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IRENEUSZ WALASZCZYK

Mid-Cretaceous events at the marginal part of the Central European Basin (Annopol-on-Vistula section, Central Poland)

ABSTRACT: The nature of the mid-Cretaceous events in the Albian — Lower Turonian sequence exposed at Annopol-on-Vistula (Central Poland) is discussed. At least four of the five distinguished here discontinuities are shown to be correlable with the equivalent phenomena in other Polish sections and with commonly recognized events. So, being earlier referred to the activity of local uplifting movements of the Annopol Swell, they are interpreted here as the global events record. The activity of the Annopol Swell was only a favorable factor for the event expression through the limiting terrigenous influx, and it was also responsible for the condensation phenomena in the intervals between. The bathymetrical analysis of the foraminifers shows that only one of the events (*i.e.* the mid-Cenomanian event) unquestionably represents a eustatoevent, while the others are expressions of both bathymetrical and chemical changes in the mid-Cretaceous sea.

INTRODUCTION

It appears well evidenced that the development of the mid-Cretaceous transgression was associated with a set of the widespread and approximately isochronous events. The established succession of events is valuable in paleogeographical and ecological interpretations, and it is commonly regarded as a promising tool in stratigraphic correlations (*e. g.* CARTER & HART 1977, HART 1980, ERNST & *al.* 1983, DAHMER & ERNST 1986). Universal application of the "event-stratigraphy" requires however further studies including evaluation of the isochroneity of events on a global scale and also more insight into their very nature. The latter problem is related to a various sedimentary expression of every particular event in contrasting paleogeographic and facies settings.

This paper concerns the problem of recognition of equivalent events in the strongly condensed mid-Cretaceous section exposed at Annopol-on-Vistula in Central Poland and located at the mariginal part of the

Central European Basin (Text-fig. 1; *see also* MARCINOWSKI & RADWAŃSKI 1983). This section on one hand is excellently suited to the event recognition due to a lack of intensive terrigenous sedimentation and preservation of rich fossil assemblages making possible a record and precise dating of the global oceanic processes. On the other hand, however, it was placed during the mid-Cretaceous on a swell structure, the

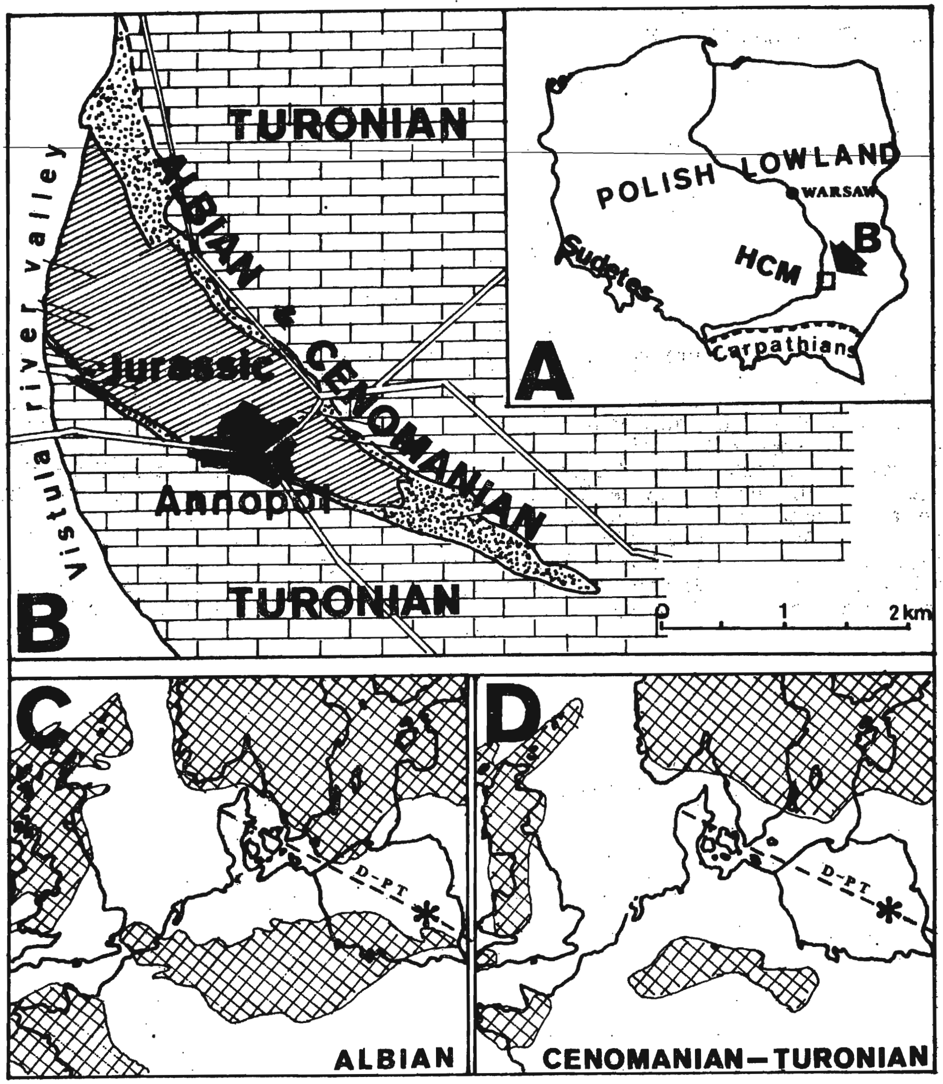
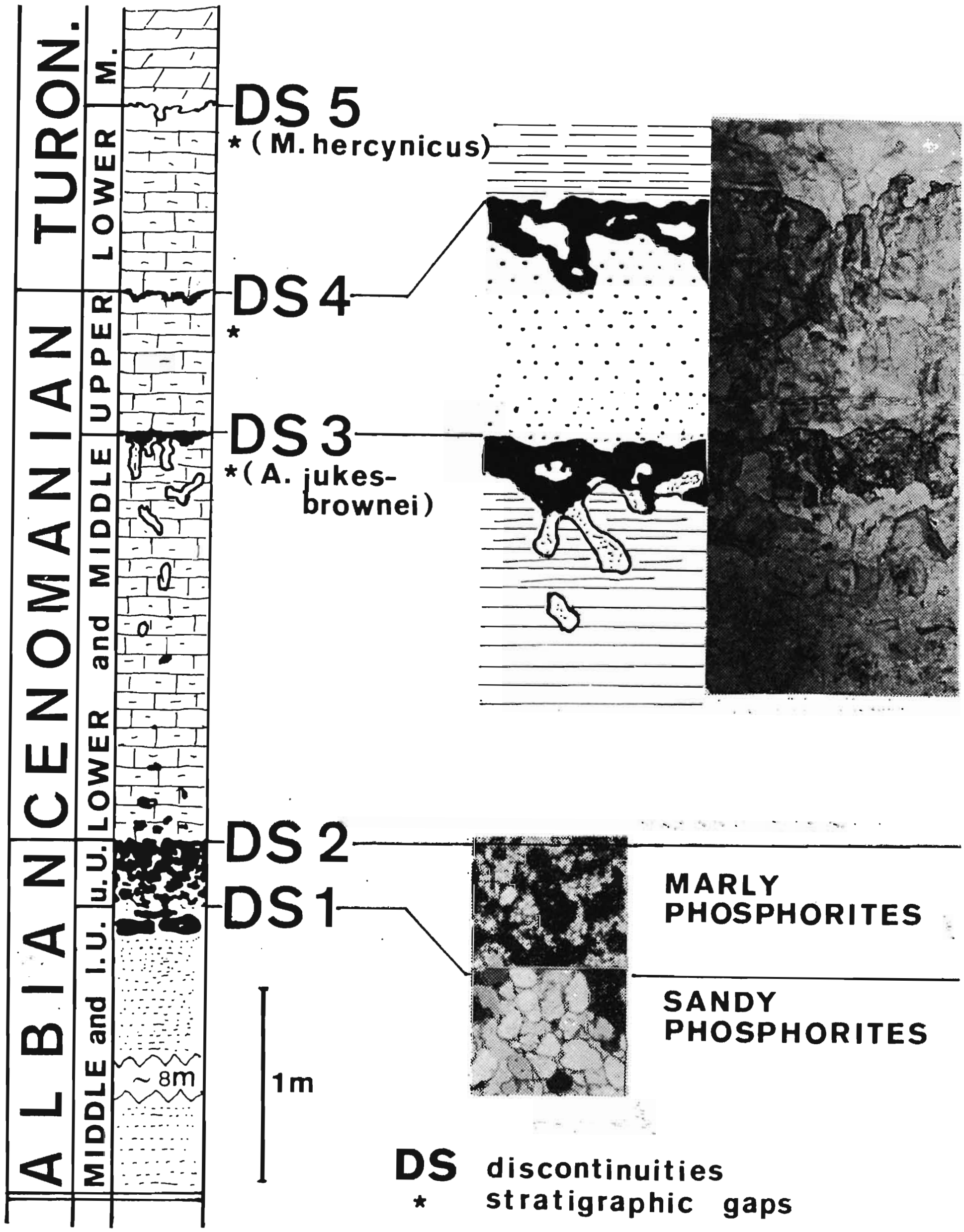


Fig. 1. Geologic setting of the Annopol-on-Vistula region

A — Location of the studied area in Poland; HCM — Holy Cross Mountains
B — Geologic sketch-map of the Annopol-on-Vistula region
C-D — Paleogeographic maps of Central Europe during Albian and Cenomanian/ /Turonian times; asterisked is the studied area (*taken from* ZIEGLER 1982; *in* C minor modification *after* MARCINOWSKI & WIEDMANN 1985)



Lithology, stratigraphy, discontinuities and associated stratigraphic gaps within the mid-Cretaceous sequence exposed at Annopol-on-Vistula

Field photo through the courtesy of Ass.-Professor S. CIEŚLIŃSKI activity of which could have been expressed in a similar way as the presumed events. A differentiation between these two factors is the aim of the present study.

GEOLOGICAL SETTING

The mid-Cretaceous deposits (Albian — Turonian) of the studied area, near Annopol-on-Vistula, are exposed along the limbs of the Laramide anticlinal structure, and they rest with a slight angular unconformity (1—2°) upon the Jurassic (Kimmeridgian) substrate (*see* Text-fig. 1*A*—*B*). The mid-Cretaceous deposits represent a typically transgressive sequence. Starting with the Middle Albian near-shore sands and sandstone, the sequence passes upwards into marly sands and marls of the Upper Albian and Cenomanian which, in turn, are overlain by almost pure carbonates of the Turonian (Text-fig. 2). The very characteristic components of the Annopol section are nodular phosphates of the Middle — Upper Albian and the phosphatic mineralization associated with the Middle and Upper Cenomanian hardgrounds. Single phosphatic nodules occur also in sandy glauconitic marls of the Lower — Middle Cenomanian and rarely also in the Lower Turonian marls.

The Annopol section occupies an exceptional position among the extra-Carpathian mid-Cretaceous sequences of Poland, which are commonly characterized by the intensive terrigenous sedimentation. This situation aroused from the peculiar paleogeographic setting of this area during the mid-Cretaceous, *viz.* its position on a swell structure (the Annopol Swell — *see* CIEŚLIŃSKI 1976, MARCINOWSKI & RADWAŃSKI 1983) rising within the axial part of the Polish Danish Trough (*see* Text-fig. 1*C*—*D*).

BIOSTRATIGRAPHY

The biostratigraphic position of particular lithological units of the Annopol sequence has been studied earlier by SAMSONOWICZ (1925, 1934), POŻARYSKI (1947, 1948, 1956), CIEŚLIŃSKI (1959, 1976), and recently advanced thouroughly and summarized by MARCINOWSKI (1980), MARCINOWSKI & RADWAŃSKI (1983), MARCINOWSKI & WALASZCZYK (1985), and MARCINOWSKI & WIEDMANN (1985). The stratigraphic subdivision applied in this paper is in agreement with the last four cited papers (MARCINOWSKI 1980, MARCINOWSKI & RADWAŃSKI 1983, MARCINOWSKI & WALASZCZYK 1985, MARCINOWSKI & WIEDMANN 1985) and the reader is referred to there for detailed stratigraphic data.

Excepted is however the Cenomanian/Turonian boundary which, contrary to previous opinions, does not represent a continuous deposition and is marked by a sedimentary break with a stratigraphic gap. Moreover, a stratigraphic gap is also confined to the Lower/Middle Turonian boundary and is associated with the hardground. The lack here of *Mytiloides hercynicus* (PETRASCHECK) indicates the gap comprising the upper zone of the Lower Turonian in the bipartite division of this substage (*i.e.* into Mytiloides mytiloides and Mytiloides hercynicus Zones).

LABORATORY DATA

The fieldworks for the present study were carried out in 1983—1984 as a part of the graduate paper (WALASZCZYK 1984).

Laboratory studies included petrographical investigations based on 40 thin sections, *XRD*-analyses of phosphorites, and a micropaleontologic study. The plankton/benthos ratio graph (*see* Text-fig. 4) was plotted basing on 17 samples, with 200 specimens counted in every sample (the lowest three samples are excluded because of low frequency of foraminifers). The *XRD*-analyses were performed in the Geological Survey of Poland.

SEDIMENTARY RECORDS

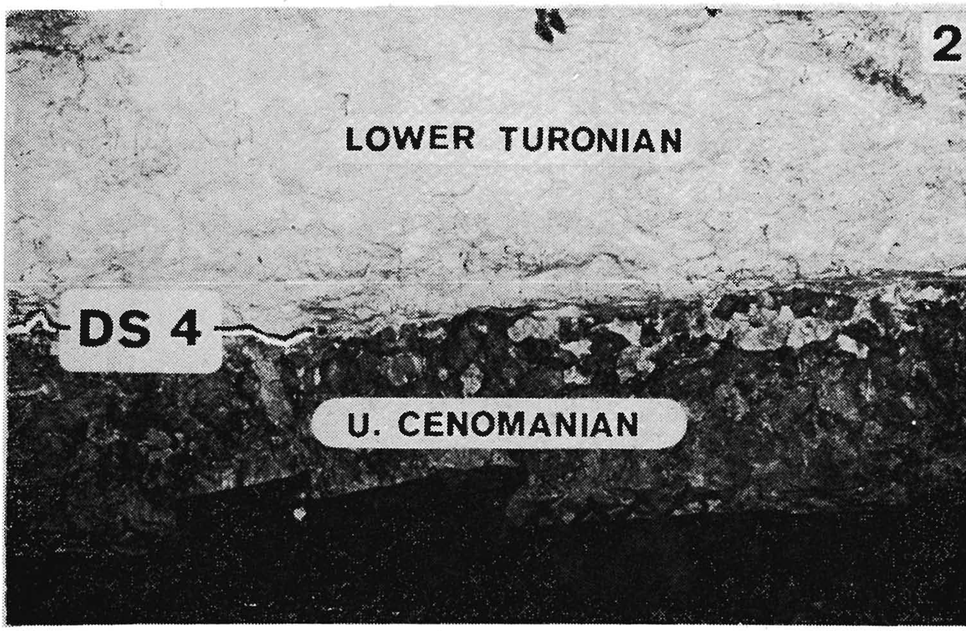
Five discontinuities may be distinguished in the section exposed at Annopol-on-Vistula, represented either by distinct lithological boundaries or by hardground horizons, to which stratigraphic gaps are confined (Text-fig. 2). The intervals between are the condensed units with reworked and mixed sediments.

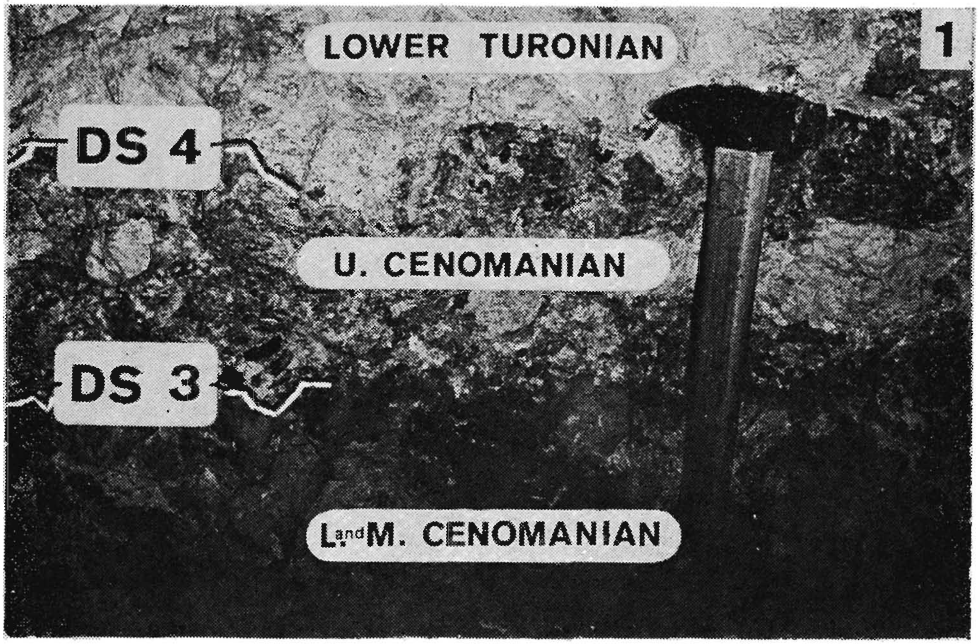
Discontinuity No. 1

It is placed within the Albian phosphorite bed separating the sandy phosphates of the Middle — low-Upper Albian and the marly phosphates of the uppermost Albian (Stoliczkaia dispar Zone). These two kinds of phosphates differ macro- and microscopically.

The Middle — low-Upper Albian sandy phosphates form large (up to 20 cm in diameter) spindle-shaped, light to dark brown phosphoclasts composed of densly packed quartz, glauconite, subordinately feldspar and chalcedony grains, cemented with microcrystalline fluorapatite (*see* microphoto *in* Text-fig. 2). No microfaunal tests were found in thin sections. The macrofauna is composed of ammonite moulds and shells and also sparse inoceram fragments. There occur also wood fragments, phosphatized and bored by the bivalves *Gastrochaena* sp. (Pl. 2, Fig. 1).

The uppermost Albian marly phosphates are composed of small (commonly less than 1 cm in diameter) light to dark brown phosphoclasts, many of which represent phosphatized fossil moulds, cemented into larger aggregates. The phosphates are matrix-supported micro- to cryptocrystalline phosphates with a varying

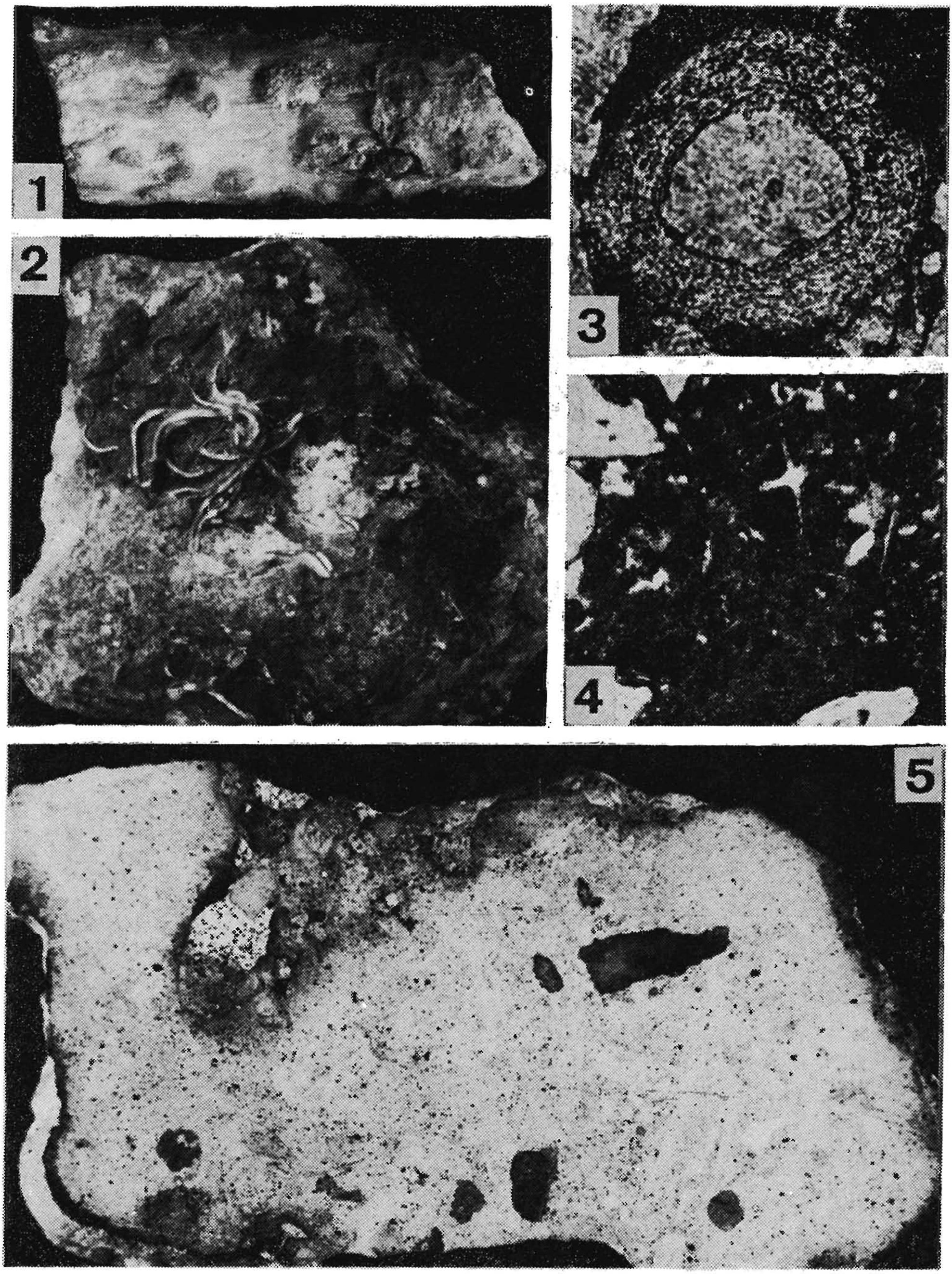




1 — Mid-Cenomanian hardground (Discontinuity No. *3*) and the overlying sequence: Upper Cenomanian marls — Discontinuity No. *4* — Lower Turonian limy marls; underground gallery of the abandoned phosphorite mine at Annopol-on-Vistula

2 — Discontinuity No. *4* with Upper Cenomanian marls beneath and Lower Turonian limy marls above; underground gallery of the abandoned phosphorite mine at Annopol-on-Vistula

Both photos through the courtesy of Ass.-Professor S. CIEŚLIŃSKI



1 — Phosphatized wood fragment bored by the bivalve *Gastrochaena* sp.; lower part of the phosphorite bed (Middle — low-Upper Albian)

2 — Lag intraclast with serpulid encrustations and glauconite veneer; mid-Cenomanian hardground (Discontinuity No. 3)

3 — Phosphatic ooid with quartz nucleus; upper part of the phosphorite bed (uppermost Albian — Stoliczkaia dispar Zone)

4 — Crypto- to microcrystalline phosphatic matrix of marly phosphoclast; upper part of the phosphorite bed (uppermost Albian — Stoliczkaia dispar Zone)

5 — Lag intraclast with burrows and phosphoclasts, glauconitized and phosphatized at the surface; mid-Cenomanian hardground (Discontinuity No. 3)

Photos 1, 2, 5 in nat. size; taken by S. ULATOWSKI
Photos 3 × 70 and 4 × 40; taken by J. MODRZEJEWSKA

matrix/grains ratio (Pl. 2, Fig. 4; *see also* microphoto *in* Text-fig. 2). The grains, besides the dominating quartz and glauconite, are composed of phosphatic pellets, ooids (*see* Pl. 2, Fig. 3) and differently preserved microfossil tests, primarily planktic foraminifers of the genus *Hedbergella*.

Besides the areas with one, distinct phosphorite bed (eastern part of the NE margin of the Holy Cross Mountains, also the Lublin Upland) no equivalents of this dicontinuity may be indicated in other Albian sections of Poland, as they are commonly represented by the continuous sandy sedimentation, and their faunistic documentation is unsufficient to make any time determination.

Discontinuity No. 2

It forms the boundary between the Albian phosphorite bed and the Lower Cenomanian sandy glauconitic marls. This discontinuity was firstly reported by CIEŚLIŃSKI (1976) who suggested also a stratigraphic gap at this boundary, comprising the Lower and ?low-Middle Cenomanian. However, basing on the ammonite assemblages MARCINOWSKI (1980) showed this assumption to be groundless.

The Albian/Cenomanian boundary is also sharply marked in other mid-Cretaceous sections of Poland. In the Polish Jura it is marked by the appearance of calcium carbonate content (MARCINOWSKI 1974). In the SW margin of the Holy Cross Mountains, a conglomeratic band is mentioned at this time interval (HAKENBERG 1969, 1978), and along the NE margin of the Holy Cross Mountains this boundary is placed at the upper surface of the phosphorite bed, similarly as in the Annopol section (*see e. g.* CIEŚLIŃSKI 1959).

Discontinuity No. 3

It is expressed by a composite hardground horizon, terminating the Lower — Middle Cenomanian sandy glauconitic marls (Text-figs 2—3, and Pl. 1, Figs 1—2), with a thick (up to 30 cm) hard part, and with glauconitic and phosphatic mineralizations (Pl. 2, Figs 2, 5), encrustations (Pl. 2, Fig. 2), and complex genetical history (*see* Text-fig. 3). Discontinuity No. 3 was firstly recognized and interpreted by POŻARYSKI (1956) and the associated stratigraphic gap, comprising the Acanthoceras jukesbrownei Zone, was postulated by MARCINOWSKI (1980).

The discussed discontinuity is accompanied also by a distinct rise of the plankton/benthos ratio within foraminiferal assemblages, although its sedimentary expression (hardground development) is rarely observed in other sections. A radical increase of the planktic foraminifers frequency of the same age is, however, commonly observed in the other Cenomanian sections of Poland (HUSS 1962, ZAPAŁOWICZ-BILAN 1981, GAWOR-BIEDOWA 1982).

Discontinuity No. 4

It is represented by a well manifested omission surface at the top of the haevily glauconitic Upper Cenomanian marls (*see* Pl. 1, Figs 1—2), and is overlain by limy marls of Lower Turonian age. It was firstly reported by POŻARYSKI (1948), and a stratigraphic gap was suggested by CIEŚLIŃSKI (1976).

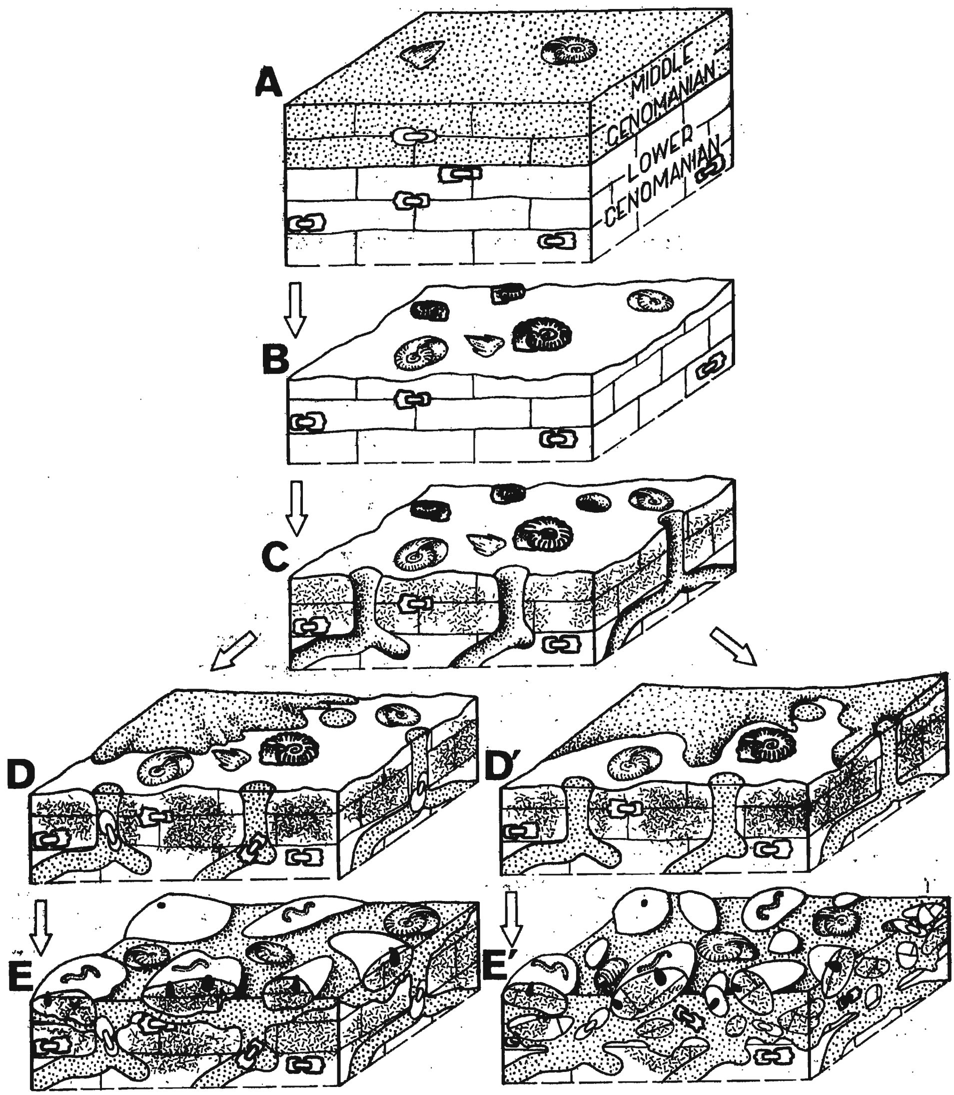


Fig. 3. Development of the mid-Cenomanian hardground (*taken from*: MARCINOWSKI & WALASZCZYK 1985, Fig. 2)

A — Sedimentation period up to a part of the Middle Cenomanian (including the Turrilites acutus Zone)
B — Break in sedimentation (Acanthoceras jukesbrownei Zone) with erosion down to Lower Cenomanian deposits; phosphatization of moulds, sometimes also of shells; formation of the residual lag
C — Non-deposition period; settling of the burrowing fauna and incipient substrate cementation
D — Very slow sedimentation; filling of burrows with new sediment as well as with small particles (up to 3—4 cm in diameter) of the residual lag
D' (alternative) — Like *D*, but without filling of burrows by the residual lag
E — Erosional episode; boring, encrusting of phosphatic nodules, and impregnation with phosphates and glauconite of the eroded hard substratal fragments (formation of hiatus concretions)

Except single examples of the continuous deposition across this boundary in other parts of Poland (*e. g.* Glanów section in the Polish Jura, *see* MARCINOWSKI 1974), it is commonly marked by condensation horizons, hardgrounds, clay layers (*see* CIEŚLIŃSKI & POŻARYSKI 1970; CIEŚLIŃSKI & JASKOWIAK 1973; HAKENBERG 1969, 1978; MILEWICZ 1959, 1963), and other distinct lithological breaks (MARCINOWSKI 1974).

Discontinuity No. 5

It is a hardground horizon (initial hardground *sensu* KENNEDY & GARRISON 1975) with the well defined *Thalassinoides*-type burrows, usually weakly glauconitized. This Lower Turonian hardground with an associated sedimentary gap, of unprecised stratigraphic extent, was firstly reported by POŻARYSKI (1948). This gap comprises the Mytiloides hercynicus Zone.

The boundary between the Lower and Middle Turonian is distinct in almost every section in Poland where the deposits of both these substages occur (*see* BUKOWY 1956, MARCINOWSKI 1974). The stating however, about its time-equivalence with this discontinuity in the Annopol section is difficult, as the Lower Turonian sequence in Poland is most commonly not subdivided into the two herein distinguished zones. From the own experience it appears that the majority of the deposits assigned to the Inceramus labiatus Zone (regarded as the equivalent of the Lower Turonian) belong to the Mytiloides mytiloides Zone (*e. g.* in the Polish Jura, the Cracow Upland including).

BATHYMETRICAL CHANGES RECORDED BY FORAMINIFERS

The interpretation of bathymetry at which the studied deposits were laid down is based on relative changes of the plankton/benthos ratio and on the distribution in the profile of planktic foraminifers depth groups (Text-fig. 4), similarly as given in the referenced papers (GRIMSDALE & van MORKHOVEN 1955, HART & TARLING 1974, CARTER & HART 1977, BÉ 1977, HART & BAILEY 1979, HART 1980, 1983).

The actual distribution of foraminiferal assemblages in the Annopol section is strongly influenced by secondary factors, mainly vertical displacement of tests and homogenization of the deposits due to activity of burrowing infauna. A downward introducing of the microfauna is particularly well evidenced in the Albian, where the typically uppermost Albian species of *Rotalipora* occur in the unquestionably lowermost Middle Albian sands, just beneath the phosphorite bed (*see* Text-fig. 4). In these sands the foraminifers occur only in the uppermost (30 cm thick) bioturbated part. Moreover, as the foraminifers do not occur in large,

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E' (alternative) — Like *E*, but with more extensive erosion and reworking; for the first time the Middle Cenomanian ammonites are introduced into the Lower Cenomanian deposits sandy phosphoclasts but only in the marly ones, their initial range must have been limited to the upper part of the phosphorite bed and later they have only been transported downward (*see* Text-fig. 4).

Similarly, in the fillings of burrows beneath the Discontinuity No. 3 (mid-Cenomanian hardground) there occurs a foraminiferal assemblage

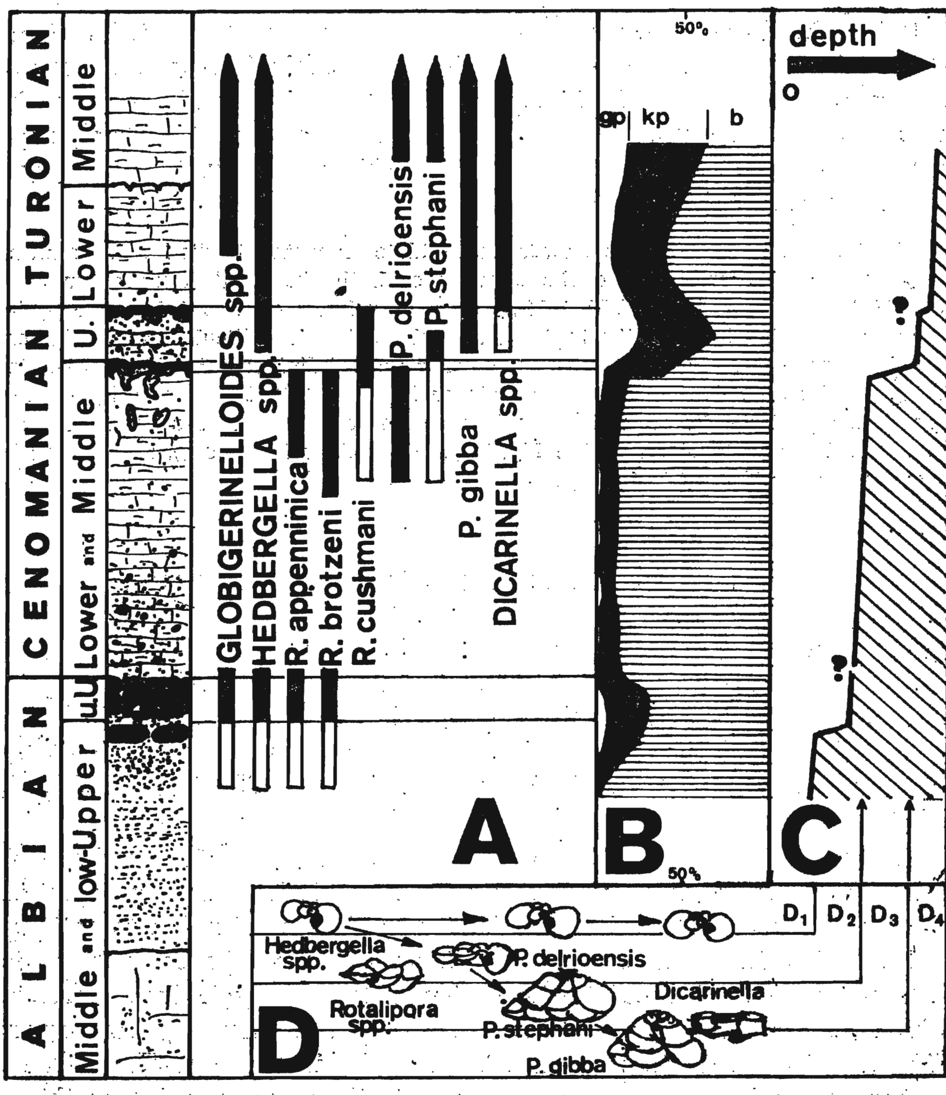

Fig. 4. Foraminifers in the mid-Cretaceous section at Annopol-on-Vistula

A — Distribution of the selected planktic foraminifers; white parts of the ranges are the intervals of secondary introducing
B — Planktic/benthic ratio graph
C — Interpreted paleodepth of the mid-Cretaceous sequence
D — Distribution of planktic foraminifers depth groups (*after* HART & BAILEY 1979)

with abundant *Rotalipora cushmani* (MORROW) being different from that occurring in the surrounding sediment (*see* Text-fig. 4).

The most probably the activity of the infauna is responsible also for the occurrence, in the Upper Cenomanian marls, of many planktic foraminifers characteristic of the Turonian (*see* Text-fig. 4), as may be judged from the burrows descending from the Turonian marls into the Upper Cenomanian heavily gluconitic marls (*see* Pl. 1, Fig. 1).

Any marked contribution of the planktic foraminifers to the whole foraminiferal assemblage, being rather low in its Albian — Middle Cenomanian interval, is confined to the upper part of the profile (B *in* Text-fig. 4). In its lower part, a small peak only is observable in the Upper Albian phosphorite bed. It is associated, however, with a frequency increase of the small, globular hedbergellids, and so of the shallow-marine forms. This may suggest an increase of the surface water productivity rather than of the water depth. Such interpretation is supported by recent observations of the high organic production of the surface waters over the phosphogenic areas (BATURIN & BEZRUKOV 1979, COOK & McELHINNY 1979).

A rapid increase of the planktic foraminifers content is related (B *in* Text-fig. 4) to the mid-Cenomanian hardground (Discontinuity No. *3*). In the fillings of burrows descending to about 1 m down from the hardground the plankton/benthos ratio is about 30% with the rich occurrence of *Rotalipora cushmani* and *Praeglobotruncana* spp.

The most impressive is the Upper Cenomanian peak, associated also with the appearance of the deep water morphotypes of the planktic foraminifers. However, at least part of them could have been secondarily introduced here during Lower Turonian time. Moreover, an important role could have played the ecological factors, namely bottom conditions not well-suited for organic life, what is indicated by a radical decrease of the benthic foraminifers diversity, and by an almost complete lack of the benthic (and also nectic) macrofauna, though it abundantly occurs both below and above in the section. This Upper Cenomanian crisis in organic life is the widespread phenomenon, and its cause was a subject of diversified interpretations (*see* HART & TARLING 1974, MARCINOWSKI 1980).

To summarize, basing on the foraminiferal analyses a distinct sea level rise may be suggested for the Discontinuity No. *3* (mid-Cenomanian hardground) and less distinctly also for the Discontinuities Nos *1* and *4*. No change in foraminiferal assemblage which could be interpreted as a response to the sea level rise may be attributed to the Discontinuities Nos *2* and *5*. A decrease of the ratio after the Albian and Upper Cenomanian peaks may hardly be interpreted as the shallowing of the sea as these peaks were ecologically controlled, and in the case of the Upper Cenomanian peak it is also of taphonomical nature.

GLOBAL INTERPRETATION

Discontinuities and associated condensation phenomena, reworking and hardground formation were reported in all the earlier surveys on the Annopol section (SAMSONOWICZ 1925, 1934; POŻARYSKI 1948, 1956), being ascribed later to the activity of the Annopol Swell (*e. g.* CIEŚLIŃSKI 1976, MARCINOWSKI & RADWAŃSKI 1983). However, equivalents of the here recorded discontinuities are more or less variably recorded also in other mid-Cretaceous sections in Poland. Moreover, basing on the detailed stratigraphic framework in the study area (MARCINOWSKI 1980, MARCINOWSKI & RADWAŃSKI 1983, MARCINOWSKI & WALASZCZYK 1985, MARCINOWSKI & WIEDMANN 1985) possible is also their correlation with the same age phenomena in NW Europe. This suggests that they should be referred to the widespread mid-Cretaceous events.

The most striking example is the mid-Cenomanian Discontinuity No. *3* with associated rise of the plankton/benthos ratio indicative of a deepening pulse (*see* Text-fig. 4). This is isochronous with the widespread, so-called mid-Cenomanian non-sequence, recognized on the foraminiferal assemblage analyses by HART & TARLING (1974) and subsequently reported from Europe, North Atlantic and North America (CARTER & HART 1977; HART & BAILEY 1979; HART 1980, 1983; DAHMER & ERNST 1986). It is noteworthy that at this very time the mid-Cretaceous transgression encroached the Sudetes from NW (MILEWICZ 1959, 1963; S. RADWAŃSKI 1966) and this well evidences the mid-Cenomanian eustatic rise.

Similarly, except of the Discontinuity No. *1*, associated probably with a rise of the sea level (Text-fig. 4), the rest three may easily be correlated with the equivalent phenomena in West Germany or England (*e. g.* JEFFERIES 1963, KENNEDY 1969, SEIBERTZ 1979, ERNST & *al.* 1984, HILBRECHT 1986), where they are interpreted as the eustato-events, though with different opinions on the direction and nature of these changes (*compare* HART 1980, ERNST & *al.* 1983). Basing on the Annopol example, little may be said in this case and only at the Cenomanian/Turonian boundary a deepening pulse is assumed (*see* Text-fig. 4).

Instead, of importance in looking for a nature of particular events may be the fact of correlation in time of the Discontinuity No. *4* with the widespread and short-timed Cenomanian/Turonian boundary anoxic event (*e. g.* SCHLANGER & JENKYNS 1976; JENKYNS 1980, 1985; de BOER 1983; HART & BIGG 1982). This event, though differently interpreted as about its origin, characterizes a special kind of oceanic circulation with a crisis of carbonate sedimentation (de BOER 1983).

Thus, at Annopol region where the terrigenous sedimentation was strongly limited, the crisis of carbonate production could have led to the non-depositional conditions and to the formation of the discontinuity.

CONCLUSION

At least four of the five discontinuities observed in the Annopol section, well correlable with the equivalent phenomena in other sections in Poland and in far-distant regions, represent the record of the global mid-Cretaceous events. Discontinuity No. *3* is unquestionably eustato-event while the others are probably of more complex nature though in the case of Discontinuities Nos *1* and *4* bathymetrical changes are also assumed.

The activity of the Annopol Swell was only a favorable factor through hampering the terrigenous sedimentation, as it must be kept in mind that any event expression requires propitious local sedimentary conditions, and in areas with intense local tectonics or high terrigenous influx there is little chance of its record.

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Institute of Geology
of the University of Warsaw,
Al. Żwirki i Wigury 93,
02-089 Warszawa, Poland

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I. WAŁASZCZYK

ŚRODKOWOKREDOWE NIECIĄGŁOŚCI SEDYMENTACYJNE W PROFILU ANNOPOLA NAD WISŁĄ

(Streszczenie)

Praca przedstawia próbę interpretacji nieciągłości sedymentacyjnych w środkowokredowym profilu Annopola nad Wisłą (*patrz* fig. 1). W skondensowanych utworach albu — dolnego turonu wyróżnić można 5 nieciągłości (*patrz* fig. 2—3 oraz pl. 1—2) podkreślonych raptowną zmianą litologii (nieciągłości *1—2*) lub wyrażonych powierzchniami twardych den ze stowarzyszonymi lukami stratygraficznymi (nieciągłości *3 — 5*). W trzech przypadkach (nieciągłości *1, 3* oraz *?4*) ustalić można również ich związek ze zmianami głębokości zbiornika sedymentacyjnego (*patrz* fig. 4).

Nieciągłości w profilu Annopola, z racji jego położenia w środkowej kredzie na synsedymentacyjnie podnoszącej się strukturze (tzw. Próg Wisły lub Próg Annopola), przypisywane były działalności tej struktury. Ich dobra korelacja czasowa z analogicznymi zjawiskami w innych profilach Polski i Europy może świadczyć jednakże, iż są one lokalnym wyrazem powszechnych, środkowokredowych wydarzeń. Działalność Progu Annopola, poprzez zwolnienie sedymentacji, była czynnikiem sprzyjającym zapisowi tych wydarzeń, jak też odpowiedzialnym za kondensację osadów w interwałach pomiędzy poszczególnymi nieciągłościami.