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Faunal condensation and mixing in the uppermost Maastrichtian/Danian Greensand (Middle Vistula Valley, Central Poland)

ABSTRACT: The Greensand exposed at Nasilów and Bochońnica near Kazimierz-on-Vistula (Middle Vistula Valley, Central Poland) contains diverse uppermost Maastrichtian and Danian fossils. One may here distinguish the phosphatized Maastrichtian, unphosphatized Maastrichtian and the Danian assemblages. Their occurrence in the Greensand is a result of condensation and mixing processes, among which the most important were: the formation of the residual lag composed of fossils and concretions, and the vertical displacement of sediment and fossils by infaunal organisms. The recognition of the complex history of fossil assemblages in connection with sedimentological data permits to place the Cretaceous/Tertiary boundary within the Greensand, just below the residual lag.

INTRODUCTION

In the last years our understanding of the condensation and mixing phenomena has increased significantly (see WENDT 1970; FÜRSICH 1971, 1978; BAIRD 1978, 1981; SEILACHER 1985; MARCINOWSKI & WALASZCZYK 1985; WALASZCZYK 1987). In the present paper the authors demonstrate these phenomena and their meaning for the local stratigraphy on the example of the uppermost Maastrichtian/Danian Greensand exposed at Nasilów and Bochońnica near Kazimierz-on-Vistula in the Middle Vistula Valley, Central Poland (Text-fig. 1A). The occurrence of Maastrichtian and Danian assemblages in this unit caused up to now significant divergences in opinions on its stratigraphical position (KONGIEL 1935, 1958; POŻARYSKI 1938; POŻARYSKA 1952; POŻARYSKI & POŻARYSKA 1960; POŻARYSKA 1965; BŁASZKIEWICZ 1980; KRACH 1974, 1981; RADWAŃSKI 1985; ABDEL-GAWAD 1986).

GEOLOGICAL SETTING

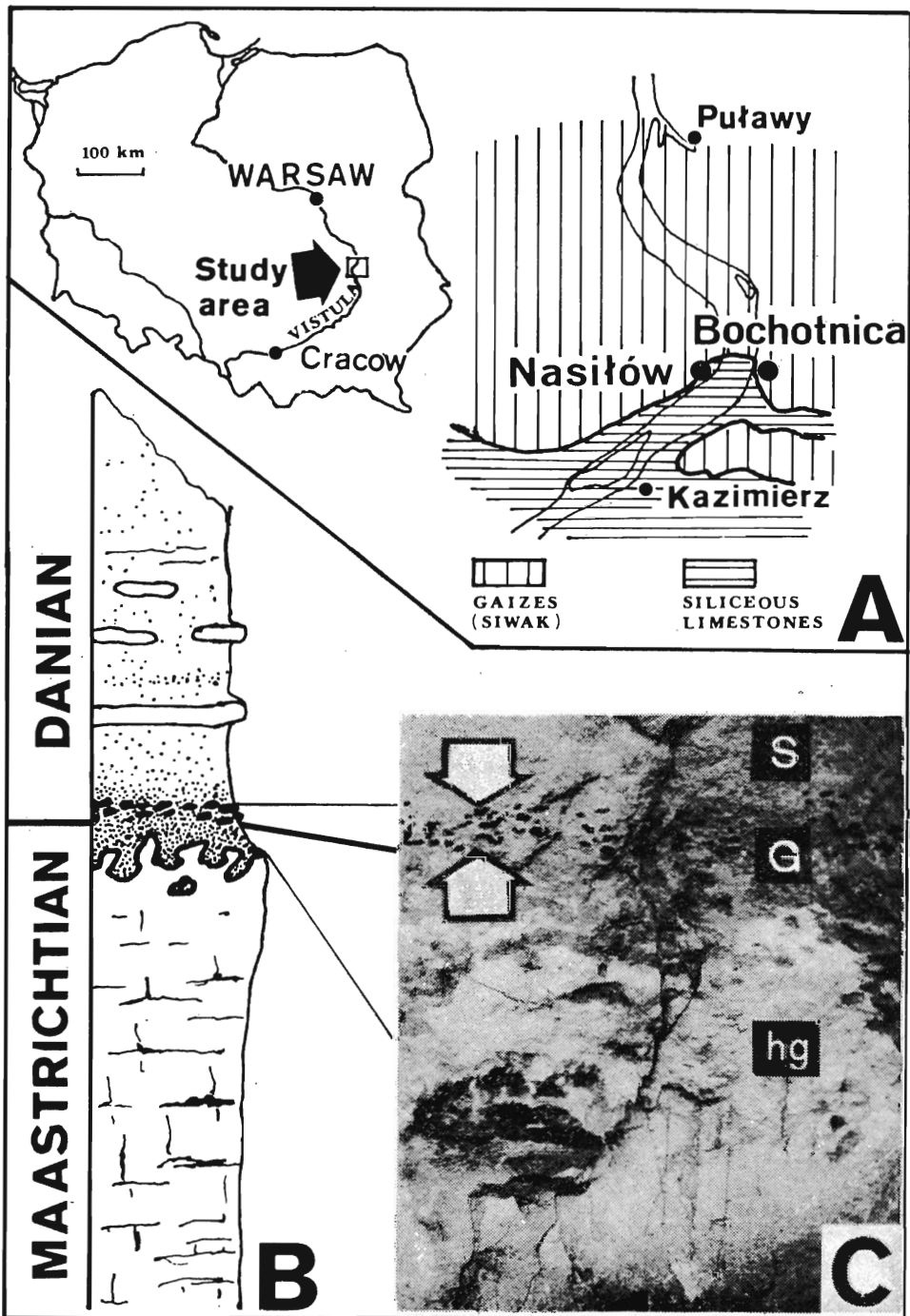
The Greensand exposed at Nasilów and Bochoznica terminates the mid- and Upper Cretaceous sequence exposed along the Middle Vistula Valley, between Annapol-on-Vistula and Puławy (POŻARYSKI 1938, MARCINOWSKI & RADWAŃSKI 1983). Geotectonically, this sequence belongs to the Border Synclorium (see MARCINOWSKI & RADWAŃSKI 1983), forming a simple monocline with a gentle regional dip of about 3° to NE (POŻARYSKI 1938)

The Greensand overlies the sequence of siliceous limestones (so-called opokas) capped with a hardground of the uppermost Maastrichtian age (BŁASZKIEWICZ 1980, ABDEL-GAWAD 1986) and is overlain by the gaizes and limestones of the so-called Siwak (Text-fig. 1). The Siwak was regarded as of Danian age by KONGIEL (1935, 1958), POŻARYSKI (1938), POŻARYSKA (1952), RADWAŃSKI (1985) and ABDEL-GAWAD (1986). On the contrary, POŻARYSKI & POŻARYSKA (1960), WOŻNY (1964), POŻARYSKA (1965), KRACH (1974, 1981) regarded this unit as being of Montian age.

The authors accept the Upper Danian age of the Siwak as stated recently by RADWAŃSKI (1985). This age is confirmed by the authors' own investigations of planktic foraminifers being the most meaningful group for the lowermost Tertiary stratigraphy. Among this group, in the samples from Nasilów and Bochoznica the following taxa were recorded: *Globoconusa daubjergensis* (BRÖNNIMANN), *Subbotina pseudo-bulloides* (PLUMMER), *S. trivialis* (SUBBOTINA), *S. varianta* (SUBBOTINA). They all form a typical Danian assemblage (see HANSEN 1970a, b, SALAJ, 1980, MOORKENS 1982). The assemblage of *G. daubjergensis* (BRÖNNIMANN) from the Siwak has the mean diameter value of the last whorl 160—170 µm; these values are comparable with those obtained by HANSEN (1970a) for the populations from Middle/Upper Danian of Denmark. Many benthic foraminifers cited by POŻARYSKA (1965) as indicating the Montian age of the Siwak were found later in the unquestionably Danian deposits (SALAJ & al. 1976, HAGN & al. 1981) and some others are aragonitic ones and as such they are not good guide fossils (HANSEN 1970b).

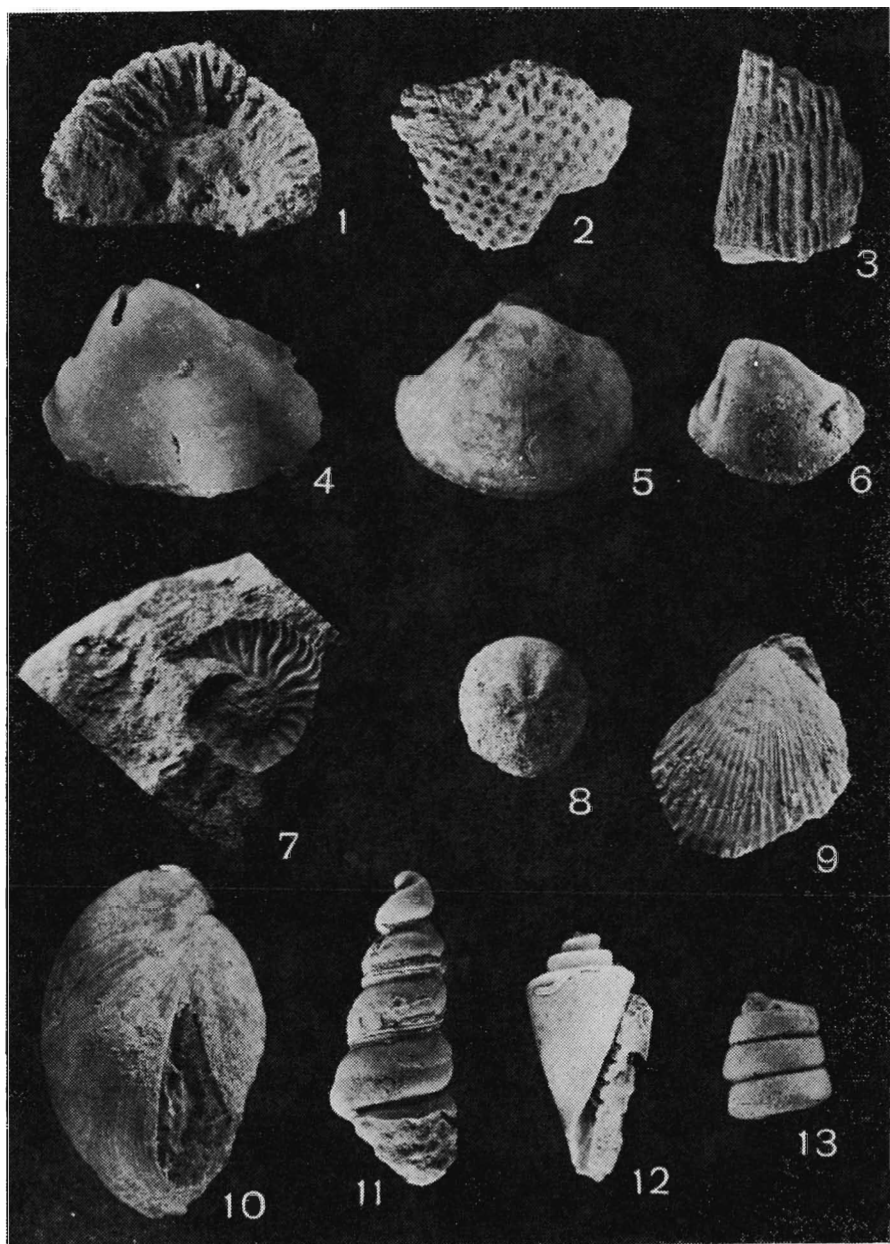
THE GREENSAND

The base for the Greensand is formed by an intensively burrowed hardground which terminates the uppermost Maastrichtian siliceous limestones (Text-fig. 1B—C and Text-fig. 2). Following the classification of KENNEDY & GARRISON (1975a, p. 325) it is an incipient hardground with a cemented part up to 1 m thick and with soft, strongly brecciated opoka cover ca. 20 cm thick (Text-fig. 2A—B). The most characteristic feature of the hardground are well visible burrows *Thalassinoides* sp.



A — Geological sketch-map of the studied area, **B** — Lithostratigraphic column of the sequence, **C** — Close-up view of the Greensand (phosphatic layer is arrowed) and the underlying hardground as exposed in the Bochoćnica quarry (taken from: ABDEL-GAWAD 1986, Text-fig. 10)

hg — hardground capping the siliceous limestones, G — Greensand, S — Siwak



Assemblage of phosphatized Maastrichtian fossils from the Greensand

All specimens from Nasilów, except of 10 and 13 from Bochoznica; taken in nat. size, except otherwise stated

1-3 — Sponge fragments; 4 — *Crasatella* sp.; 5 — *Mutiella coarctata* ZITTEL; 6 — *Nucula truncata* NILSSON, $\times 2$; 7 — *Hoploscaphites constrictus* (SOWERBY), $\times 2$; 8 — ?*Micrastra vistulensis* KONGIEL, $\times 1.5$; 9 — *Merklinia variabilis* (v. HAGENOW); 10 — *Neoliothyris obesa* (DAVIDSON); 11 — *Turritella* sp.; 12 — *Imbricaria limburgensis* BINKHORST; 13 — cerithiid gastropod, $\times 1.5$

and *Ophiomorpha saxonica* (GEINITZ) filled with the greensand. Particularly intensive burrowing is confined to the soft opoka cover which, as a result acquires a breccia appearance (pseudobreccia *sensu* BROMLEY 1975, BOTTJER 1985).

The Greensand itself is about 0.5 m thick layer of marly glauconitic sandstone, pale to dark green in color, and composed of angular quartz, glauconite and microfossil tests (mainly of the foraminifers) set in the marly matrix.

The foraminifers are represented primarily by the benthic forms. Among the planktic ones the typically Cretaceous Heterohelicidae dominate, though there also occur (cf. POŻARYSKA 1965) such Danian forms as *Globoconusa daubjergensis* (BRÖNNIMANN) and *Subbotina pseudobulloides* (PLUMMER).

The greensand bears no depositional textures and only in some deeper and larger burrows within the underlying hardground the primary lamination is preserved (Text-fig. 2B). It is worth noting that in the laminated parts the Danian foraminifers are completely absent.

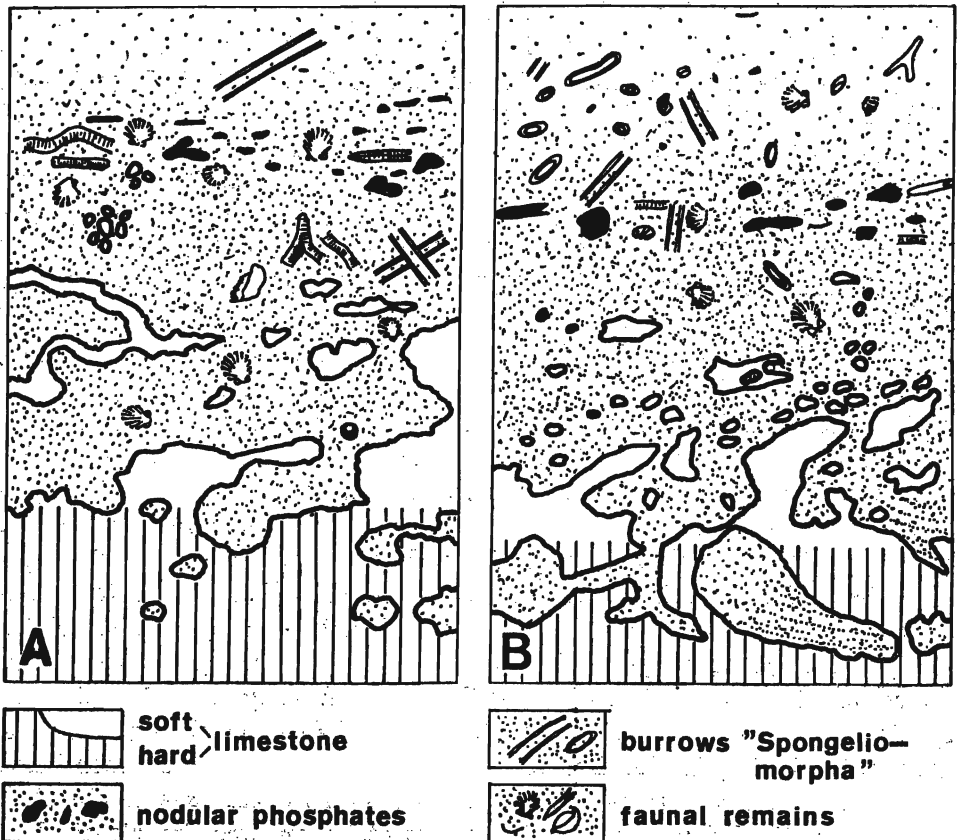


Fig. 2. Detailed views of the Greensand and the underlying hardground

Numerous burrows *Thalassinoides* sp., *Chondrites* sp. and "Spongiomorpha" *annulata* KENNEDY are present within the sediment (Text-fig. 2). They were also found in the earlier-burrow fillings in the underlying hardground.

In the upper part of the Greensand there is a distinct layer (Text-fig. 1B—C and Text-fig. 2) with abundant nodular phosphates and very rich unphosphatized Maastrichtian and Danian fossils (see KONGIEL 1935, KONGIEL & MATWIEJEWÓWNA 1937, KONGIEL 1962, POPIEL-BARCZYK 1968, KRACH 1981, RADWAŃSKI 1985, ABDEL-GAWAD 1986).

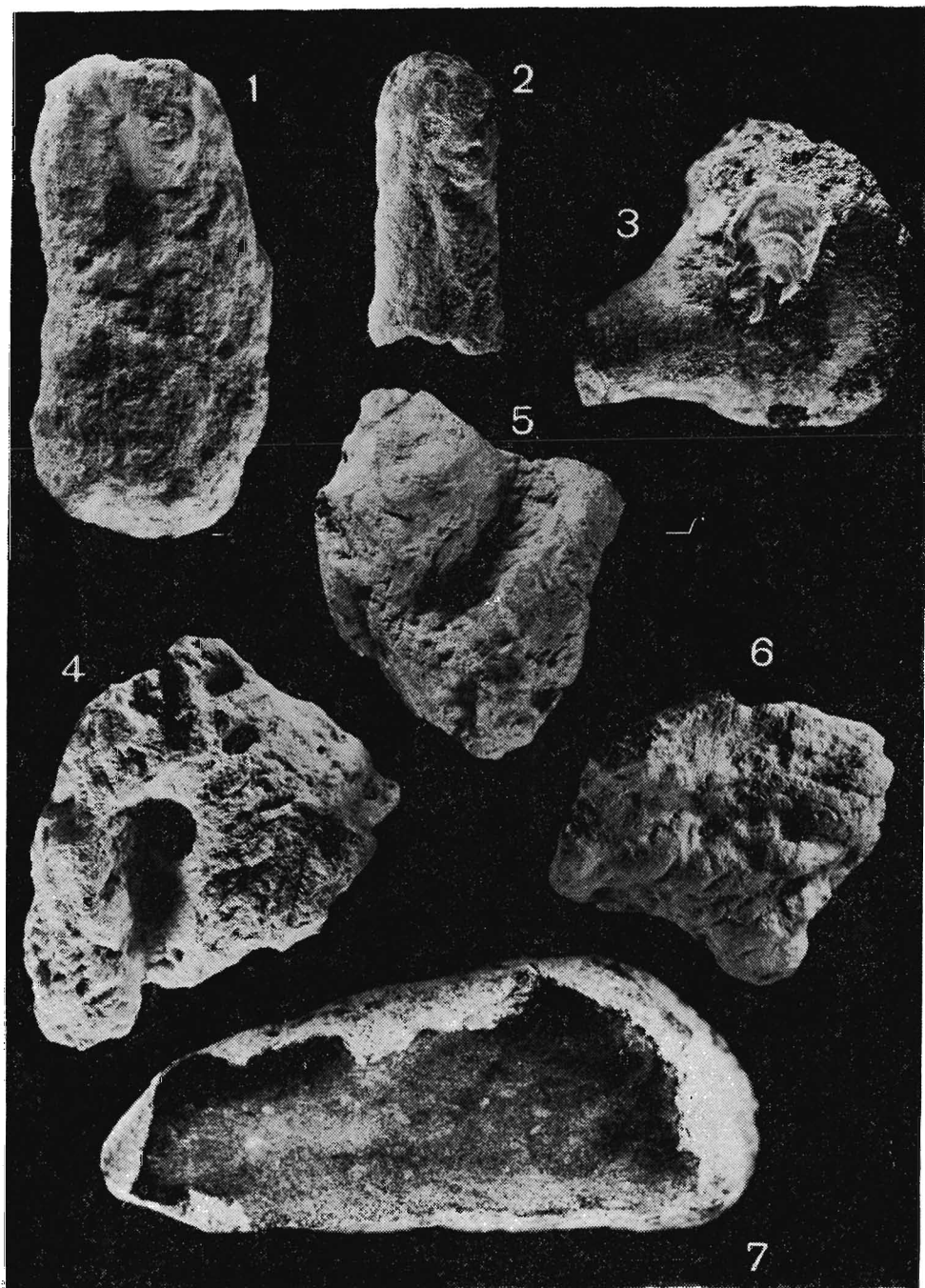
THE FOSSIL ASSEMBLAGES

Three groups of fossils may be distinguished within the Greensand basing on their stratigraphical ranges and state of preservation. These are: the phosphatized Maastrichtian assemblage, the unphosphatized Maastrichtian assemblage, and the Danian assemblage.

The phosphatized Maastrichtian assemblage is represented mainly by sponges, internal moulds of brachiopods, bivalves and gastropods, and also by belemnite guards with phosphatized alveolar fillings as well as by rare shark teeth and vertebrae (Table 1 and Pl. 1, Figs 1—13).

Numerous epizoans (*Spondylus*, *Placunopsis* and *Pycnodonte*) and borings (ichnogenera *Talpina* and *Trypanites*) are present in the belemnite guards, and former ones also on the sponges (Pl. 2, Fig. 3). Sinuous, surface canals occurring on some of the moulds are rather burrows produced prior to the filling became hard and when the shell was still present (compare FÜRSTICH & al. 1981, HENDERSON & McNAMARA 1985).

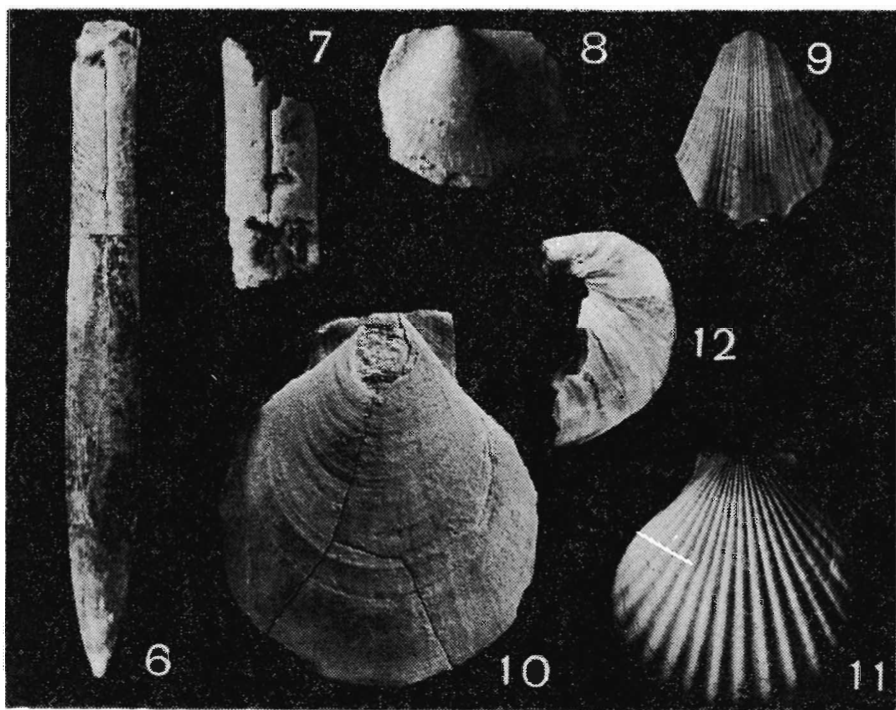
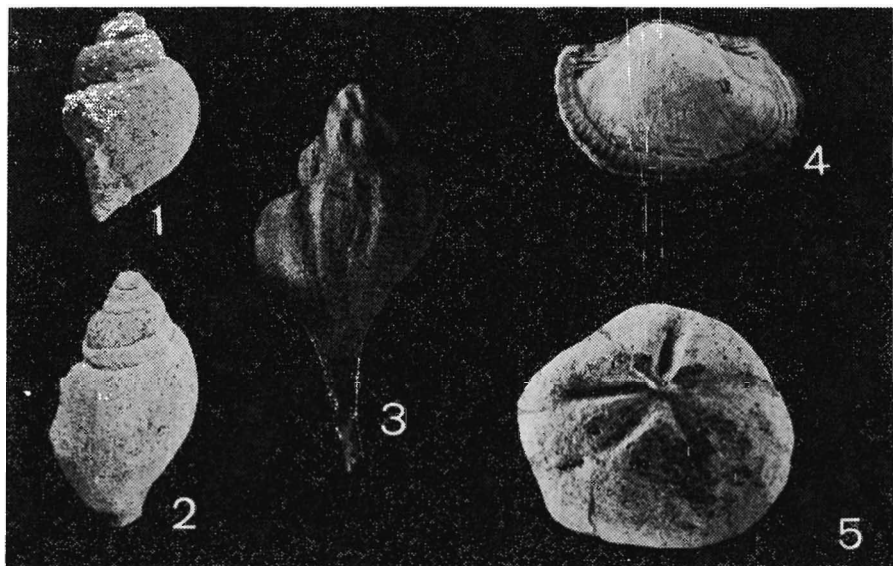
One feature of the phosphatized assemblage deserves special attention. This assemblage is significantly different from that preserved within the underlying hardground. The uppermost Maastrichtian hardground assemblage is dominated (see ABDEL-GAWAD 1986) by bivalves and gastropods of the genera *Aporrhais*, *Lyropecten*, *Limopsis*, *Turritella*, and *Opis*, as well as ammonites *Hoploscaphites constrictus* (SOWERBY) and *Baculites* spp. Very characteristic are also giant gastropods *Volutispina kazimiri* (KRACH) and some bivalves, like *Pholadomya* and *Panopea*. These forms are absent or very scarce in the phosphatized assemblage (with exclusion of *Lyropecten*). This concerns above all the ammonites. The authors found only two fragmentary specimens of *Hoploscaphites constrictus* (SOWERBY), being the first ammonite finding in the Greensand (Pl. 1, Fig. 7). On the other hand, some forms not known within the hardground appear (see Table 1) in the phosphatized fauna, for instance *Crasatella* sp. and *Imbricaria limburgensis* BINKHORST.



Phosphatized Maastrichtian concretions from the Greensand

All specimens from Nasitów, except of 1 from Bochoznica; taken in nat. size

1-2 — Burrow fillings; 3 — concretione sponge with attached *Spondylus* sp.; 4 — burrowed and scratched concretion; 5 — another concretion with a burrow in its centre (note scratch marks inside the burrow); 6 — the same concretion from the opposite side; 7 — polished section, to show strongly phosphatized zone along the margin of the concretion



Assemblage of Danian fossils from the Greensand of Bochoznica

1 — *Ampulospira austriaca* (TRAUB); 2 — *Scaphella crenistria* (KOENEN); 3 — *Clavilithes* sp.; 4 — *Cucullaea volgensis* BARBOT; 5 — *Diplodetus depressus* (KONGIEL)

Assemblage of unphosphatized Maastrichtian fossils from the Greensand of Bochoznica

6 — *Belemnella kazimirovicensis* (SKOŁOZDRÓWNA); 7 — strongly abraded and bored fragment of a *Belemnella* guard; 8 — *Oxytoma danica* (RAVN), $\times 2$; 9 — *Neithea sercostata* (WOODWARD); 10 — *Mimachlamys* sp.; 11 — *Lyropecten acuteplicatus* (ALTH); 12 — *Pycnodonte vesiculare* (LAMARCK)

Some phosphatized Maastrichtian fossils are enclosed in phosphatic concretions. These concretions bear numerous burrows with scratch marks (Pl. 2, Figs 4—6), suggesting crustaceans as producers (compare FÜRSICH 1979, BAIRD 1981, FÜRSICH & *al.* 1981). Some tubular specimens up to 10 cm long represent probably fillings of larger burrows (Pl. 2, Figs 1—2).

Very rare borings (ichnogenus *Gastrochaenolites*) and epizoans (*Gryphaeostrea*) were found in some concretions.

The moulds and concretions vary from pale brown to black in color. They are built of phosphatized (with fluorapatite as revealed by X-ray diffraction analysis), occasionally highly glauconitic limestone. In most specimens the strong phosphatization is confined to the marginal zone (Pl. 2, Fig. 7).

The whole phosphatized material is well comparable to those described from the lithologically similar Cretaceous sequences of England (KENNEDY & GARRISON 1975b) and the USA (FÜRSICH & *al.* 1981). Concretions and moulds represent probably early diagenetically cemented carbonate material which subsequently underwent superficial phosphatization, similarly as demonstrated by KENNEDY & GARRISON (1975b) for the Cenomanian Glauconitic Marl phosphorites.

Among the rich fauna noted in the Greensand there occur many uppermost Maastrichtian forms being not phosphatized (Table 2; Pl. 3, Figs 6—12). This concerns mainly single valves of calcitic bivalves and brachiopods, isolated plates and spines of echinoids, belemnites and sponge fragments. Some double-valved brachiopods and bivalves are filled with opoka, viz. *Neoliothyris obesa* (DAVIDSON), *Carneithyris* spp., *Kingenella kongieli* POPIEL-BARCZYK, *Cretirhynchia limbata* (SCHLOTHEIM), *Lyropecten acuteplicatus* (ALTH). The others are filled with greensand, for instance *Neoliothyris obesa* (DAVIDSON), *Carneithyris* spp., *Kingenella kongieli* POPIEL-BARCZYK, *Cretirhynchia woodwardi* (DAVIDSON) and *Gyropleura inaequirostrata* (WOODWARD).

Whereas the majority of fossils are fragmentary, the state of preservation of others is very good (cf. KONGIEL 1958, POPIEL-BARCZYK 1968, RADWAŃSKI 1985), as evidenced mainly by brachiopods with complete brachidia and belemnite guards with very thin alveolar walls.

A distinct group, regarding its state of preservation, is represented by aragonitic bivalves and gastropods occurring as fine moulds and imprints (Pl. 3, Figs 1—4). These which were determined to the species level are unequivocally of the Danian age (Table 3; see also KRACH 1981). In the lack of contradictory proof the authors assume the Danian age for the remaining fauna with the same state of preservation (Table 3).

Table 1

Assemblage of phosphatized Maastrichtian fossils from the Greensand

Systematic groups	Frequency	Trophic category	Age range
SPONGES	A	ep. SF	
SOLITARY CORALS:			
Caryophyllia sp.	R	ep. SF/C	K/T
Trochocyathus sp.	A	ep. SF/C	K/T
POLYCHAETES:			
Sclerostyla septenaria	O	ep. SF	K
BRACHIOPODS:			
Neolithyrina obesa	F	ep. SF	K
Carneithyris spp.	A	ep. SF	K/T
BIVALVES:			
Nucula truncata	F	in. DF	K
Nucula sp.	F	in. DF	K/T
Arca sp.	R	ep. SF	K/T
Lyropecten acuteplicatus	A	ep. SF	K
Merklina variabilis	R	ep. SF	K
Neithea sexcostata	R	ep. SF	K
Spondylus sp.	R	ep. SF	K/T
Placunopsis sp.	R	ep. SF	K
Limea granulata	R	ep. SF	K
Limatula sp.	O	ep. SF	K/T
Pycnodonte vesiculare	O	ep. SF	K
Gryphaeostrea canaliculata	R	ep. SF	K/T
Rhynchostreon suborbiculatum	R	ep. SF	K
Lucina sp.	R	in. SF	K/T
Fimbria sp.	R	in. SF	K/T
Mutiella coarctata	R	in. SF	K
Crasatella sp.	O	in. SF	K/T
Pleuriocardia noeggerathi	O	in. SF	K
Tellina sp.	R	in. SF	K/T
Trapezium trapezoidale	R	in. SF	K
Gyropleura inaequirostrata	R	ep. SF	K

FREQUENCY: R — rare, O — occasional, F — frequent, A — abundant

Trophic categories after WALKER & BAMBACH (1974): ep. — epifaunal, in. — infaunal, sl. — semiinfaunal, n — nectic; SF — suspension feeder, DF — deposit feeder, B — browser, S — scavenger, C — carnivore

Systematic groups	Frequency	Trophic category	Age range
GASTROPODS:			
<i>Pleurotomaria</i> sp.	R	ep. B	K/T
<i>Emarginula</i> sp.	R	ep. B	K/T
Cerithiidae indet.	O	ep. B	K/T
<i>Turritella plana</i>	R	si. SF	K
<i>Turritella</i> sp.	R	si. SF	K/T
Vermetidae indet.	R	si. SF	K/T
<i>Xenophora</i> sp.	R	ep. B	K/T
<i>Natica cretacea</i>	O	in. C	K
<i>Tritonium</i> sp.	O	ep. C	K/T
<i>Imbricaria limburgensis</i>	R	ep. C	K
<i>Ringicula</i> sp.	F	ep. C	K/T
<i>Cylichna</i> sp.	O	ep. C	K/T
CEPHALOPODS:			
<i>Belemnella kazimiroviensis</i>	F	n. C	K
<i>Hoploscaphites constrictus</i>	R	n. C	K
ECHINOIDS:			
? <i>Micraster vistulensis</i>	R	si. DF	end.
FISHES:			
Shark teeth and vertebrae	O	n. C	

AGE: K/T — forms passing the Cretaceous/Tertiary boundary, K — forms restricted to the Cretaceous, T — forms restricted to the Tertiary, end. — endemites

TAXONOMY of the fossils and their ranges based on: ŁOPUSKI (1911—1912), KRACH (1931, 1981), KONGIEL (1935, 1949, 1962), KONGIEL & MATWIEJEWÓWNA (1937), POPIEL-BARCZYK (1968), PUGACZEWSKA (1977), ABDEL-GAWAD (1986) as well as: WOODS (1889—1913), ROSENKRANTZ (1960), GLIBERT (1973), GLIBERT & VAN de POEL (1973), HEINBERG (1979), BELYAKOVA & *al.* (1981), AMITROV & *al.* (1981), DHONDT (1982).

To this assemblage there must be included also some echinoids (Pl. 3, Fig. 5), oysters, serpulids and perhaps also the moulds of some solitary corals as may be concluded basing on their presence in the Siwak.

The distribution of the Danian macrofossils within the Greensand is uneven. The majority of the specimens are to be found in the phosphatic layer, while only few (mainly burrowing *Nucula* and *Cucullaea*) occur beneath.

Table 2

Assemblage of unphosphatized Maastrichtian fossils from the Greensand (explanations the same as for Table 1)

Systematic groups	Frequency	Trophic category	Age range
SPONGES	A	ep. SF	
POLYCHAETES:			
<i>Sclerostyla septenaria</i>	F	ep. SF	K
<i>Glomerula gordialis</i>	O	ep. SF	K/T
BRACHIOPODS:			
<i>Neolothyrina obesa</i>	F	ep. SF	K
<i>Carneithyrus</i> spp.	A	ep. SF	K/T
<i>Kingenella kongieli</i>	F	ep. SF	K
<i>Cretirhynchia limbata</i>	F	ep. SF	K
<i>Cretirhynchia woodwardi</i>	R	ep. SF	K
CIRRIPEDES:			
<i>Cretiscapellum</i> sp.	R	ep. SF	K
BIVALVES:			
<i>Oxytoma danica</i>	O	ep. SF	K
<i>Mimachlamys cretosa</i>	O	ep. SF	K
<i>Mimachlamys</i> sp. (close to forms from opoka)	F	ep. SF	K
<i>Lyropecten acuteplicatus</i>	A	ep. SF	K
<i>Lyropecten pulchellus</i>	R	ep. SF	K
<i>Neithea sexcostata</i>	R	ep. SF	K
<i>Spondylus serratus</i>	R	ep. SF	K
<i>Atreta nilssoni</i>	O	ep. SF	K
<i>Plagiostoma cretacea</i>	R	ep. SF	K
<i>Plagiostoma hoperi</i>	F	ep. SF	K
<i>Limatula</i> sp.	R	ep. SF	K/T
<i>Pycnodonte vesiculare</i>	A	ep. SF	K
<i>Hytissa lunata</i>	R	ep. SF	K
<i>Hytissa semiplana</i>	R	ep. SF	K
<i>Gryphaeostrea canaliculata</i>	A	ep. SF	K/T
<i>Gyropleura inaequirostrata</i>	R	ep. SF	K
CEPHALOPODS:			
<i>Belemnella kazimiroviensis</i>	A	n. C	K
<i>Belemnella pensaensis</i>	R	n. C	K
ECHINOIDS:			
<i>Typocidaris serrata</i>	A	ep. B/S/C	K
<i>Phymosoma</i> sp.	O	ep. B/S/C	K

Table 3

Assemblage of Danian fossils from the Greensand (explanations the same as for Table 1)

Systematic groups	Frequency	Trophic category	Age range
SOLITARY CORALS:			
<i>Stephanocyathus</i> sp.	R	ep. SF/C	T
POLYCHAETES:			
<i>Glomerula gordialis</i>	O	ep. SF	K/T
BIVALVES:			
<i>Nucula</i> spp.	A	in. DF	K/T
<i>Cucullaea volgensis</i>	A	in. SF	T
<i>Gryphaeostrea canaliculata</i>	A	ep. SF	K/T
<i>Cyrena</i> sp.	R	in. SF	K/T
<i>Crasatella krachi</i>	R	in. SF	T
<i>Crasatella</i> sp.	O	in. SF	K/T
<i>Pholadomya</i> sp. (close to forms from Siwak)	R	in. SF	T
GASTROPODS:			
Cerithiidae indet.	F	ep. B	K/T
<i>Rhinoclavis</i> sp.	R	ep. B	K/T
<i>Ampulospira austriaca</i>	F	in. C	T
<i>Euspira detrita</i>	O	in. C	T
<i>Arrhoges gracilis</i>	F	in. SF	T
<i>Columbarium heberti</i>	O	ep. C	T
<i>Clavilithes</i> sp.	R	ep. C	T
<i>Scaphella crenistria</i>	O	ep. C	T
<i>Surcula</i> sp.	R	ep. C	K/T
ECHINOIDS:			
<i>Diplodetus depressus</i>	R	si. DF	T
<i>Echinocorys cf. rectus</i>	R	si. DF	T

FAUNAL CONDENSATION AND MIXING

The uppermost Maastrichtian unphosphatized fossils filled with the glauconitic sediment represent indigenous animals which lived during sedimentation of the glauconitic sands in the latest Maastrichtian sea (compare KONGIEL 1958, POPIEL-BARCZYK 1968, RADWAŃSKI 1985).

The same may be probably stated also on the majority of other Maastrichtian unphosphatized fossils, especially on those characterized by a very good state of preservation.

The source of phosphatized fossils is more problematical, but information on their origin is provided by an analysis of lithology and taxonomic composition of the phosphatized assemblage.

The phosphates could have not been formed originally within the Greensand. This is indicated by the original lithology of the phosphatized material, being completely different from the surrounding sandy sediment. They could have not been formed also through the phosphatization of the opoka fragments from the underlying hardground, what was suggested recently by RADWAŃSKI (1985). This is evidenced by: (i) high glauconite content in some nodules not observable in the hardground, and (ii) differences in taxonomic composition of the phosphatized and hardground faunal assemblages. Thus, two possibilities concerning the birth place of the phosphatized concretions and fossils may be considered: (i) the phosphates come from any place outside the studied area, or (ii) they are derived from a carbonate unit formerly present in the discussed area and removed later by erosion with remaining early cemented nodules and fossils forming a kind of the residual lag (compare POŻARYSKA 1965, RADWAŃSKI 1985) deposited along the surface at which the erosion had stopped. The authors accept the second possibility as any significant lateral transport should be excluded basing on a lack of any differentiation in size or in state of preservation of the phosphatized material between the outcrops, and on the lack of their rounding.

The timing of the residual lag formation and the erosion of the carbonate unit is not obvious. These phenomena could have taken place both in the uppermost Maastrichtian and in the Lower and/or Middle Danian. The authors regard the second case as more probable due to the existence of a stratigraphic gap in the section, comprising the Lower and Middle Danian. The Danian time of the erosional event is evidenced also by the lack of unequivocally Maastrichtian epibionts on the surfaces of moulds and concretions. Thus, the Cretaceous/Tertiary boundary should be placed within the Greensand, just below the layer with abundant phosphates and fossils (Text-fig. 1B).

Danian fossils concentrated together with Maastrichtian ones in the uppermost part of the Greensand clearly represent an assemblage colonizing the sea-bottom after the erosional event. But the presence of the Danian micro- and macrofossils below the residual lag needs a separate discussion. Their spotty or patchy occurrence, the presence among them of mainly burrowing bivalves, and the occurrence of the Danian foraminifers only in the burrowed (non-laminated) parts of the

greensand well prove the secondary introduction of the Danian elements into the Maastrichtian deposits through the activity of infauna. Analogical cases have recently been recognized by FÜRSICH (1978), MARCINOWSKI & WALASZCZYK (1985) and WALASZCZYK (1987).

The life activity of infauna is a very effective factor in mixing of the bottom sediment. It was demonstrated in many recent shallow marine environments (RHODS 1967, CLIFTON & HUNTER 1973, ALLER 1982, TUDHOPE & SCOFFIN 1984). According to the experiments by CLIFTON & HUNTER (1973), due to an "undermining" activity of infauna the rock fragments lying originally on the bottom are introduced in short time into the sediment down to 30 cm. Similar depth of mixing was observed in the mid-Cretaceous sequence at Annapol-on-Vistula (MARCINOWSKI & WALASZCZYK 1985, WALASZCZYK 1987).

Two groups of infauna had probably the greatest significance in the bioturbational process. These are burrowing crustaceans, e.g. producers of the "*Spongeliomorpha*" burrows (KENNEDY 1967) crossing both the residual lag and the pure greensand beneath (Text-fig. 2), and deposit-feeding nuculids very common in the Danian assemblage. In modern environments the activity of the latter group has a great bearing on the bottom reworking (see ALLER 1982; and references in BAIRD 1981).

THE GREENSAND DEVELOPMENT

Summarizing the above considerations one may conclude that the Greensand appears to be a result of a complex history of redeposition, condensation and mixing. Four stages of its development may be distinguished basing on sedimentological and paleontological data (Text-fig. 3).

Stage 1 (uppermost Maastrichtian)

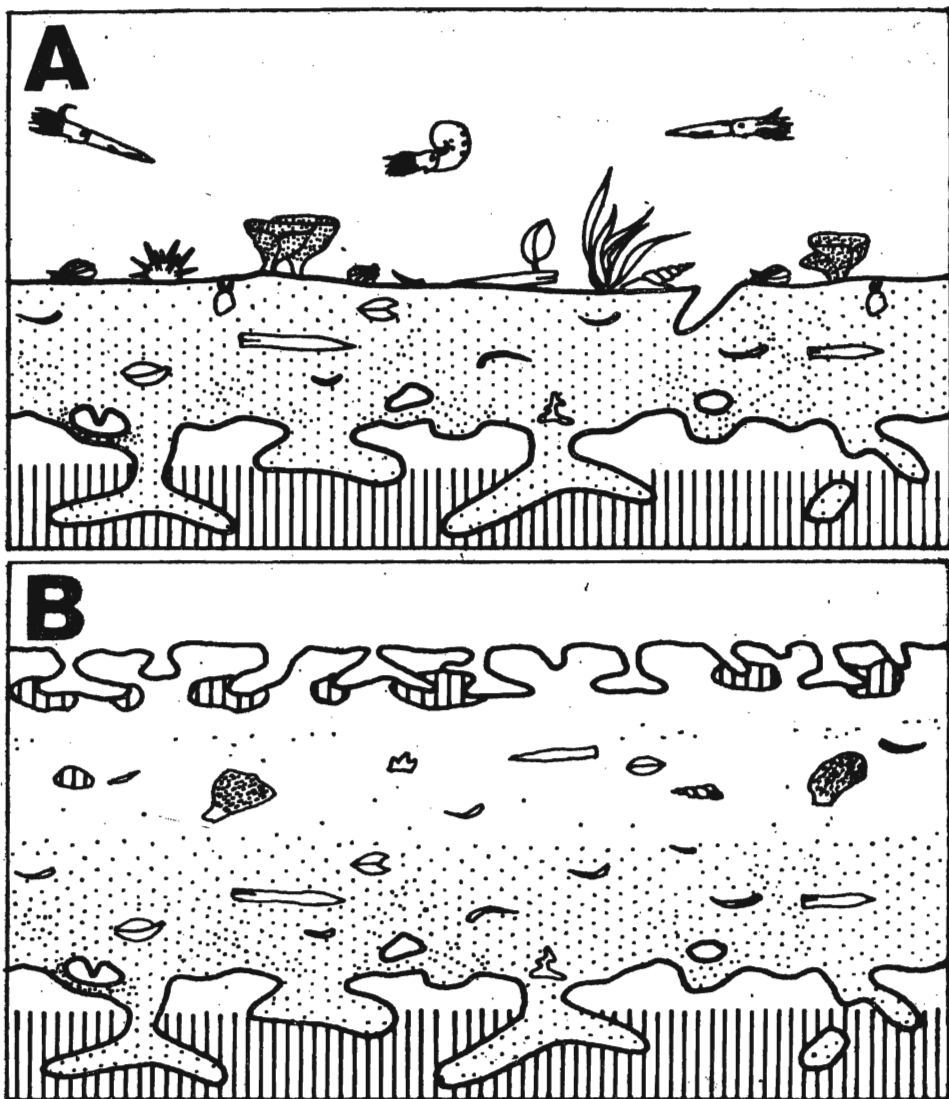
Renewal of the sedimentation after its stop during the hardground formation, deposition of the greensand followed by the carbonate unit sedimentation (Text-fig. 3A).

Stage 2 (uppermost Maastrichtian)

Stop of sedimentation and the early diagenetic cementation of the substrate along with burrowing organisms activity (Text-fig. 3B).

Stage 3 (Lower and/or Middle Danian)

Erosion of the carbonate unit and formation of the residual lag (Text-fig. 3C) along with phosphatization of the carbonate concretions and



moulds in a way probably analogical to that postulated by KENNEDY & GARRISON (1975).

Stage 4 (Upper Danian)

Sedimentation of the gaizes, *i.e.* the Siwak, and mottling of the sediment by diverse infaunal biota (Text-fig. 3D), leading to an intense reworking and vertical displacement of sediment grains, phosphatic nodules and the Danian and Maastrichtian fossils even into the burrows within the underlying hardground (burrow-in-burrow structures).

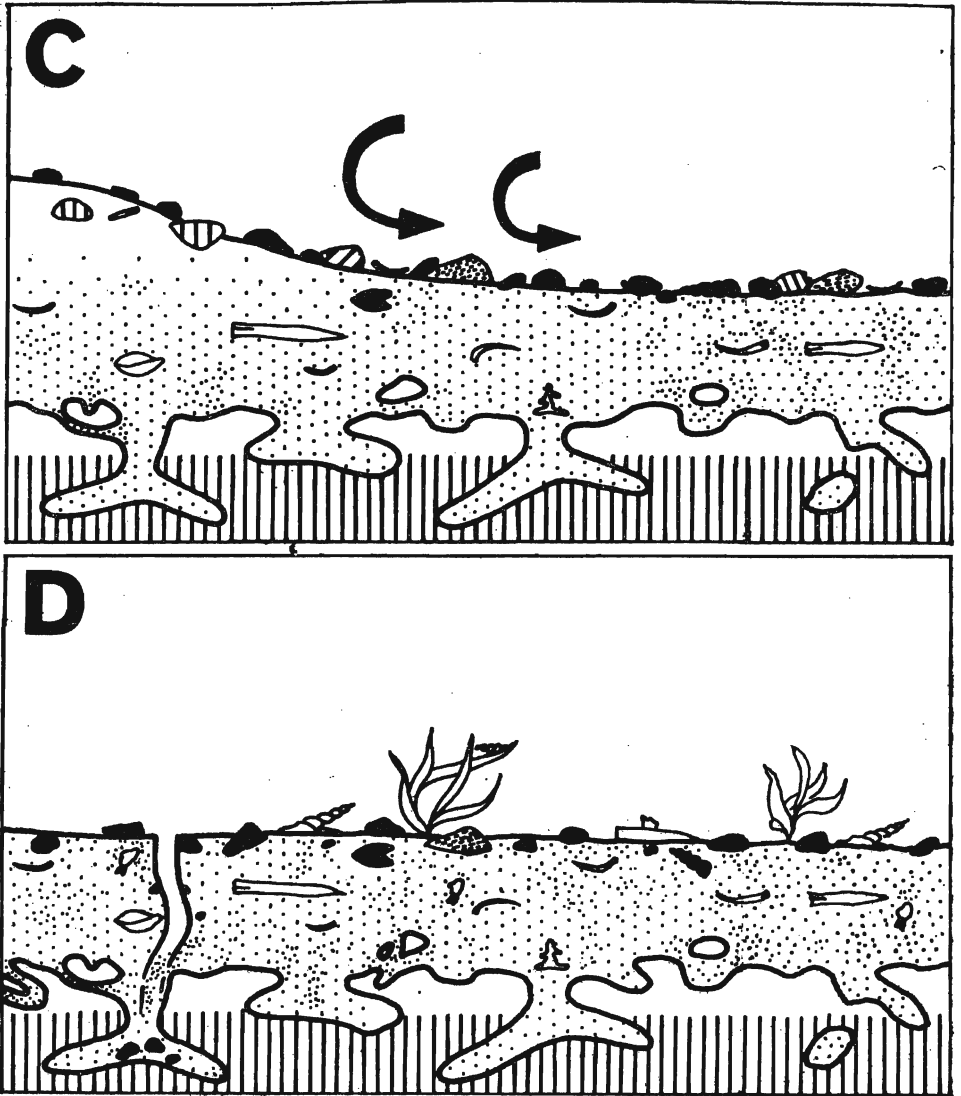


Fig. 3. Reconstruction of the Greensand development; detailed explanations in the text

SUMMARY AND CONCLUSIONS

An analysis of the stratigraphical ranges and the preservation state and distribution of the fossil assemblages preserved within the Greensand provides a lot of information about the history of sedimentation of this unit. Three assemblages are to be distinguished: unphosphatized Maastrichtian, phosphatized Maastrichtian and the Danian assemblage. The recognition of the complex history of these assemblages permits to place the Cretaceous/Tertiary boundary just below the residual lag abounding

in phosphorites and fossils. Up to now the Greensand was regarded as of uppermost Maastrichtian age (KONGIEL 1935, 1958; POŻARYSKI 1938; RADWAŃSKI 1935), or as of either Danian or Montian age (POŻARYSKI & POŻARYSKA 1960, WOŻNY 1964, POŻARYSKA 1965, BŁASZKIEWICZ 1980, KRACH 1981). Such a significant disagreement in opinions was caused by the fact that particular authors based their conclusions either on Maastrichtian or on Paleocene (Danian or Montian) elements present in the Greensand. In the "Paleocene" interpretation the Maastrichtian fossils were regarded as redeposited from the underlying deposits (e.g. POŻARYSKA 1965, BŁASZKIEWICZ 1980, KRACH 1981). This study, like many others (e.g. FÜRSICH 1978, SEILACHER 1985, MARCINOWSKI & WALASZCZYK 1985), shows that a simple model may sometimes be insufficient and that any stratigraphical and/or ecological conclusions must be preceded by a careful taphonomical analysis of the whole fossil assemblage contained in a given sedimentary unit. This also corroborates the significance of infaunal organisms in the formation of drastic lithological boundaries within diverse sedimentary sequences (see BAIRD 1978, 1981; EKDALE & BROMLEY 1984; MARCINOWSKI & WALASZCZYK 1985; WALASZCZYK 1987).

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**KONDENSACJA I WYMIESZANIE ZESPOŁÓW FAUNISTYCZNYCH
NAJWYŻSZEGO MASTRYCHTU I DANU
W PIASKOWCU GLAUKONITOWYM NASIŁOWA I BOCHOTNICY**

(Streszczenie)

Piaskowiec glaukonitowy odsłaniający się w kamieniołomach w Nasiłowie i Bochotnicy koło Kazimierza nad Wisłą (patrz fig. 1—2) zawiera bogaty i zróżnicowany zestaw skamieniałości najwyższego mastychtu i danu (por. POŻARYSKI 1938, KONGIEL 1962, POŻARYSKA 1965, KRACH 1981, RADWAŃSKI 1985, ABDEL-GAWAD 1986). Na podstawie analizy zasięgów wiekowych i stanu zachowania poszczególnych form wyróżnić można trzy zespoły skamieniałości: sfosfatoryzowany mastychcki (patrz tab. 1 oraz pl. 1), niesfosfatoryzowany mastychcki (patrz tab. 2 oraz pl. 3, fig. 6—12) i dański (patrz tab. 3 oraz pl. 3, fig. 1—5). Współwystępowanie ich w piaskowcu glaukonitowym jest rezultatem procesów kondensacji i wymieszania, spośród których najważniejsze było powstanie rezydualnej warstwy konkrecji oraz pionowe przemieszanie osadu i skamieniałości przez organizmy infaunalne (skorupiaki i małże). Oba te procesy miały miejsce w danie. Rekonstrukcja historii zespołów skamieniałości w połączeniu z wynikami analizy sedymentologicznej (patrz pl. 2 oraz fig. 3) pozwala umiejscowić granicę kreda/trzeciorzęd w obrębie piaskowca glaukonitowego tuż poniżej rezydualnej warstwy z licznymi konkrecjami i fauną.
