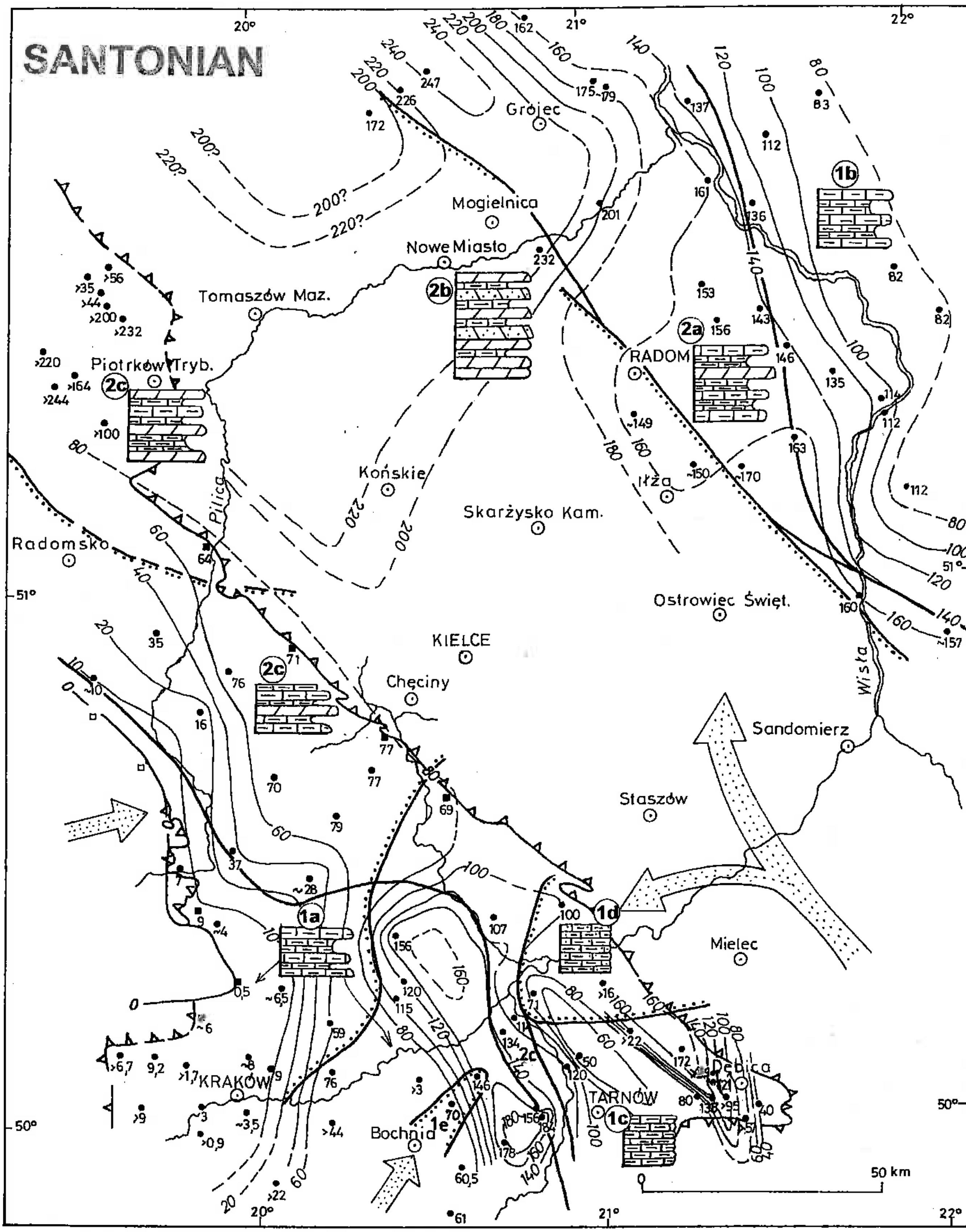

Fig. 8. Thickness and facies patterns of Santonian deposits
Explanations see Figs. 1, 2 and 4

Rozkład miąższości i wykształcenie facjalne osadów santonu
Objaśnienia na fig. 1, 2 i 4

with a second zone of increased thickness (up to about 70 m) located north-west of Grójec.

Shallower-water facies (1), deposited closer to the source area, have been recognised in extremely outer, relative to the Holy Cross segment of the trough, parts of the region: 1a — in close proximity to the afore-mentioned area without Coniacian deposits, 1b and 1c — in the northeastern part of the discussed area (NE of Radom), located on a stable substrate of the East European Craton. In the latter case, marly limestones were deposited in subregion located more outward and marly limestones and marls developed in the area closer to the trough (M. Jaskowiak-Schoeneichowa, A. Krassowska, 1983). Probably, these deposits represent pelagic, carbonate sedimentary environments. Similar facies, although with a substantial admixture of detrital quartz (I. Heller, W. Moryc, 1984; M. Jaskowiak-Schoeneichowa, A. Krassowska, 1983) occur also in two places closer to the probable trough's axis: 1d — west of Mielec and 1e — north-west of Mogielnica (Fig. 7).

Part of the Coniacian sections belonging to the facies zone 1a (located close to the sediment-source area), whose earlier stratigraphic position (R. Marcinowski, 1974) has been moved by I. Walaszczyk (1992) from Early Turonian to Middle Coniacian, consists of sandy glauconitic limestones with thickness not exceeding one metre. In other sections of this facies region, marls and marly limestones occur.

Facies considered as representing deeper marine conditions (deeper pelagic facies) and with higher subsidence (2) occur symmetrically, closer to the trough's axis. These are opokas, marly limestones and marls differing from the previously described deposits mainly by the presence of silica content and siliceous sponge remains.

SANTONIAN

In the Santonian the area without deposition, located north of Kraków (Fig. 8), decreased when compared to the Coniacian one. The deposit thickness increase concentrically towards the trough. In the southern part of the investigated area, between Bochnia and Dębica, this simple pattern is complicated by the occurrence of two zones with greater thickness (up to 160–180 m), separated by an elongated area with thickness decreasing to 50 m (Fig. 8).

Shallower-water facies (1) — marls and marly limestones, similarly as earlier, are located either in the vicinity of the area north of Kraków devoid of Santonian deposits (1a), or on the slope of the East European Craton (1b). Additionally, in the southeastern part of the present Miechów Syncline near Bochnia and between Tarnów, Dębica, Mielec and the inlet of Nida river into Wisła, facies with increased amount of terrigenous material have been recognised (I. Heller, W. Moryc, 1984; W. Moryc, 1996). Marls occur near Tarnów (1c) and sandy marls west of Mielec (1d) and north-east of Bochnia (1e).

Facies deposited closer to the basin axis (2a, 2b and 2c) are characterised by the occurrence of gaizes and opokas within marly deposits. It is interpreted that silica, being one of the rocks components, is of sponge origin, thus indicating a deeper-water sedimentation.

The distribution of Santonian deposits containing detrital quartz, as well as other facies (Fig. 8), precludes (similarly as in the Coniacian) the possibility of transport direction from the north-east — from the East European Craton. It seems, that in the north and central parts of the Miechów Syncline the detrital components were derived from the west and south-west — from the Kraków Swell towards the Mid-Polish Trough (see also I. Walaszczyk, 1992). Source areas of the detrital quartz in the southern part of the Miechów Syncline (vicinity of Bochnia and west of Mielec) could have been located south-west of Bochnia — actually a region beneath the Carpathian thrusts, and east of Staszów–Mielec line, in the area of the present Lower San Anticlinorium, respectively.

Detrital material reached the zone of the present northeastern margin of the Holy Cross Mountains from the direction of the contemporary Mid-Polish Trough (Fig. 8).

CAMPANIAN

During the Campanian the deposit thickness was still increasing in both flanks of the trough towards its axis (Fig. 9). Also the facies are arranged centripetally. Shallower-water areas (1) occur closer to the Kraków Swell (1a — marls and marly limestones) and near the edge of East European Craton (1c — marls and marly limestones). Further east chalk was being deposited (1b). Additionally, in the region west of Mielec, closer to the trough, similarly as in the Coniacian and Santonian, a zone 1d has been distinguished, in which sandy marls were being deposited (W. Moryc, 1996).

Deeper-water facies (2), forming closer to the Mid-Polish Trough in its both flanks, are developed as marls, opokas and gaizes in some places (2a and 2b). North of Jędrzejów a multiple, cyclic interlaying of marls and opokas has been observed (W. Machej, 1970). South of Tarnów occurs a zone of deposits originated in deeper-water conditions (2c — marly limestones with flints and opokas) (I. Heller, W. Moryc, 1984).

Location of source areas, indicated by the occurrence of sandy quartz fraction, has changed when compared to the Santonian. The source of sandy terrigenous material in the area south-west of Bochnia has disappeared. In all other cases, the location of sediment-source areas and probable transport directions of sandy material seem to be similar.

The depositional environments were similar to those distinguished in the Coniacian and Santonian. The only difference was that during the Campanian the sedimentation extended over the whole area.

MAASTRICHTIAN

Due to a later epigenetic erosion the Maastrichtian sections are not complete. In comparison to older stages of Late

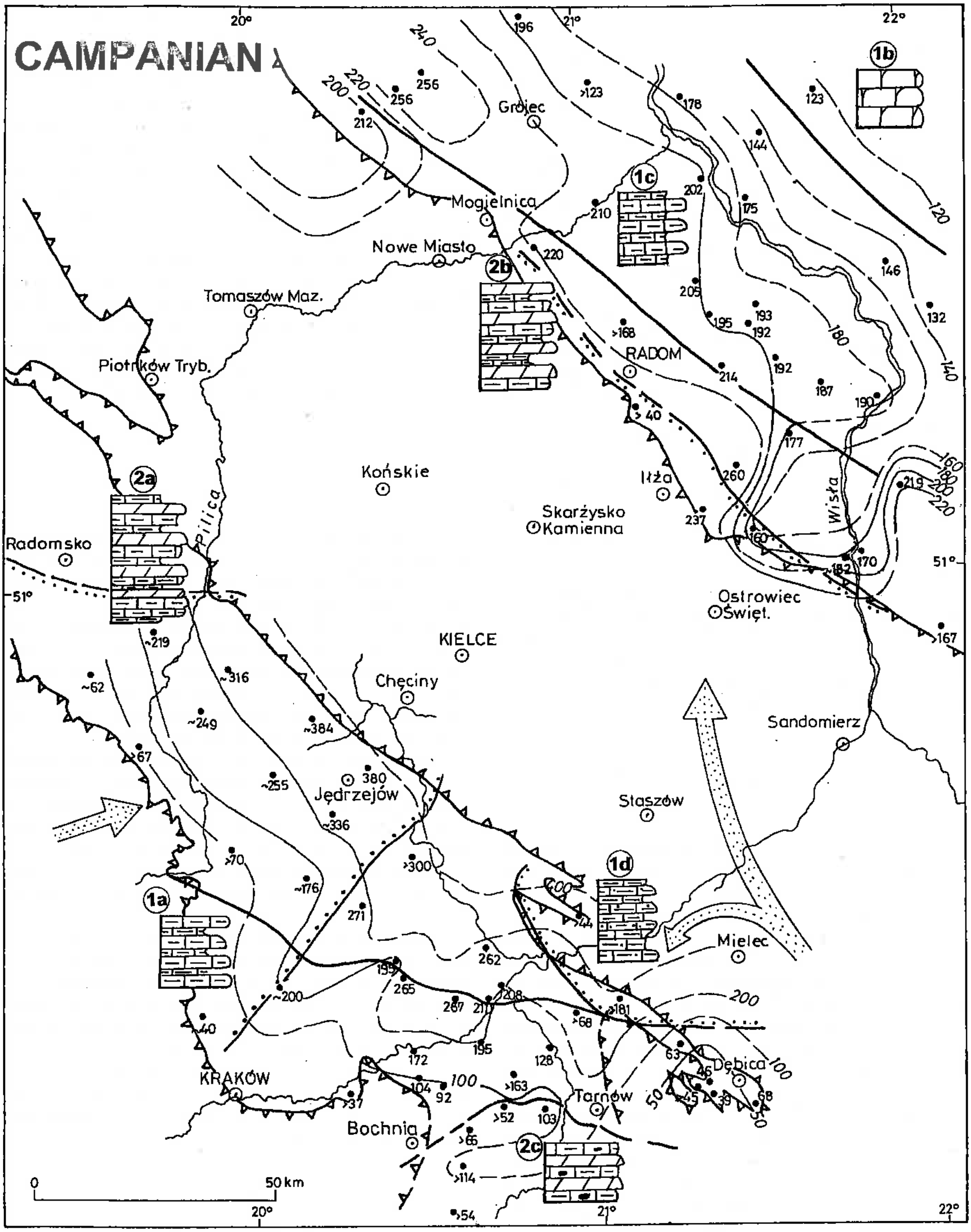

Fig. 9. Thickness and facies patterns of Campanian deposits
Explanations see Figs. 1, 2 and 4

Rozkład miąższości i wykształcenie facjalne osadów kampanu
Objaśnienia na fig. 1, 2 i 4

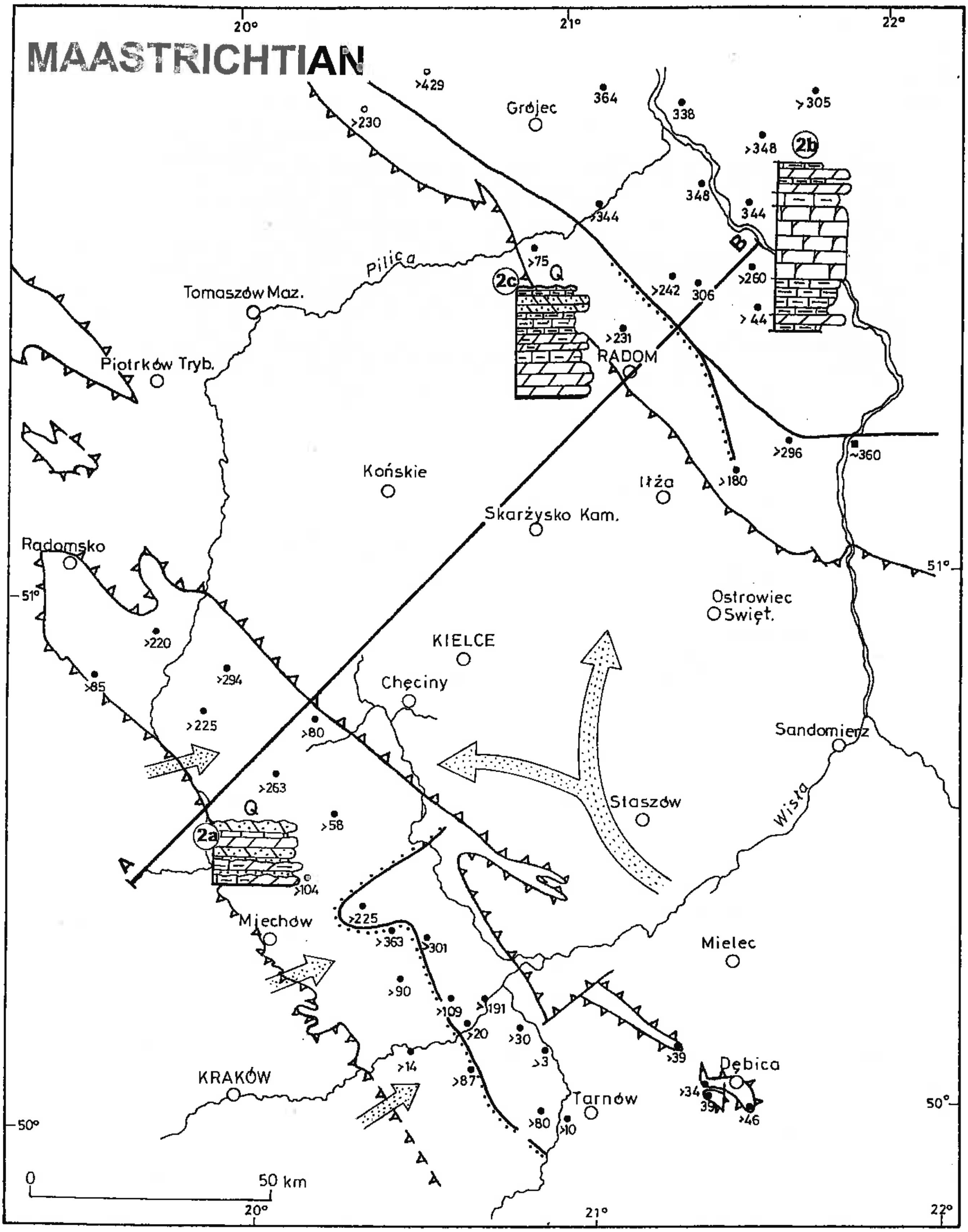

Fig. 10. Thickness and facies patterns of Maastrichtian deposits

Q — Quaternary, A–B — cross-sections line of Figs. 11 and 12; other explanations see Figs. 1, 2 and 4

Rozkład miąższości i wykształcenie facjalne osadów mastrychtu

Q — czwartrzęd, A–B — linia przekojów przedstawionych na fig. 11 i 12; pozostałe objaśnienia na fig. 1, 2 i 4

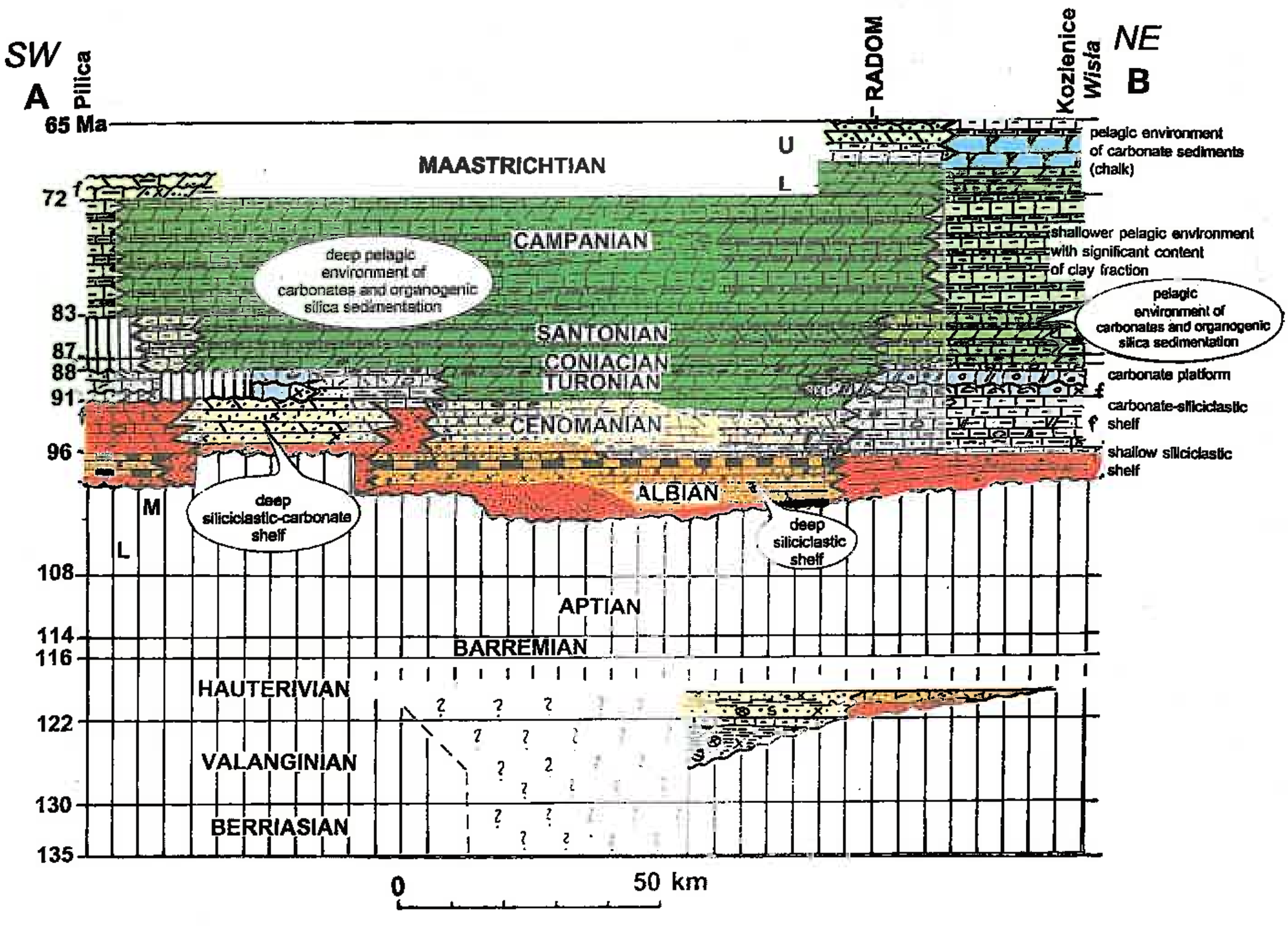

Fig. 11. Chronostratigraphic diagram of lithofacies and sedimentary environments characteristic for Holy Cross segment of the Mid-Polish Trough
Lithological explanations see Figs. 2 and 4

Diagram chronostratygraficzny litofacji i środowisk sedymentacyjnych charakterystycznych dla świętokrzyskiego fragmentu bruzdy śródpolskiej
Litologia jak na fig. 2 i 4

Cretaceous (except for the Cenomanian) the amount of sandy detrital material reaching the depositional basin has increased considerably (Fig. 10). According to J. Rutkowski (1965, 1976) in the central area of the Miechów Syncline the sandy material was, in its western part (vicinity of Miechów), transported from the south-west, and in the eastern part (vicinity of Motkowice) from the direction of the Mid-Polish Trough. The latter transport direction of the detrital material in this part of the basin has not been observed so far. On the other hand, the dispersal of sandy material in the Coniacian, Santonian and Campanian, west of Mielec, has ceased.

In the Maastrichtian three areas with various depositional development have been distinguished. During the Early Maastrichtian in the area of the present Miechów Syncline gaizes, opokas and calcareous sandstones were prevailing (E. Senkowicz, 1959; I. Heller, W. Moryc, 1984). This region (2a) can be interpreted as a deep-water siliciclastic-carbonate shelf, periodically undergoing shallowing and with evidence of winnowing (erosional surfaces).

In the north-east, in the Warsaw–Lublin Syncline (the depositional development after M. Jaskowiak-Schoeneichowa and A. Krassowska, 1983) it was possible to distinguish two regions, that repeat the Santonian and Campanian pattern: region 2b, where marly limestones with rare interbedded opokas were deposited, and region 2c closer to the hitherto axis of the trough, where mainly opokas were formed.

In the Late Maastrichtian only the regions 2b and 2c can be compared. It can not be excluded that palaeobathymetric conditions have been reversed: near Radom (2c) large influx of sandy material is observed with relatively smaller biogenic silica content, and in the region 2b the pelagic chalk facies have appeared, forming up to then further to the north-east.

SUMMARY

SUCCESSION OF DEPOSITIONAL ENVIRONMENTS

Overall lithofacies development and the succession of depositional environments is shown in the chronostratigraphic diagram (Fig. 11) compiled along a line extending from the springs of Pilica river through Radom to Kozienice. Two sedimentary megacycles are observed here: fragmentarily preserved regressive phase of the Jurassic–Early Cretaceous megacycle (J. Kutek, 1994*a*), represented by the deposits of Upper Valanginian and Lower Hauterivian, and the main Cretaceous cycle containing in this part deposits between Middle Albian and Maastrichtian. Subordinate sedimentary cycles, detected by biostratigraphic documentation of stratigraphic gaps accompanied by detailed lithological analysis, are age equivalents of Albian, Cenomanian, lower part of Lower Turonian, upper part of Lower Turonian up to Upper Turonian and finally from Coniacian to Maastrichtian, respectively. They could not be shown on the diagram due to its simplified form.

The sedimentation development proceeded from the environments of shallow siliciclastic shelf (mainly in the Albian) through deeper siliciclastic shelf with increasing content of sponge-derived silica (in the Cenomanian depocenters), siliciclastic-carbonate shelf (in some places in the Cenomanian and Turonian) and carbonate platform with organodetrital sedimentation (in marginal belts of the Turonian basin) finally ranging to pelagic environments. The latter were characterised by influx of finest terrigenous fractions (marls and opokas). Facies of this type appeared in the trough's centre in the Turonian and later expanded successively towards the NE and SW. Last member in this succession of sedimentary environments is represented by pure carbonates lacking terrigenous material, which resulted in formation of chalk deposits. Superimposed on the described synthetic vertical succession of sedimentary environments, is the clear trend of earlier occurrence of the upper members in the north-east region, with smaller content of terrigenous material, and with increased carbonate productivity instead.

Disappearance of areas undergoing denudation, as well as those devoid of sedimentation was taking place parallel with the occurrence of progressively deeper sedimentary environments and smaller content of terrigenous material. All these features reflect a development of the transgression. It reached its maximum in the Campanian. Until Campanian an outward migration of boundaries between the presumed sedimentary environments was continuing progressively larger area was being covered by pelagic facies, and areas of shallow shelf were disappearing. Maastrichtian deposits represent the regressive phase of the Cretaceous megacycle.

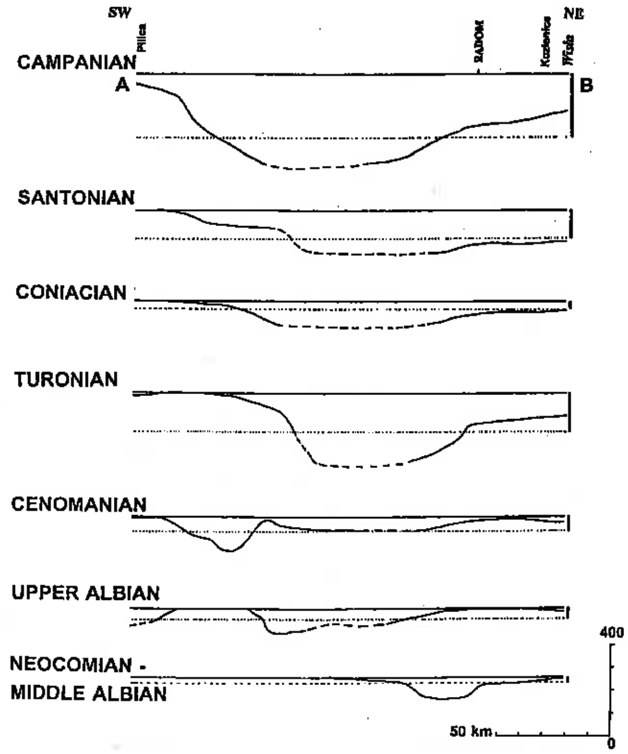

Fig. 12. Palaeotectonic cross-sections of Holy Cross segment of the Mid-Polish Trough

Vertical line on right side of the picture express medium thickness of deposits; location on Fig. 10

Przekroje paleotektoniczne przez świętokrzyski odcinek bruzdy śródpolskiej

Linia pionowa z prawej strony rysunku przedstawia uśrednioną miąższość osadów; lokalizacja na fig. 10

The chronostratigraphic scheme (Fig. 11) is merely an attempt to look at facies changes from the temporal point of view. The level of biostratigraphic documentation of the successive stage boundaries differs very much. It reflects a long-lasting habit of locating the stage boundaries in the intervals of lithological changes, identifying thus the lithostratigraphic boundaries as the chronostratigraphic ones. Not having the possibility of correcting the stratigraphy, the authors only wish to emphasise, that, for example, stair-shape character of the boundary of deep siliciclastic shelf environment in the SW part of the basin (Fig. 11) may in fact not indicate trangressive pulses at the stages boundaries, if the biostratigraphic boundaries are diachronous relative to the lithofacies.

BASIN ZONATION AND SYNSEDIMENTARY ACTIVITY OF THE SUBSTRATE

Frequently stressed parallel trends of facies zones and the longitudinal axis of the Mid-Polish Trough are expressed (Fig. 11) in the occurrence of an axial zone with an area of earliest onset of sedimentation and earliest appearance of deep siliciclastic shelf environments, and following pelagic sedimentation. Only during the Albian the two marginal zones in the NE and SW display some symmetry in sedimentary development. In other stages the SW slope of the trough was characterised by larger content of terrigenous material, long-lasting occurrence of eroded areas (or only those lacking deposition), higher variability of sedimentary environments up to the Turonian, and, generally also during this time interval — by higher energy of depositional environments. In the Campa-

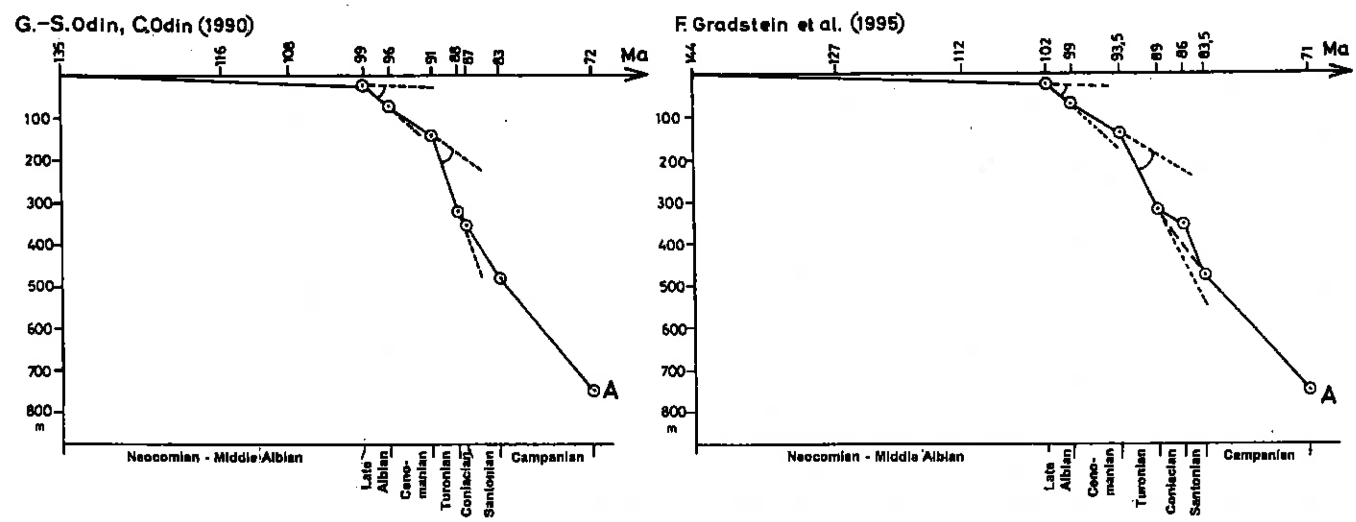

Fig. 13. Curve of medium subsidence along the cross-section Pilica–Radom–Kozienice
Location on Fig. 10

Krzywa średniej subsydencji wzdłuż przekroju Pilica–Radom–Kozienice
Lokalizacja przekroju na fig. 10

nian the differences vanished, but already in the Maastrichtian they became accentuated again during the regression and the beginning of the trough's inversion.

Chronostratigraphic diagram reveals, the existence of particular zones, where boundaries of various sedimentary environments were persistently present within different stages. Repeated occurrence of such boundaries during a long time in some zones suggests that the basins depth was influenced by different rate of subsidence of the basin substrate, related to the occurrence of tectonic discontinuities. One can distinguish two fault zones (Fig. 11) defining the axial part of the trough and its marginal parts.

First of fault zones runs SW of Radom, where the boundaries between various environments are located in the Hauterivian and since the Albian to the Santonian, constituting the northeastern limit of the trough's axial zone. The effects of higher subsidence rate are evidenced by the fact, that Valanginian deposits were preserved in this area, and by earlier occurrence of the Middle Albian transgressive deposits during the next sedimentary megacycle. Another evidence is the appearance of deeper-water facies by the end of Albian and by the end of Cenomanian, which became widespread only during the upper stages of the Cretaceous. In the Coniacian and Santonian bigger organic silica content and the terrigenous quartz influx are the only expressions of differences in sedimentary conditions. These may be related to the activity of the Nowe Miasto–Iłża Fault, which during the Triassic and Early to Middle Jurassic formed the NE-limit of the trough (M. Hakenberg, J. Świdrowska, 1997). During the Cretaceous its role was smaller, as it is not reflected in large thickness gradients. The facies seem to be a longer-lasting and more sensible indicator of the subsidence variability in the basin.

Second fault zone, active since the Albian to the Turonian (Fig. 11), runs close to the present southwestern contact of the Mesozoic with the Palaeozoic of the Holy Cross Mountains. In the Turonian it was also accompanied by substantial thickness gradients (Fig. 6). It can be supposed, that a major synsedimentary fault limiting the trough from the south-west have been active here. Its maximum activity occurred in the Turonian. It would coincide with the zone of intensive tectonic deformations of the Mesozoic rocks, related to the trough's inversion (E. Stupnicka, 1970; W. Pożaryski, 1971).

Asymmetry of the basin observed in the transversal cross-section up to the Turonian, resulted from the activity of these discontinuities: initially, until the Cenomanian the depositional axis was located near the NE border of the trough, later in the Turonian it has moved towards SW trough boundary. Since the Coniacian the role of limiting faults has been decreasing and up to the Campanian the asymmetry is difficult to interpret. When concluding about the subsidence during the Maastrichtian, one should take into account in addition to the deposits thickness also the probable increase of the water depth towards the NE, where pelagic lithofacies of opokas and chalk have appeared.

PROBLEM OF DATING THE ONSET OF THE INVERSION

Local occurrence of sandy admixture in the deposits, observed since the Coniacian to the Maastrichtian, enables one to suppose that two directions of terrigenous material dispersal existed. The dispersal pattern is not related to the sediment-thicknesses. First direction, from the south-west, i.e. from the areas frequently lacking deposits, does not rise any interpretation problems. The second direction, from the central part of the trough appears when in the southern part of the area large sediment-thickness variability exists and the general pattern of izopachs changes from the NW–SE to latitudinally trend. Sandy material admixture occurs in Coniacian, Santonian and Campanian in the vicinity of Mielec

(Figs. 7, 8 and 9) and in Santonian and Campanian in the area SW of Radom (Figs. 8 and 9).

Higher sandy admixture in the deposits is accompanied neither by decrease of their thickness nor by a general change in the depositional conditions. With the opoka-marly lithofacies still prevailing, it may be suggested, that the sandy material was derived from beyond the limits of the investigated basin — probably from the S and SE — and was dispersed by marine currents to the environments of pelagic deposition. Distribution of terrigenous material alone can not be a sufficient proof of the inversions onset on this area.

The process of the basin shallowing and increasing input of clastic material is observed only in the Maastrichtian. It proceeded asymmetrically and was more pronounced and occurred earlier in the southwestern zone of the basin. On one hand it is suggested by the fact of occurrence in the Miechów Syncline of the Lower Maastrichtian deposits only, on the other by the appearance in northeastern flank of chalk facies, indicating lack of terrigenous material influx.

SUBSIDENCE RATE

In order to compare subsidence rates, or, strictly speaking rates of preserved sediment accumulation, which can be considered proportional to the rate of subsidence, cross-sections have been prepared (Fig. 12), showing degree and mode of deflection of a direct substrate of consecutive Cretaceous stages, inferred from the thickness of the deposits filling the basin. The cross-sections have been localised along the same line as the chrostratigraphic diagram (Fig. 10).

For every stage average sediment thickness has been calculated. Basing on this, the average subsidence curve has been drawn (Fig. 13). Comparison a results using two time scales (G. S. Odin, C. Odin, 1990; F. Grandstein *et al.*, 1995) reveals, that the differences between them do not affect conclusions concerning the subsidence curves. The only important suggestion is, that due to differences in time of duration of Coniacian and Santonian, these stages should be considered as a single time interval. One change has been made in respect to the thickness maps, by including the Lower and Middle Albian to the distinct time-interval characterised by numerous gaps. Upper Albian, as a horizon of rapidly developing transgression, was treated separately.

After long-lasting and repeated uplifting of the area close to the Jurassic/Cretaceous boundary (S. Cieśliński, 1976; J. Kutek, 1994*a*) the subsidence became faster in the beginning of the Late Albian transgression. However, the rate of deposition in the Albian did not reach high values (Fig. 13). The increase of subsidence rate in the Turonian is related to considerable rate of sediment accumulation, which combined with the observation of a synsedimentary activity of the SW zone of the limiting fault, indicates important role of tectonic subsidence.

Translated by Piotr Łuczyński

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EWOLUCJA ŚWIĘTOKRZYSKIEGO ODCINKA BRUZDY ŚRÓDPOLSKIEJ W KREDZIE

Streszczenie

Analiza rozwoju sedymentacji i subsydencji osadów kredy (fig. 1–10) w szeroko pojętym mezozoicznym obrzeżeniu Gór Świętokrzyskich (synkliny: miechowska, tomaszowska, południowa część synkliny łódzkiej oraz SW część synkliny warszawsko-lubelskiej) została wykonana na podstawie materiałów publikowanych, archiwalnych i własnych.

Równoległość stref facjalnych do podłużnej osi basenu jest wyrażona (fig. 11) obecnością części osiowej z najwcześniej rozpoczynającą się sedymentacją i najwcześniej pojawiającymi się środowiskami głębokiego szelfu silikoklastycznego, a później sedymentacją pelagiczną. Dwie strefy obrzeżające od NE i SW jedynie w albie wykazują pewną symetryczność rozwoju sedymentacji. W pozostałych piętrach SW skłon bruzdy cechował się większym udziałem materiału terygenicznego, długotrwałym występowaniem obszarów denudowanych lub jedynie omisyjnych, większym zróżnicowaniem warunków sedymentacji po turon włącznie i generalnie również w tym przedziale czasowym wyższą energią środowisk sedymentacyjnych. W kampanie te różnice zanikły, lecz już w mastrychcie zaznaczyły się znowu w związku z regresją i początkami inwersji bruzdy.

Można wyróżnić 2 główne strefy uskokowe (fig. 11), wyznaczające osiową część bruzdy i jej partie obrzeżające. Pierwsza strefa uskokowa zaznacza się na SW od Radomia, gdzie granice różnych środowisk lokują się w hoterywie i od albu po santon, stanowiąc NE ograniczenie osiowej części bruzdy. Druga strefa uskokowa, czynna od albu po turon, przebiega w pobliżu obecnego południowo-zachodniego kontaktu mezozoiku z paleozoikiem Gór Świętokrzyskich (Kamieńsk–Przedbórz–Chęciny–Mielec). W turonie wiążą się z nią również znaczne gradienty miąższości (fig. 6). Można przypuszczać, że działał tu wielki synsedymentacyjny uskok ograniczający bruzdę od południowego zachodu. Maksimum jego aktywności przypadało w turonie.

Na podstawie przekrojów paleotektonicznych (fig. 12) przedstawiono krzywą subsydencji średniej, charakteryzującą ten fragment basenu. Okresy przyspieszenia subsydencji w kredzie, to późny alb i turon (fig. 13). Pierwszy z nich wynika głównie z kontrastu w stosunku do długotrwałego i powtarzalnego wynoszenia obszaru na przełomie jury i kredy; tempo akumulacji w albie nie osiągnęło dużych wartości. Zdarzenie turońskie natomiast wiąże się ze znacznym tempem gromadzenia się osadów, co w połączeniu z synsedymentacyjną aktywnością SW strefy uskoku ograniczającego dowodzi dużej roli subsydencji tektonicznej. Rozkład miąższości i facji osadów kredy oraz sposób występowania terygenicznych domieszek piaszczystych (począwszy od koniaku) skłaniają do wniosku, że na świętokrzyskim odcinku bruzdy śródpolskiej inwersja nie rozpoczęła się przed mastrychtem.