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Condensed Cretaceous sequence with stromatolites in the Polish Jura Chain

ABSTRACT: The Cretaceous stromatolites from the Polish Jura Chain (western margin of the Miechów synclinorium) are described. The high-energy, shallow marine water below the intertidal zone is postulated as an environment of their formation. A considerable content of collophane gives them a composite, partly biosedimentary and partly inorganic character. In the northern area (Pniaki), the stromatolites overlie condensed Cenomanian-Turonian deposits, the microfacial analysis of which reveals a cyclic detrital inflow. The appearance of the stromatolitic layer is preceded by an increase in the detrital inflow, connected with the decrease in rate of sedimentation and probably, shallowing. The submarine nondepositional surface occurs in both the northern (Pniaki) and southern (Bocieniec) area in the top of the stromatolitic layer. Since at Bocieniec, this layer is connected with conglomerate, the age of which has, on the basis of *Lewesiceras peramplum* (Mantell), been determined as Turonian, the stromatolitic layer is also assigned to the Turonian.

INTRODUCTION

The Cretaceous stromatolites, known from very few localities (Niegodzisz 1965, Achauer & Johnson 1969) have only rarely been described. For this reason, the Upper Cretaceous stromatolites in the Polish Jura Chain (*cf.* Fig. 1) have been subjected to accurate studies. In the two outcrops, they occur at a discontinuity surface, corresponding to a considerable stratigraphic gap, which is also observed in several other outcrops, but in which it is not accompanied by the stromatolites. For an accurate determination of the character of this discontinuity surface and of the evolution of sedimentary environment leading to the formation of stromatolites and discontinuity surface, a microfacial analysis has been presented of the sequence in which they occur. The analysis was made for the Pniaki profile containing a stromatolitic layer and, comparatively, for two selected profiles (Skrajniwa, Zalesice), in which different conditions were observed near the nondepositional surface. The present paper also contains a description of the ammonite *Lewesiceras peramplum* (Mantell), whose presence in the conglomerate from Bocieniec, enabled along with sedimentological premises, a different determination of the age of stromatolites from Bocieniec than that previously accepted.

The writers' heartfelt thanks are extended to Dr. S. Cieśliński of the Geological Survey of Poland for making available specimens of cephalopods collected from the conglomerate at Bocieniec and to Professor H. Makowski for lending a specimen from the Turonian of Volhynia, which has been used for comparative purposes in the paleontological part of the paper. Thanks are also due to Dr. R. Chlebowski for a profitable discussion.

GENERAL STRATIGRAPHY

The stratigraphy of the Cretaceous deposits in the Polish Jura Chain, *i.e.* in the western margin of the Miechów synclinorium has been elaborated by many authors (Sujkowski 1926, 1929, 1934; Panow 1934; Różycki 1937, 1938; Kowalski 1948; Rutkowski 1965, 1971; Bukowy 1968; Marcinowski 1970).

For the purposes of the present paper, this area has been divided into two regions: the northern, including Zalesice, Skrajniwa, Lelów and Pniaki, and southern, contained between Podgaj and Bocieniec (Fig. 1).

In the two areas, the Cretaceous deposits include an Upper Albian — Turonian transgressive cycle, and the Santonian or directly Campa-

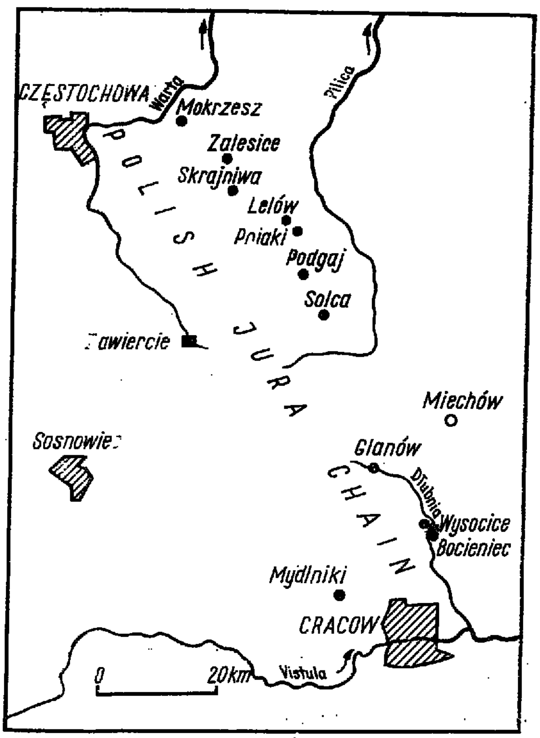


Fig. 1

Exposures of the transgressive Cretaceous deposits in the western margin of the Miechów synclinorium

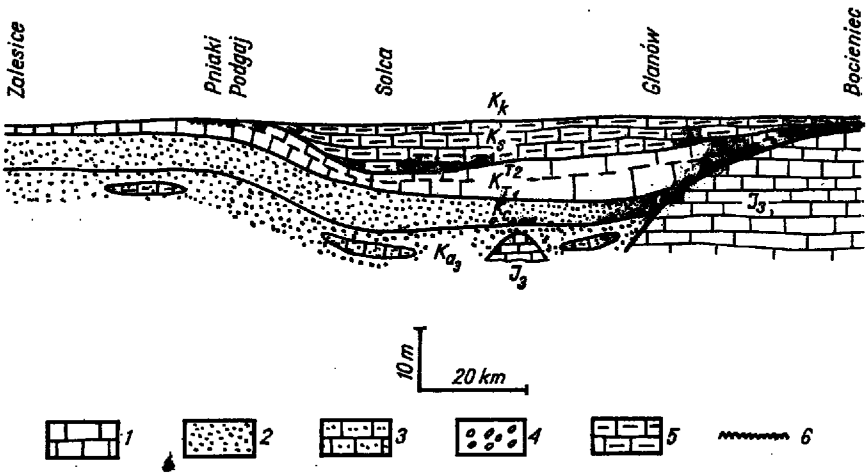


Fig. 2

Schematic section of Cretaceous deposits in the western margin of the Miechów synclinorium (cf. Text-fig. 1); bottom of the Lower Campanian is the correlation level

1 limestones, 2 sands, 3 sandstones, 4 conglomerates, 5 marls, 6 stromatolites; J_3 Upper Jurassic, Ka_3 Upper Albian, Kc Cenomanian, Kt_1 Lower Turonian, Kt_2 lower part of the Upper Turonian, Ks Santonian, Kk Campanian

nian (Fig. 2) [1], everyone of which overlies the discontinuity surface associated with a stratigraphic gap. In the northern region, the gap above the Lower Turonian includes the Upper Turonian, Coniacian and Santonian. In all the three studied profiles from the northern area (Zalesice, Skrajniwa, Pniaki), this gap has an identical range (Różycki 1937, 1938). In the southern area, it is subject a contraction at the bottom and top, since it is already in the environs of Podgaj that the lower part of the Upper Turonian and, near Solca, the Santonian (Różycki 1938) appear.

The lithological sequence is nearly identical in all the profiles of the northern area. The sedimentation starts with noncalcareous quartz sands intercalated by sandstones and gravels. These rocks, containing glauconite, belong to the Upper Albian. Topwards, they turn into marly sands and sandstones with glauconite (Cenomanian). They are overlaid by sandy limestones, the frequency of quartz and glauconite in which decreases topwards (Lower Turonian, I. labiatus and I. lamarcki Zones).

In the southernmost part of the area under study (Poręba Dzierżna, Wolbrom, Glanów, Bocieniec) various Cretaceous members (Upper Albian, Cenomanian, Turonian, Santonian) directly overlie Upper Jurassic limestones. A complete sedimentary sequence, including the Upper Albian, Cenomanian and Turonian is in this region similar to that in the northern

[1] This generalized section only approximately illustrates the problems of mutual relationships between the Cretaceous deposits and of their contacts with the Jurassic substrate. A detailed section and a commentary, dealing with these problems, will be included in a separate paper, now being prepared by R. Marcinowski.

area, except for the conglomerates, or single quartz pebbles (Fig. 2) which are common in its transgressive members. In the entire area, the deposits of the transgressive cycle have a reduced thickness, which is particularly marked in the Cenomanian and Turonian. The thickness of the Cenomanian makes up about 20 and of the Turonian 5 to 6 per cent of the thickness of deposits equivalent in age in the south-eastern margin of the Miechów synclinorium. Even if we take into account the fact that in the area under study the Turonian is incomplete and represented by at most three zones, while in the south-eastern margin of the Miechów synclinorium all the four Turonian zones are known (cf. Cieśliński & Pożaryski 1970), a considerable difference is unquestionable.

In the stratigraphic reduction and condensation, occurring in the deposits under study, are also confirmed by mixed ammonite assemblage in the Cenomanian of the environs of Mokrzesz and Zalesice (Marcinowski 1970).

MICROFACIAL ANALYSIS OF THE NORTHERN PROFILES

A condensed sedimentary sequence, including deposits of the uppermost Cenomanian, Turonian and Campanian (except for its lower, sandy part), has been subjected to microscopic studies. These deposits under- and overlie a discontinuity surface, with which the stromatolites are associated. Three profiles: Zalesice, Skrajniwa and Pniaki (Figs 3—5) are investigated from the northern area. A stratigraphic gap is marked in all the three profiles, but the stromatolites occur only at Pniaki. Observations made at Skrajniwa and Zalesice allow for a certain generalization of those from Pniaki and which concern the history of sedimentation and the character of discontinuity surface.

The method of investigation

The studies have been based on Carozzi's (*e.g.* 1958) method, which is founded on a measurement of the apparent maximum grain size (clasticity index) and of the frequency of the components (frequency index). The frequency have been measured on a 60 sq mm surface of a thin section. The clasticity and frequency measurements have been taken for quartz and glauconite and the frequency alone for biogenic components. The last-named are planktonic foraminifers (mostly *Globigerina*, *Globotruncana* and *Rotalipora*), inoceram fragments and sponge spicules. All these values are shown as variation curves drawn alongside the stratigraphic columns.

Other microfauna and fossil fragments (echinoderms, benthic foraminifers, brachiopods, other pelecypods) occurred in so small numbers that they might be safely disregarded in measurements.

Vertical evolution of microfacies

All the three profiles are condensed and their stratigraphy have been elaborated. Particular stratigraphic members are only several scores of *cm* thick. Thus, the vertical analysis of microfacial changes is in this case expected not so much to state precisely the correlation as to present the facial evolution of the deposits. The values of clasticity and frequency index for the same stratigraphic members in various profiles considerably differ, *e.g.* the Turonian at Zalesice is on the whole poorer in quartz than in the remaining two profiles. For this reason no correlated microfacies have been distinguished which are determined by a closed variability range of indices corresponding to particular components. The course of individual curves in all profiles is, however, approximately the same, despite their being shifted in the scale of the values measured in particular profiles. Consequently, similar to each other are also the relationships between particular curves for each of the profiles. The evolution of microfacies in the profiles under study is shown below with the reference to the stratigraphic units distinguished.

The Cenomanian (upper part). — The lowermost part of the profiles is characterized by a considerable quartz and glauconite content, with an almost complete lack of biogenic components, or, at most, of the presence of inoceram fragments and single planktonic foraminifers.

The Lower Turonian, Inoceramus labiatus Zone. — The frequency of quartz considerably exceeds (Pl. 1, Fig. 5) that of biogenic components (inocerams, plankto-

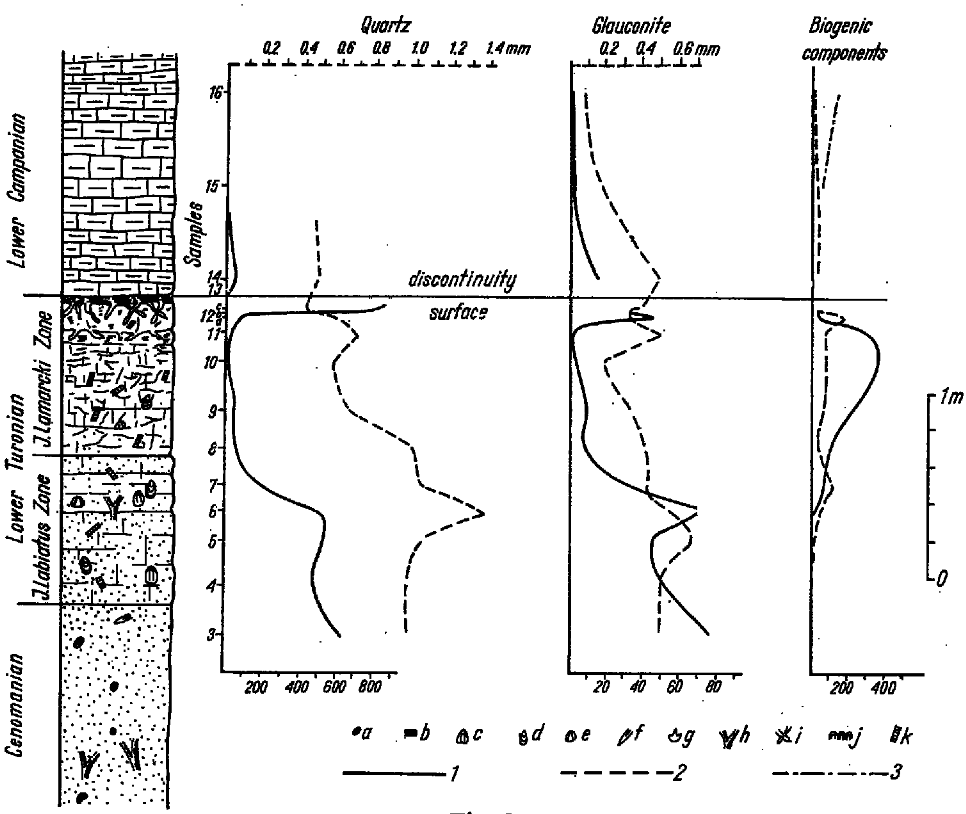


Fig. 3

Vertical succession of microfacies in the Cretaceous deposits at Zalesice

For quartz and glauconite: *1* frequency, *2* clasticity; for biogenic components: *1* inoceram fragments, *2* planktonic foraminifers (mostly *Globigerina, Globotruncana, Rotalipora*), *3* sponge spicules; *a* ferrugineous nodules, *b* ferrugineous crusts, *c* brachiopods, *d* inocerams, *e* echinoids, *f* belemnites, *g* fish teeth, *h* burrows *Ophiomorpha nodosa* Lundgren, *i* indeterminable burrows, *j* stromatolites, *k* inoceram fragments

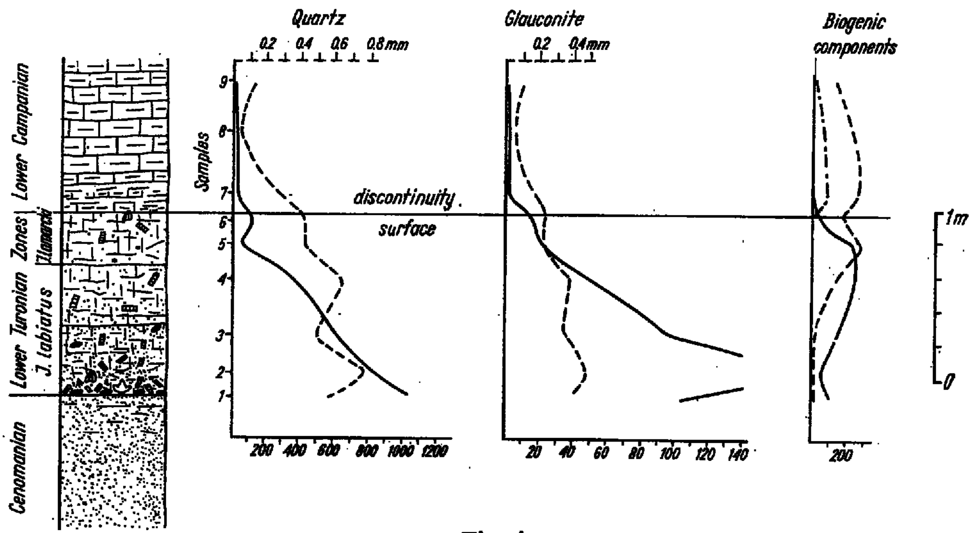


Fig. 4

Vertical succession of microfacies in the Cretaceous deposits at Skrajniwa (for explanations see Text-fig. 3)

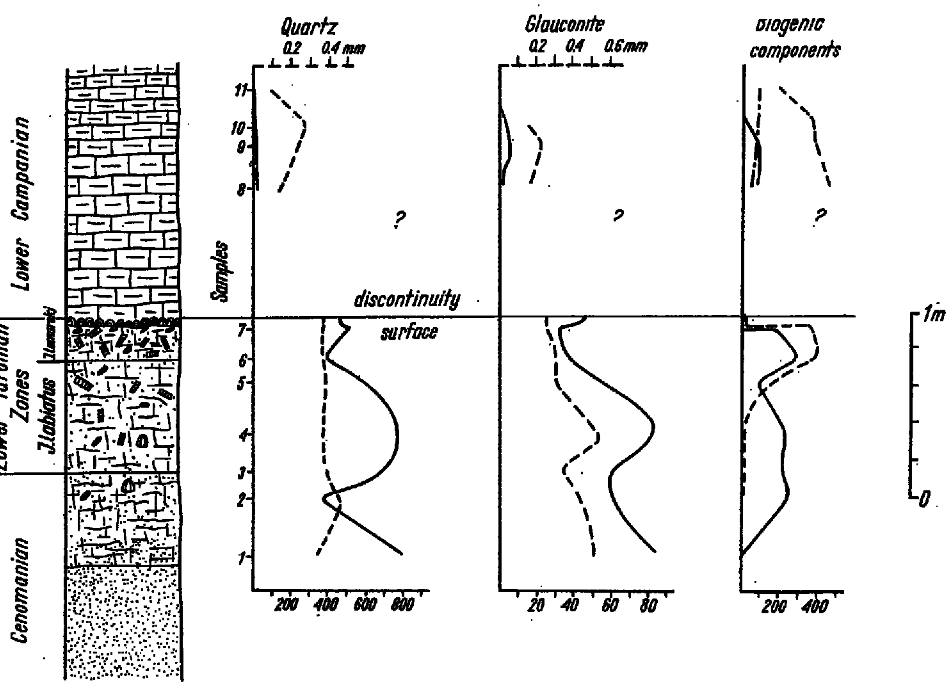


Fig. 5

Vertical succession of microfacies in the Cretaceous deposits at Pniaki (for explanations see Text-fig. 3) nic foraminifers). The frequency and the clasticity index of glauconite in the neighbourhood of the bottom of this zone are lower than in the Cenomanian, within the range of this horizon reach maximum values and towards the top once again display lower values, which causes a convex shape of the curves. The parallelism is more or less apparent with the curve of the frequency of quartz. The decrease in the frequency of quartz and glauconite is accompanied by an increase in the frequency of biogenic components (inocerams, planktonic foraminifers).

The Lower Turonian, Inoceramus lamarcki Zone. — The frequencies of quartz, inoceram fragments and planktonic foraminifers take similar values. The frequency of quartz in the Turonian (Pl. 1, Fig. 6) takes the smallest values not lower than in the bottom of this zone. Such values persist at Zalesice (Fig. 3; Pl. 1, Fig. 4) almost throughout the I. lamarcki Zone, and at Skrajniwa (Fig. 4) they appear approximately halfway the zone. The minimum frequency of quartz corresponds to the maximum frequency of inocerams and planktonic foraminifers. A marked increase in the frequency of quartz, reaching its maximum directly under the discontinuity surface (Pl. 1, Fig. 3) or under the underlying stromatolite layer (Pniaki, Fig. 5), takes place topwards the zone, that is towards the discontinuity surface in all the profiles. This is accompanied by an increase in the frequency of glauconite or a certain stoppage of a recrease in its amount. However, no increase in the clasticity index of quartz and glauconite is observed with an increase in frequency. The frequency of biogenic components radically drops together with an increase in the amount of quartz. At Pniaki, a relative decrease in the amount of quartz and increase in the amount of glauconite (Figs 5 and 7; Pl. 1, Fig. 2) occur in the stromatolitic layer.

The Lower Campanian. — A complete change in microfacies (Pl. 1, Fig. 1) takes place above the discontinuity surface. The frequency of quartz and glauconite suddenly drop although their clasticity decrease slowly and uniformly. The matrix predominates over particles. The frequencies of quartz, glauconite and biogenic components are similar to each other, although the planktonic foraminifers display a tendency to predominate over the remaining components. Steadily increasing amounts of sponge spicules appear with an increase in the distance from the discontinuity surface and with a decrease in the amount of planktonic foraminifers.

Interpretation of the evolution of microfacies

The microscopic observation of lithological changes in the Cenomanian-Turonian transgressive sequence reveals an increase in the amount of calcium carbonate instead of the terrigenic material, which takes place towards the top of the sequence. The microfacial analysis shows that these changes are not uniform, but display a certain cyclic manner manifested by the existence of two maxima in the detrital inflow: one within the range of the I. labiatus Zone and the other under the top surface of I. lamarcki Zone, that is, just below the discontinuity surface. If an increase in the clasticity of glauconite and a more or less distinct increase in the amount of quartz correspond to the former, no such increase is recorded in the case of the latter. If the maximum in the I. labiatus Zone is, therefore, likely to be connected with the shallowing of the basin, the cause of the maximum below the discontinuity surface may result from two factors. The amount of quartz in this place may be a function of either bathymetric conditions, or the rate of sedimentation. In the latter case, it would increase as a result of a decrease in the rate of chemical sedimentation. Such a decrease, displayed already in the upper part of the I. lamarcki Zone, would be preceded, therefore, by the appearance of the stromatolites (Pniaki) or ferrugineous crusts (Zalesice) and, finally, the formation of nonsedimentational surface. Besides, both factors, alternately named above need not necessarily exclude each other.

A constant ratio of the frequency of quartz to that of glauconite, amounting to 10 : 1 is characteristic of all the profies. In addition to morphological characters of the grains of glauconite (rounding), this indicates that glauconite underwent intraformational reworking and, the same as quartz, was transported. The curve of its maximum apparent diameter is actually a real clasticity curve (*cf.* Carozzi 1958, p. 137).

A decrease in the frequency of quartz and glauconite in the Campanian, with more slowly decreasing indexes of their clasticity, are indicative of a decrease in the influencing alimentary area. This coincides with a gradual deepening of the basin, manifested also by an increase in the frequency of sponge spicules together with a decrease in the frequency of other biogenic components.

The frequency curve of planktonic foraminifers steadily displays an inverse variation in regard to the clasticity and frequency of quartz and glauconite. A similar relation to the curves of quartz and glauconite is displayed by the frequency curve of the inocerams. Such a relation of the frequency of inocerams to that of clastic minerals indicates, as shown by Carozzi (1958, p. 147), conditions of a strong water agitation and detrital inflow. Thus, with certain bathymetric fluctuations, the sedimentation of the entire sequence below the nonsedimentational surface takes places in a high-energy environment.

THE CRETACEOUS AT BOCIENIEC

Bocieniec is an only locality of the stromatolites in the Cretaceous deposits of the southern part of the area. Since the deposits underlaying the stromatolitic layer are limited to conglomerates only (Rutkowski 1965, 1971), no microfacial analysis of this profile's deposits has been conducted. They are transgressively disposed (Fig. 6) on an uneven and sloping surface of the Upper Jurassic limestones, in which they are wedged in the form of clastic dykes. The age of the conglomerate has so far been determined as Cenomanian-Turonian (Rutkowski 1965). An ammonite *Lewesiceras peramplum* (Mantell), found therein by Dr. S. Cieśliński and which is described in the present paper, shows that they belong to the Turonian (probably Upper). The stromatolitic layer occurs

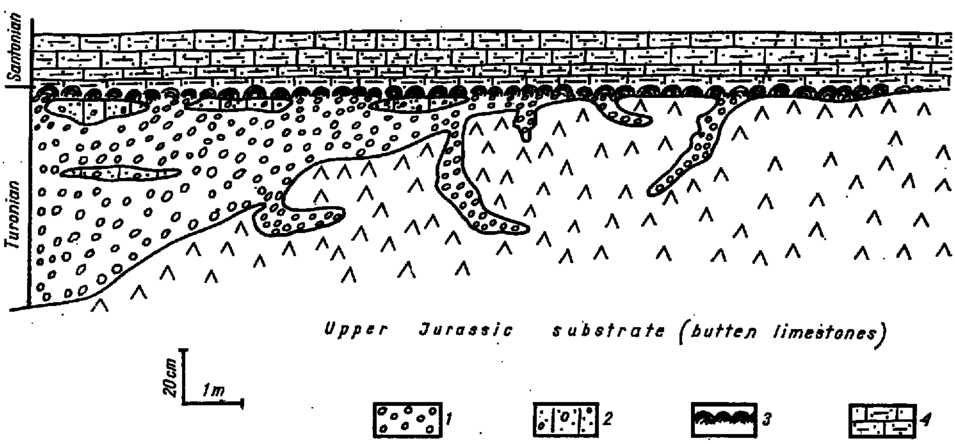


Fig. 6

Schematic section of the Cretaceous transgressive deposits at Bocieniec
1 conglomerates, 2 sandy limestones, 3 stromatolites, 4 sandy marls

on the boundary between the conglomerate and Santonian marls. It has been supposed so far (Rutkowski 1965, 1971) that the discontinuity surface occurred between the conglomerates and stromatolitic layer which, therefore, was believed to be of Santonian age. It turns out, however, that this layer is closely bound with the conglomerate on the accumulative surface of which it is deposited without any sharp outlined boundary. Thus, the same as at Pniaki, the stromatolitic layer at Bocieniec is of Turonian age and, consequently, it is not transgressive, but connected with a submarine nonsedimentational surface.

THE STROMATOLITES

In the western margin of the Miechów synclinorium, the Cretaceous stromatolites are known from two localities: Pniaki in the north and Bocieniec in the south. At Pniaki, their presence was first found by Różycki (1938) and at Bocieniec by Rutkowski (1965). No closer characteristics of them have, however, been given thus far. The stromatolites from Pniaki considerably differ in many respects from those from Bocieniec and, therefore, here they are separately described. The terms used for their description in principle strictly correspond to those given by Hofmann (1969).

Pniaki

The structure of the stromatolitic layer. — The stromatolites form a layer only to two *cm* thick and developed on the top surface of the Turonian glauconitic limestones (Fig. 7; Pl. 3, Fig. 1). A boundary between the Turonian limestone and this layer is distinct and uneven. The irregularities measure a few millimeters only (Fig. 7). The top of Turonian limestone is slightly impregnated with iron hydroxides and locally covered with a thin glauconitic coating. Its upper surface is formed by the apexes of stromatolitic domes. The layer is composed of many small stromatolites up to three *cm* in diameter, usually unlinked, sometimes

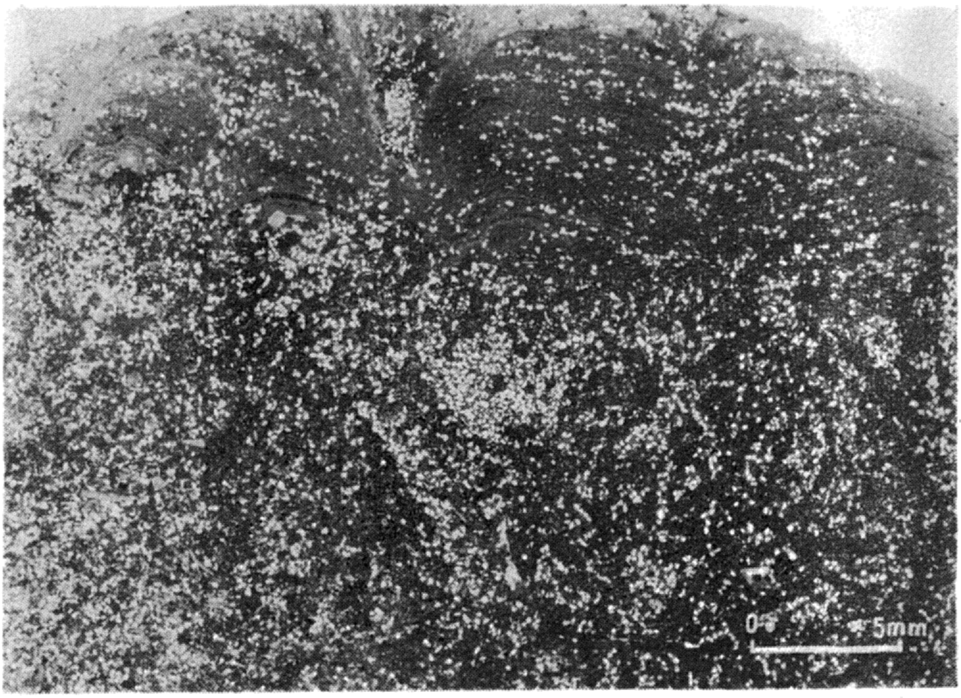


Fig. 7

Vertical section of laminated stromatolitic layer developed over the top surface of sandy limestone; Turonian, Pniaki

partly linked, continuous or very closely spaced. Individual stromatolites are dome-shaped (nodular) to stubby low-cylindrical. In relation to the accretion vector they are erect or only slightly inclined. Usually they do not branch, only some of them display a furcate branching. The stromatolites are composed of convex, uniformly curved laminae and are round to polygonal in plan outline.

Microstructure. — The stromatolites are composed of a partly chemical and partly detrital material (Figs 7, 8; Pl. 1, Fig. 2), mostly a micritic calcium carbonate. Some of the laminae, usually thin ones, consist, however, of phosphate (mostly collophane) and are frequently accompanied by iron hydroxide impregnations. Some others abound in detrital quartz and glauconite, both not more than 0.5 mm in

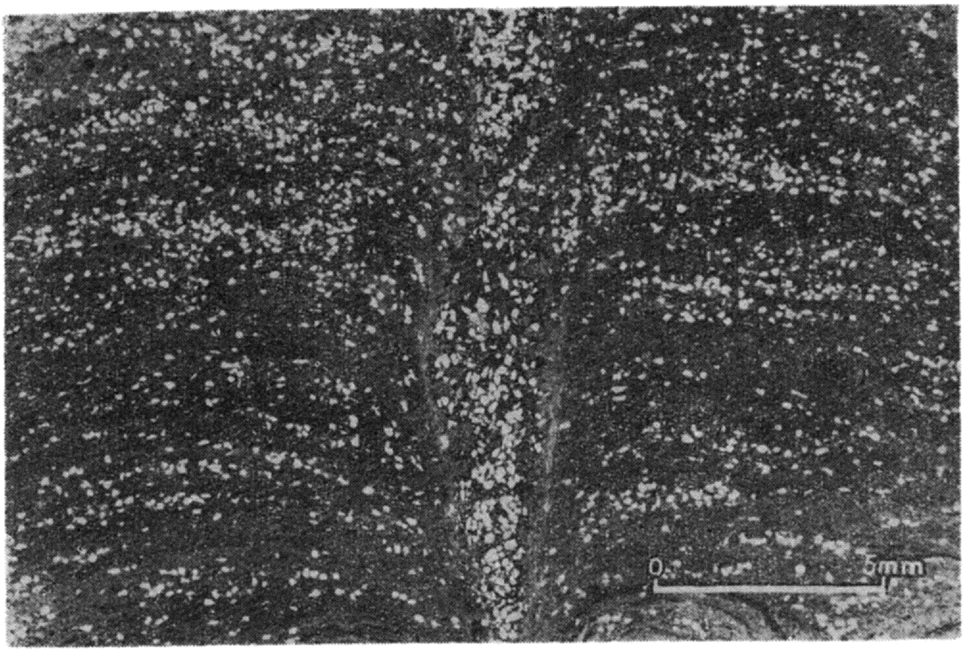


Fig. 8

Laminated stromatolites separated by an interstice (note a sandy infilling of the interstice and a few laminae abounded in detrital quartz); small colloform nods are visible on lateral surfaces of the stromatolites; Turonian, Pniaki

grain-size. The ratio of the amount of quartz to that of glauconite amounts to 10 : 1, that is, much the same as in the underlaying Turonian rocks, which indicates that, in addition to its morphological character, glauconite is reworked. Many benthic and pelagic foraminifers are here also met with. Elongate elements are arranged approximately parallel to lamination, which is distinct, although particular laminae are not sharply delineated (Pl. 1, Fig. 2). Lateral walls of stromatolites are usually coated with a thin, phosphatic crust, having mammillary collomorphic structures. They are usually preserved completely, which is indicative of a slight abrasive activity in interstitions, but sometimes they are partly truncate as a result of abrasion.

Bocieniec

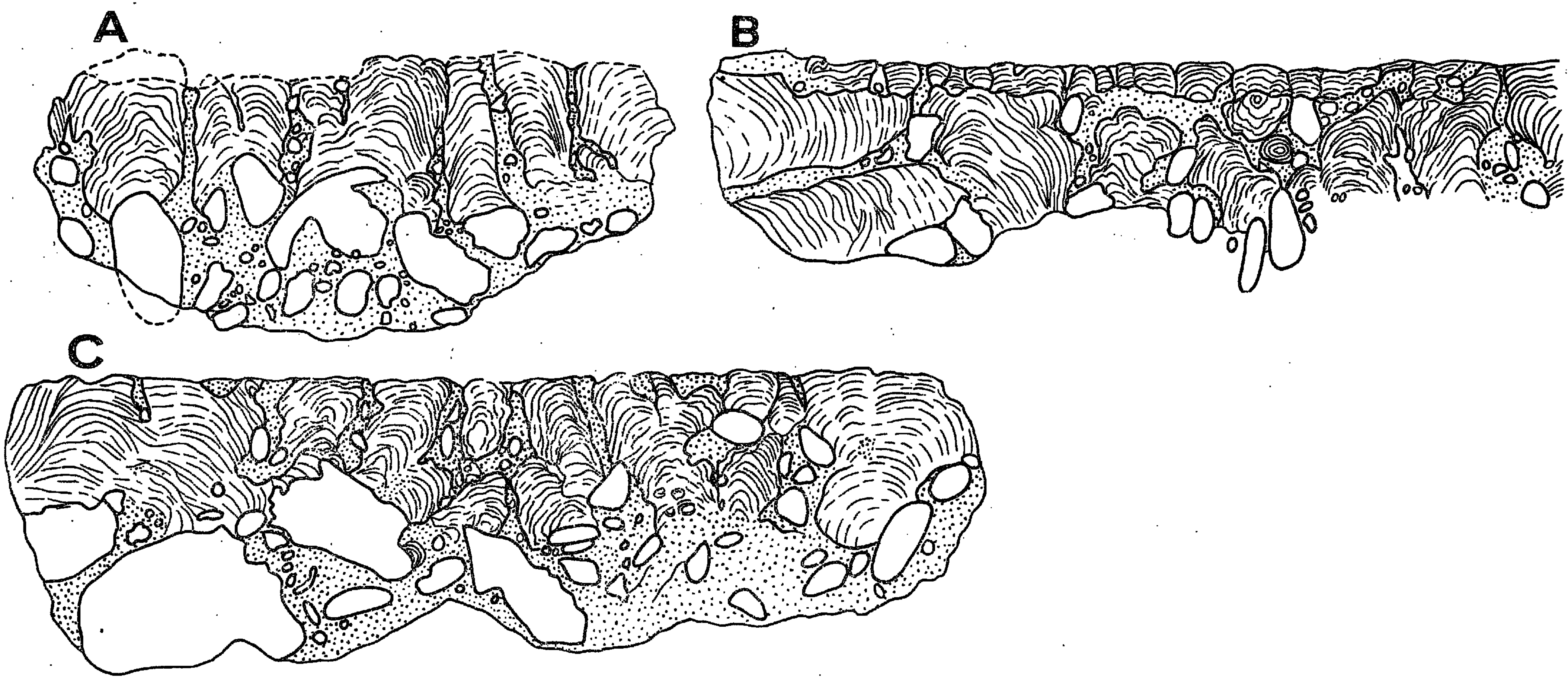
The structure of the stromatolitic layer. — The stromatolites form a layer which overlies the top of the Turonian conglomerate (Figs 9*A*—*C*; Pl. 3, Figs 2—4). No sharp delineation can, however, be made between the latter and the stromatolitic layer, since the development of stromatolites begins in various places at various levels and the inflow of quartz gravel still accompanies the formation of stromatolites. The surface of their accretion was rough and, in addition, their development in various places did not start at exactly the same time. The roughness of the substrate has a marked effect on the structure of the stromatolitic layer: many of stromatolites develop on elevations usually formed by quartz pebbles (Figs 9*A*, *C*; Pl. 3, Figs 2, 4). Due to the roughness of its bottom, the thickness of the stromatolitic layer is not uniform. The upper boundary is formed by stromatolite apexes. The layer is much less regular in structure than that at Pniaki. The stromatolites are embedded in conglomerate at various levels, separated from each other by a carbonate matrix with numerous pebbles to 15 mm in diameter (Figs 9*A*—*C*, 10). Topwards, the number of pebbles decreases and stromatolites decidedly predominate. Particular stromatolites are small and only few of them reach 4 cm in height which corresponds to the thickness of the entire layer. The accretion vectors are irregularly inclined up to an angle of 40°, curved or sinuous. The growth forms of stromatolites are nodular or, more frequently, cylindrical. Usually, they are unbranched, but near the top they display a furcate branching. In the upper part of the layer, an erosive surface, truncating the apexes of lower stromatolites, appears locally. Some of them are torn off the substrate and overturned (Fig. 9*B*). A younger generation of small stromatolite to 1 cm in height is developed on the erosive surface. The upper surface of the layer (Pl. 2) reveals a polygonal or round plan outline and a very close spacing of the stromatolites.

Microstructure. — The stromatolites consists of the same components as those at Pniaki, which, however, contain only accessory amounts of quartz and glauconite. The grain-size of these minerals is also smaller and only rarely reaches 0.2 mm. A calcareous matrix and collophane are fundamental components. The latter forms in some stromatolites the sets of laminae with a colloform internal structure almost devoid of detrital parts. The phosphatic coatings, similar in character, also cover the surface of some stromatolites (Fig. 11).

ORIGIN AND ENVIRONMENTAL SIGNIFICANCE OF THE STROMATOLITES

Since the knowledge of the Cretaceous stromatolites is insufficient, it is easier to compare them with the Jurassic ones, better known and having many characters in common.

The stromatolites coming from both localities are very small forms, most resembling in dimensions the Bathonian ones from Wola Morawicka (Szulczewski 1967, 1968) and corresponding in both size and shape to Recent attached algal biscuits *sensu* Gebelein (1969), which are, however, isolated. They are related, on the one hand, to the Jurassic and, on the other, to the Recent stromatolites also in a mixed nature of the deposit of which they are formed. A marked majority of the pre--Cambrian and Paleozoic stromatolites contain at most accessory amounts



Structures of the stromatolitic layer; Turonian, Bocieniec; nat. size

A — Stromatolites growing on uneven depositional surface of Turonian conglomerate (note the majority of stromatolites being colonized on quartz pebbles)
B — Two generations of stromatolites separated by an erosional surface: beneath some stromatolites are overturned and large quartz pebbles are embedded inbetween
C — Stromatolites developed on uneven depositional surface of Turonian conglomerate (note large quartz pebbles being the substrate of stromatolites)

of detrital particles, while, for instance, the Recent stromatolites (from Shark Bay, Australia; Logan 1961) consist in about 80 per cent of a carbonate organodetrital material. The Cretaceous stromatolites under study contain, in contradistinction to the Recent ones, a considerable amount of detrital quartz, markedly exceeding the amounts usually observed in many Jurassic (Szulczewski 1968, p. 47) and at most equalling in the Bathonian stromatolites from Wola Morawicka mentioned above. Of the stromatolites described, they are surpassed in the amount of detrital quartz only by the Lower Ordovician sandy stromatolites from New Richmond Sandstone (*cf.* Davis 1968) and similar to the pre--Cambrian ones from the Judomian complex (*cf.* Semikhatov, Komar & Serebryakov 1970, p. 115, Fig. 24), which are among exceptions in this respect.

Ancient stromatolites are conventionally interpreted as displaying of a low energy deposition. However, as pointed out by some authors (Bathurst 1967; Gebelein 1969; Neumann, Gebelein & Scoffin 1970), the biogenic mat can withstand a high energy condition and extrapolating grain-size in stromatolites to the entire environment leads to considerable

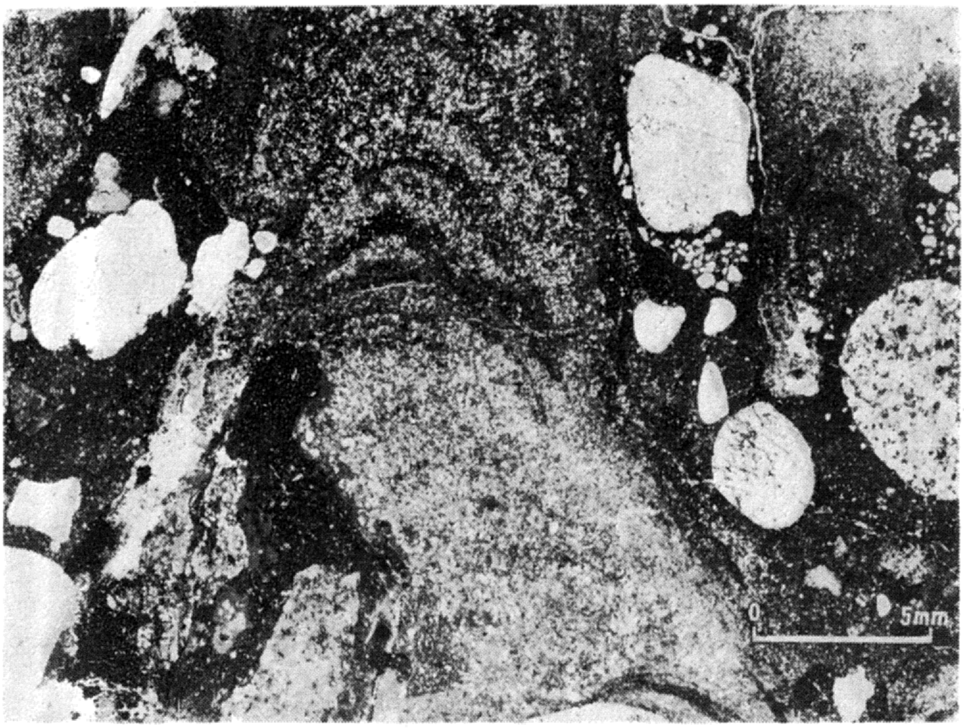


Fig. 10

Selective deposition in stromatolites which consist of fine-grained material, in contrast to matrix containing quartz gravel; Turonian, Bocieniec error because of selective binding of particles in the mat. These remarks are fully confirmed by the studies on the Cretaceous stromatolites.

The stromatolites described are the object of a markedly selective sedimentation of detrital particles (Figs 8, 9*A—C*, 10). The transported material with a grain-size not exceeding 0.20 mm at Bocieniec and 0.5 mm at Lelów is deposited therein. The latter value corresponds to maximum grain-size ever met in the Jurassic stromatolites (*cf.* Szulczewski 1963 and 1968, p. 48) in which the grains as a rule do not exceed 0.10 mm in diameter. The selection of detrital particles in respect to size is particularly distinct at Bocieniec where the grains of quartz embedded in matrix and interstices exceed 10 mm. A similar selection takes place in the biogenic mat and Recent stromatolites (Black 1933; Gebelein 1969, Fig. 9; Neumann, Gebelein & Scoffin 1970). If the detrital particles contained in stromatolites do not enable a

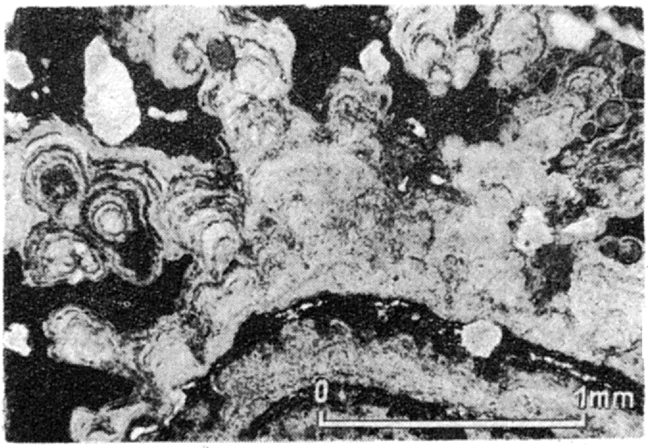


Fig. 11

Colloform phosphate encrusting the stromatolitic surface; Turonian, Bocieniec; × 35

direct reconstruction of the environment energy, this aim may be achieved by an analysis of detrital grains in interestices and matrix. This problem is related with the erodability of the mat. Filamentous algae and associated organims living at the sediment-water interface greatly increase the stability of the sediment surface. As shown by Neumann, Gebelein & Scoffin (1970), the intact biogenic mat could withstand direct current velocities of 40 to 110 cm/sec. Quartz pebbles accompanying stromatolites at Bocieniec reach 10—15 mm. The velocity at which, for this grain-size of quartz, the bed load movement stops is about 120 cm/sec (Sundborg 1967, Fig. 1). The reservation should, however, be made that Sundborg's curve diagram was drawn for a uniform material. The reading of velocity also does not take into account the sloping of the bottom, its morphology and morphology of the grains, factors which could lower the velocity he gives. The manner of concluding on the current velocity is the simplest possible, the number of unknown parameters does not, however, induce one to make use of more complex calculations. The calcareous conglomerate, directly underlaying its part with stromatolites, contains larger pebbles to 50 mm in size. The velocity of their depositing would amount respectively to about 200 cm/sec. At Bocieniec, the stromatolites were formed, therefore, under the high-energy conditions and at current velocities reaching 120 cm/sec and lower than 200 cm/sec. These velocities are comparable to or higher than the erodability of the cohesive and aggregated *Schizotrix* mat (Neumann, Gebelein & Scoffin 1970).

A mat of this type can withstand higher current velocities (110 m/sec) tnan the Recent mats of the two others types described.

Precisely *Schizotrix* is a nearly universal component of the Recent stromatolites (Ginsburg 1954, Logan 1961, Gebelein 1969). The experiments of Neumann, Gebelein & Scoffin (1970) concerned flat algal mats and, therefore, their results would be comparable with the stage of the formation of initial stromatolitic laminae. The destructive effects of current on already developed stromatolites may be expressed not only in the erosion of mat, but primarily in ripping up (Gebelein 1969). Within 96 hours, more than 90 per cent of the bisquits observed by Gebelein had been torn up from the substrate and carried off. Attached bisquits larger than 2.5 cm were ripped up by currents and in this way current velocity controlled their maximum size. A velocity of 11 cm/sec was limiting their formation, whereas the velocities corresponding the formation of the Cretaceous stromatolites were many times higher and a marked majority of them occurs in situ. Thus, concluding on the current velocity on the basis of dimensions and form of fossil stromatolites seems to be unreliable. It should be emphasized, however, that the analogy between the forms mentioned above is not complete, since Recent biscuits are not as closely spaced as the Cretaceous stromatolites.

The abundance of calcareous phosphate, forming some laminae and coatings on the surface, is a characteristic feature of the stromatolites under study. Phosphates in the stromatolites have not been described, however the stromatolites and onkolites embedded in phosphorites are known (Bushinski 1964, Fig. 2). Low-rate of sedimentation or non--deposition are largely postulated for Recent and ancient phosphorite formation. Characteristic colloform structures of collophane (Fig. 11) correspond to those sometimes described as stromatolites (*e.g.* Farinacci 1967, Fig. 4; Niegodzisz 1965, Pl. 4, Fig. 2; Pl. 5, Figs 1—2), „microstromatolites" (Turnau-Morawska 1961), or infillings after algae (Szulczewski 1963, Niegodzisz 1965). As found by Wendt (1970, p. 438), the role of organisms in such structures does not seem to be decumented and their similarity to the stromatolites is rather superficial. The discussed colloform structures resemble also limonitic "cauliflower" structures described by Jenkyns (1970, Figs 10—11) from the ferruginous horizons in the Sicilian Jurassic as well as iron-manganese colloidal structures illustrated by Wendt (1969, Pl. 21, Fig. 1) from the Jurassic of Tirol, and Tucker (1971, Fig. 1) from the Upper Devonian of France. Similar structures occur also within Recent ferromangenese nodules. A considerable role played by inorganic colloform structures in the stromatolites under study does not allow one to determine the importance of the organic factor in the formation of stromatolites. We can suppose, however, that the presence of many stromatolites, mostly consisting of calcium carbonate and detrital material, among the specimens under study indicates that the presence of algae as an agent binding the material was of a decisive importance. As long as the algal stromatolites are not divided from convergent collomorphic structures related to iron, manganese and phosphorium compounds, this problem remains open to discussion. The possibility of the presence of completely inorganic stromatolites, or, if one prefers rather, structures convergent to them, now fairly frequently emphasized (Hofmann 1969, p. 7), also concerns the Recent forms (Hofmann 1969, Figs 2 and 3). As to the bathymetry, formation of phosphatic deposits in the Recent seas takes a place in the range of 30—300 m (Bromley 1967).

In view of the doubts concerning the genesis of certain fossil stromatolites and variable data on the occurrence of Recent forms, the device "the present is the key to the past" should be regarded with a certain reserve so that we did not try to open the door with a wrong key. This is particularly true of the bathymetric conditions of the formation of stromatolites.

Certain fossil stromatolites undoubtedly come from the subtidal zone (Szulczewski 1968, Achauer & Johnson 1969, Playford & Cockbain 1969), much the same as some of the Recent ones (Monty 1965, Gebelein 1969). The stromatolites from Pniaki were probably formed under similar conditions. An accurate determination of the depth of their formation is, however, impossible. Relating them with algae results in determing their environment as not deeper than 150 m (or 200 m, after Jenkyns 1971, p. 347), because such a depth correspond to the photic zone in clear oceanic water at low latitudes. The microfacial analysis is, however, indicative of a lower depth. An increase in the frequency of quartz and glauconite directly below the discontinuity surface, observed not only at Pniaki, but also in the remaining outcrops analyzed, gives evidence that the formation of stromatolites at Pniaki took place as the result of shallowing as compared with the conditions which correspond to the sedimentation of the inoceram microfacies. This was probably a depth of at most some scores of meters. The stromatolites under discussion are considered to have grown very slowly, and also in this way they differed from the Recent ones (*cf.* Monty 1965, Gebelein 1969).

The stromatolites of Bocieniec were formed under yet more shallow-water conditions. This is manifested by yet stronger turbulence indicated by the presence of quartz gravel and broken and abraded stromatolites. This small depth is also reflected in the irregularity of the growth of stromatolites.

As found by Różycki (1938), the gap with which stromatolites are connected is a submarine discontinuity surface. The fact that it is not caused by the emergence and erosion is confirmed, according to this author, by the continuity of underlaying it stratigraphic units with a small thickness and by the lack of any traces of weathering and erosion channels. It is worth mentioning that the lack of connection between abrasion and discontinuity surface is also confirmed by an increase in the frequency of quartz and glauconite, observed directly below this surface in all the profiles analyzed (Figs 3—5). Thus, the discontinuity surface is an accumulative and not abrasive surface. An abrasion is also indicated by the character of surface neither at Pniaki, nor at Bocieniec. At Zalesice, in a position of the stromatolitic layer (Fig. 3) there occur limonitic impregnations and nodules, similar to those for which a non-depositional environment is postulated in various Jurassic condensed sequences (*e.g.* Wendt 1970, Jenkyns 1970, Jenkyns & Torrens 1971, Fürsich 1971).

In their connection with the discontinuity surfaces, the discussed Cretaceous stromatolites resemble a decisive majority of the Jurassic stromatolites, in which a marked tendency is observed to accompany stratigraphic gaps and condensed deposits (Szulczewski 1968, pp. 59, 87; Sturani 1969; Fürsich 1971; Jenkyns 1971, p. 343). In the pre-Cambrian, from which most stromatolites described come, their connection with sedimentary discontinuities is observed only rarely (Semikhatov, Komar & Serebryakov 1970, p. 153).

REGIONAL REMARKS

The terrigenic material for the Cenomanian deposits comes from an area situated south of Cracow (Sujkowski 1929). The quartz material for the rocks of the entire transgressive cycle, including the Upper Albian — Turonian in the entire area under study is most likely to come also from this region.

As shown by the observations of the development of the Santonian deposits at Bocieniec, they do not display transgressive character. In the light of these facts, Alexandrowicz's (1969, p. 55) interpretation that the Santonian is transgressive on the Cracow area seems to be doubtful, at least as concerns the conditions at Bocieniec. Numerous abrasive surfaces occurring in the Cretaceous sequence of the Cracow region, including the Santonian ones, are bound to indicate the oscillations of the Cretaceous sea and may owe their formation to a submarine erosion (Dżułyński 1953, p. 393). The distribution of Cretaceous deposits (Fig. 2) supplies evidence that in the western margin of the Miechów synclinorium the synsedimentary tectonic movements are manifested between the Upper Turonian and Santonian. They caused an elevation of the northern area a formation of a gap in the longest time interval. A morphological differentiation of the bottom of the sedimentary basin enables the sedimentation of the Santonian deposits in a lowered southern area. The Cracow region, including Bocieniec, also marked as a submarine elevation, makes up the southern boundary of this area.

A considerable decrease in thickness and a stratigraphic condensation in the Cenomanian and Turonian deposits is connected with the existence, in the Cretaceous of the area under study, of an extensive submarine threshold separating the Cretaceous sea in the region of Opole and Głubczyce from the sea of Central Poland (*cf.* Alexandrowicz 1969, p. 54). According to Alexandrowicz (1969), this threshold was formed in the Upper Turonian or Coniacian. Since the stratigraphic condensation within the transgressive sequence under study is already marked in the Cenomanian, this threshold already existed in that stage.

The investigated stratigraphic gap, is of the widespread regional nature, since shallowings, many gaps and sandy admixtures in deposits (*cf.* Pożaryski 1960, 1962) occur in the Coniacian and Santonian over almost the entire epicontinental Poland. These phenomena caused by synsedimentary tectonic movements are also observed in the Sudetes where they led to a sedimentation of flysch deposits in the Nysa graben (*cf.* Jerzykiewicz 1971).

SYSTEMATIC DESCRIPTION OF THE AMMONITES

Family **Pachydiscidae** Spath, 1922
Genus *LEWESICERAS* Spath, 1939
Type species: *Lewesiceras peramplum* (Mantell, 1822)
Lewesiceras peramplum (Mantell, 1822)
(Pl. 4, Figs 1—2 and Text-fig. 12*a*—*c*)

1822. *Ammonites peramplus*; Mantell, pp. 200—201.
1840—1842. *Ammonites peramplus*, Mantell; d'Orbigny, pp. 333—334, Pl. 100, Figs 1—2.
1840—1842. *Ammonites Prosperianus*, d'Orbigny; d'Orbigny, pp. 335—336, Pl. 100, Figs 3—4.
1853. *Ammonites peramplus*, Mantell; Sharpe, p. 26, Pl. 10; Figs 1—3.
1870. *Ammonites peramplus* Mant.; Roemer, p. 319, Pl. 35, Fig. 5.
1872. *Ammonites peramplus* Mant.; Fritsch, pp. 38—39, Pl. 8, Figs 1—2, ?3, 4.
?1872. *Ammonites peramplus?*; Fritsch, p. 39, Pl. 14, Figs 4—5.
1872. *Ammonites peramplus*, Mantell. Sharpe; Schlüter, pp. 31—36, Pl. 10, Figs 7—14.
1886. *Pachydiscus peramplus* Mantell sp.; Laube & Bruder, pp. 225—226.
[non] 1891. *Pachydiscus aff. peramplus* Mantell; Peron, Pl. 18, Figs 3—4.
1894. *Sonneratia perampla*; Grossouvre, pp. 108, 144, Text-figs 42, 63.
1923. *Pachydiscus peramplus* Mantell; Mazurek, p. 112.
1926. *Pachydiscus sharpei* nom. nov.; Spath, p. 82.
1926. *Pachydiscus cricki* nom. nov.; Spath, p. 82.
1951. *Lewesiceras peramplum* (Mantell); Wright & Wright, p. 20.
1951. *Lewesiceras mantelli* nom. nov.; Wright & Wright, p. 20.
1951. *Lewesiceras sharpei* (Spath); Wright & Wright, p. 20.
1959. *Lewesiceras peramplum* (Mantell); Naidin & Shimanski, p. 185, Pl. 12, Fig. 4 and Pl. 13, Fig. 4.

Material. — Two internal moulds somewhat glauconitized and strongly worn on one side; fragment of the final body chamber preserved in one of the moulds.

Dimension (in *mm*):

Specimen presented in:	D	Wh	Wh/D	Wt	Wt/D	U	U/D	Wt/Wh
Pl. 4, Fig. 1a-c	67.8	30	0.44	32.7	0.48	19.5	0.29	1.09
Pl. 4, Fig. 2a-c	66.5	29.3	0.44	26.0	0.39	20.3	0.30	0.88

Description. — The first specimen (Pl. 4, Fig. 1*a*—*c*), represents a broken phragmocone; its whorls are depressed, evolute, overlapping at two-thirds of the whorl height. Maximal thickness of the whorl somewhat below the middle of whorl side. Ventral side rounded. Umbilicus moderately deep with rounded margin and umbilical area almost vertical. Ornamentation consists of 8 primaries, every of which is followed by depression, marked in the form of whorl-constriction; primary rib begins from the node located on umbilical margin, and continues through whorl-side up to ventral margin, where it bends forward forming a distinct sinus. One or two intercalaries appear between every pair of primaries, almost reach the zone of maximal whorl-thickness close to the umbilical nodes and are generally less prominent than primaries. Unfortunately, intercalaries are obscured owing to worn state of the specimen, thus their course cannot be traced in detail.

The second specimen (Pl. 4, Fig. 2*a*—*c*), having the same Wh/D and U/D ratios as the previous one, differs in less prominent sculpture and more compressed whorl-section. Whorls compressed, flat-sided, thickest close to the umbilical margin. Ventral side rounded. Umbilicus moderately deep, with vertical wall. It may be noted that although ornamentation is worn as a result of corrosion, in the older part of the outer whorl it is essentially similar to that of the above specimen; whereas on the last half of the outer whorl (over the end of the phragmocone and a part of the final body chamber preserved) it undergoes modification; in the modified part, primaries begin at a distance of $^1/_3$ whorl height from the umbilical margin and are the most prominent at ventro-lateral margin and ventral side. Intercalaries short, numbering 1 to 2 for every pair of primaries.

Remarks. — The species *Lewesiceras peramplum* (Mantell) is characterized by a high variability in sculpture depending on the developmental stage. As early as 1840, d'Orbigny (1840, p. 335), distinguishing *"Ammonites Prosperianus"* and *"A. peramplus"* as allied but still separate species, assumed that the former may be a juvenile form of the latter. This suggestion was supported by subsequent authors (Sharpe 1853, Schlüter 1872, Spath 1926). However, both Spath (1926) and Wright & Wright (1951) assigned insufficient significance to the variability in ontogenetic development and proposed new species based on slight differences in shell shape and sculpture (*cf.* synonymy), which actually represent, according to the present authors, different developmental stages of the species *Lewesiceras peramplum* (Mantell). Also a part of the specimens figured by Fritsch (1872), which were considered dwarfish forms of the above species by Laube & Bruder (1886, p. 226), are placed in synonymy (with reservation caused by inadequate description and figures).

The specimen from Volhynia, USSR (Fig. 12), 22 mm in diameter, the sculpture on the innermost whorls of which was studied for comparative purposes (*cf.* explanation to Fig. 12), fully corresponds to descriptions and figures given by Sharpe (1853, Pl. 10, Fig. 3) and Schlüter (1872, Pl. 10, Figs 7—9).

When Polish specimens are compared with the description of the species given by Sharpe (1853) and Schlüter (1872) it follows that the first specimen from Bocieniec (Pl. 4, Fig. 1*a*—*c*) represents inner (juvenile) whorls of the species *Lewesiceras peramplum* (Mantell) and is the most similar to forms described and figured by Sharpe (1953, Pl. 10, Fig. 3 and inner whorls of the specimen figured in Pl. 10, Fig. 2) and by Schlüter (1872, Pl. 10, Figs 10—11). According to Schlüter (1872, pp. 31—32), the sculpture of German Turonian specimens attaining 190 mm in diameter undergoes modification from a diameter above 60 mm, expressed by lesser regularity and prominency; this was interpreted by transition from juvenile to mature stages. The author's specimen (Pl. 4, Fig. 1*a*—*c*), attaining *c.* 70 mm in diameter, is covered with sculpture typical for the juvenile stage, which indicates that if complete, it would not differ in size from the German specimens. Mature specimens of *Lewesiceras peramplum* (Mantell) commonly attain over 600 mm in diameter, whereas their sculpture consisting of wide, flat ribs are marked close to the umbilicus only (Mantell 1822, Sharpe 1853, Schlüter 1872), or, occasionally, the last whorl is completely devoid of sculpture (Mantell 1822, Sharpe 1853).

The second investigated specimen (Pl. 4, Fig. 2*a*—*c*) wiht flat compressed whorls and less prominent sculpture, although much smaller than the mature spe-

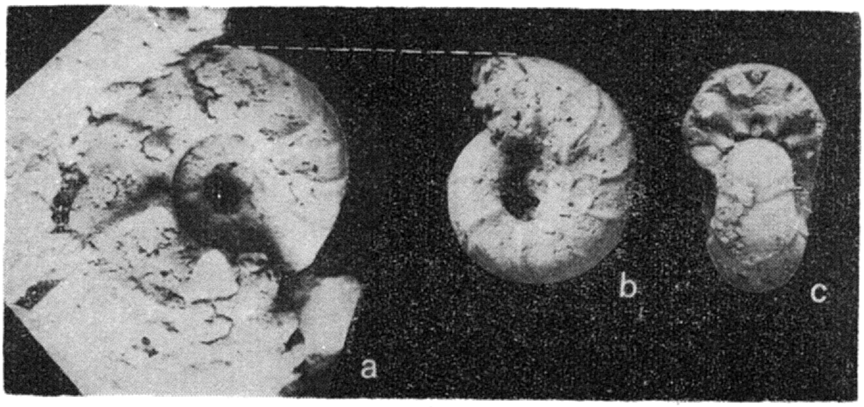


Fig. 12

Lewesiceras peramplum (Mantell) from the Turonian at Berestowiec, Volhynia, USSR (*coll.* Prof. H. Makowski)

a — side view at the 22 mm diameter
b — inner whorl of the same specimen at the 14.4 mm diameter (marked is the point of taking-off a part of the whorl); visible are 8 primaries, everyone continuing from a nod at the umbilical wall, and — in the anterior part of the whorl — short intercalaries
c — anterior view of the whorl presented in *b*

(All photos twice magnified, taken by B. Drozd, M. Sc.)

cimens of *Lewesiceras peramplum* (Mantell) discussed above, seems also to be mature. This is indicated by a change in the sculpture, marked on its body chamber. This sculpture fully corresponds to diagnosis and figure given by Naidin & Shimanski (1959, Pl. 13, Fig. 4), differing however, from that of large forms of this species.

Such differentiation in size and sculpture of both specimens discussed, which represent mature forms, as well as in the case of other forms of *Lewesiceras peramplum* (Mantell), should be interpreted as sexual dimorphism in regard to the evidence presented by Makowski (1962a, b).

Occurrence. — The species *Lewesiceras peramplum* (Mantell) is quite common in the British Cretaceous (Mantell 1822, Sharpe 1853, Peake & Hancock 1961), where its stratigraphical range comprises the whole Turonian (*cf.* Wright & Wright 1951). In Germany, the species is known to occur in the Upper Turonian, together with *Scaphites geinitzi* d'Orbigny and occasionally both in the older deposits of Inoceramus lamarcki Zone and, in younger, Inoceramus schloenbachi Zone of the uppermost Turonian (*cf.* Schlüter 1872) [1]. Moreover, *L. peramplum* (Mantell) was recorded in the Turonian of France (d'Orbigny 1840) and Czechoslovakia (Fritsch 1872, Laube & Bruder 1886) and Upper Turonian of the northern Caucasus and Crimea (Naidin & Shimanski 1959).

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[1] Prescher (1963) in his studies on the Scaphites geinitzi Zone of the Saxonian Cretaceous found that the stratigraphical range of the index species of this zone is very wide, from the Lower Turonian to the Coniacian, thus specimens of this species should not be regarded as guide fossils. The stratigraphical range of *Lewesiceras peramplum* (Mantell) in Germany is based on the positions of specimens in Schlüter's (1872) sections correlated with the subdivision of the Turonian presently accepted in Germany and Poland (*cf.* Cieśliński & Tröger 1964).

In Poland, *Lewesiceras peramplum* (Mantell) was cited exclusively from the Upper Turonian of the Opole area in Lower Silesia (Roemer 1870)[2], Cracow Upland (Panow 1934) and Mesozoic margins of the Holy Cross Mts (Mazurek 1923, Cieśliński & Pożaryski 1970)[3].

The conglomerates at Bocieniec (Fig. 6), previously estimated to be of Cenomanian-Turonian age (Rutkowski 1965), on the basis of the occurrence of this species are considered to be of Turonian, and most probably Upper Turonian age.

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[2] Schlüter (1872, p. 34) stated that although Roemer's (1870) specimen from the Opole area is inadequately figured, it belongs to this species (*cf.* synonymy).

[3] Mazurek (1923, p. 108) reported *Lewesiceras peramplum* (Mantell) from the Turonian deposits at Skotniki Duże near Busko without identifying its position in particular horizon.

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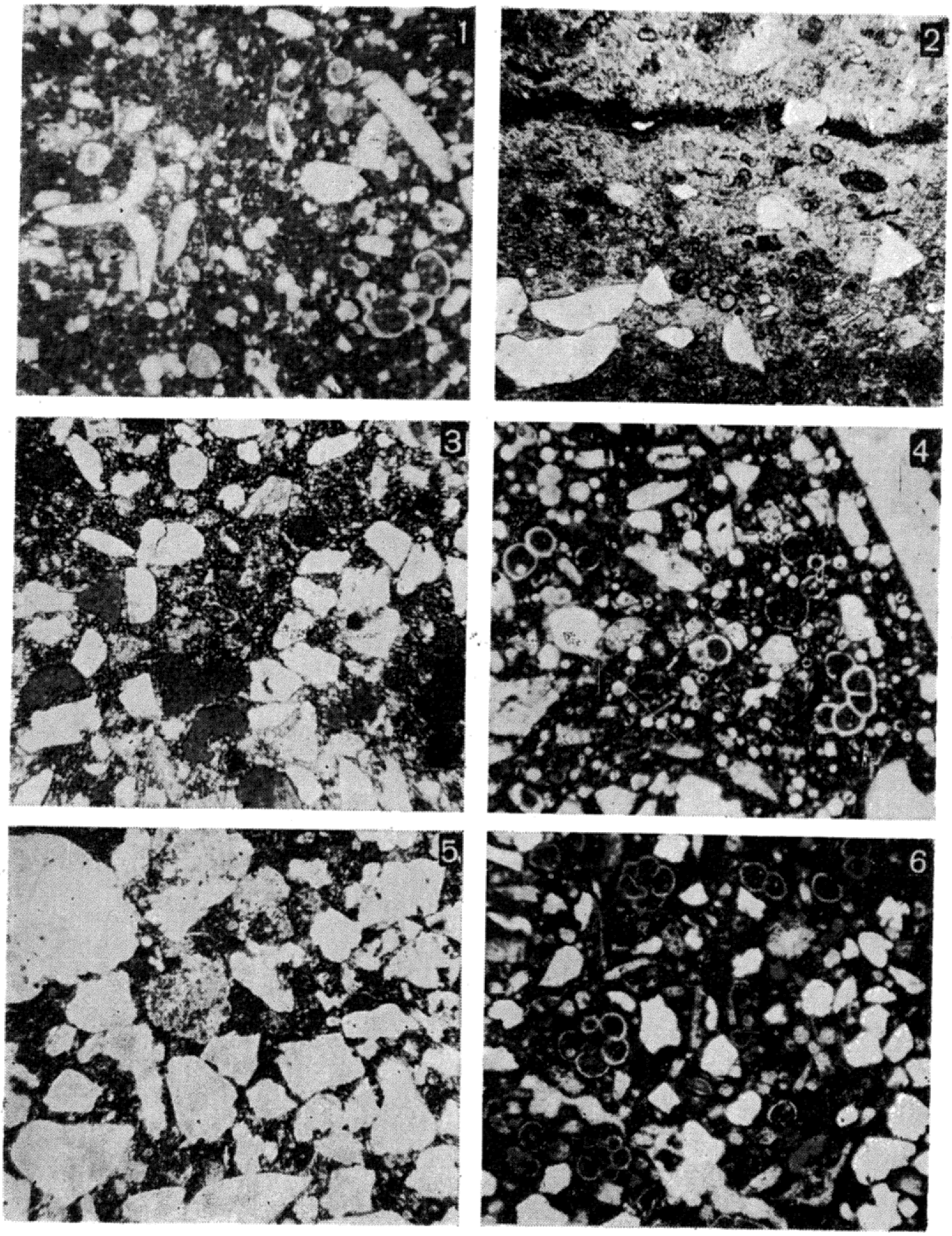
Pl. 1

Characteristic microfacies of the Turonian and Campanian

1 — microfacies with sponge spicules, inoceram fragments and planktonic foraminifers; Lower Campanian, Pniaki (sample *9*); × 35. *2* — stromatolite partly consisting of detrital quartz, glauconite and foraminifers; Turonian (I. lamarcki Zone), Pniaki × 35. *3* — microfacies corresponding to the maximum frequency of quartz and glauconite, and underlying the discontinuity surface; Turonian (I. lamarcki Zone), Zalesice (sample *12c*); × 35. *4* — microfacies with abundant inoceram fragments, planktonic foraminifers and small amount of quartz and glauconite; Turonian (I. lamarcki Zone), Zalesice (sample *11*); × 35. *5* — microfacies with abundant quartz and glauconite; Turonian (I. labiatus Zone), Zalesice (sample *5*); × 35. *6* — microfacies with quartz, inoceram fragments and planktonic foraminifers; Turonian (I. lamarcki Zone), Pniaki (sample *6*); × 35.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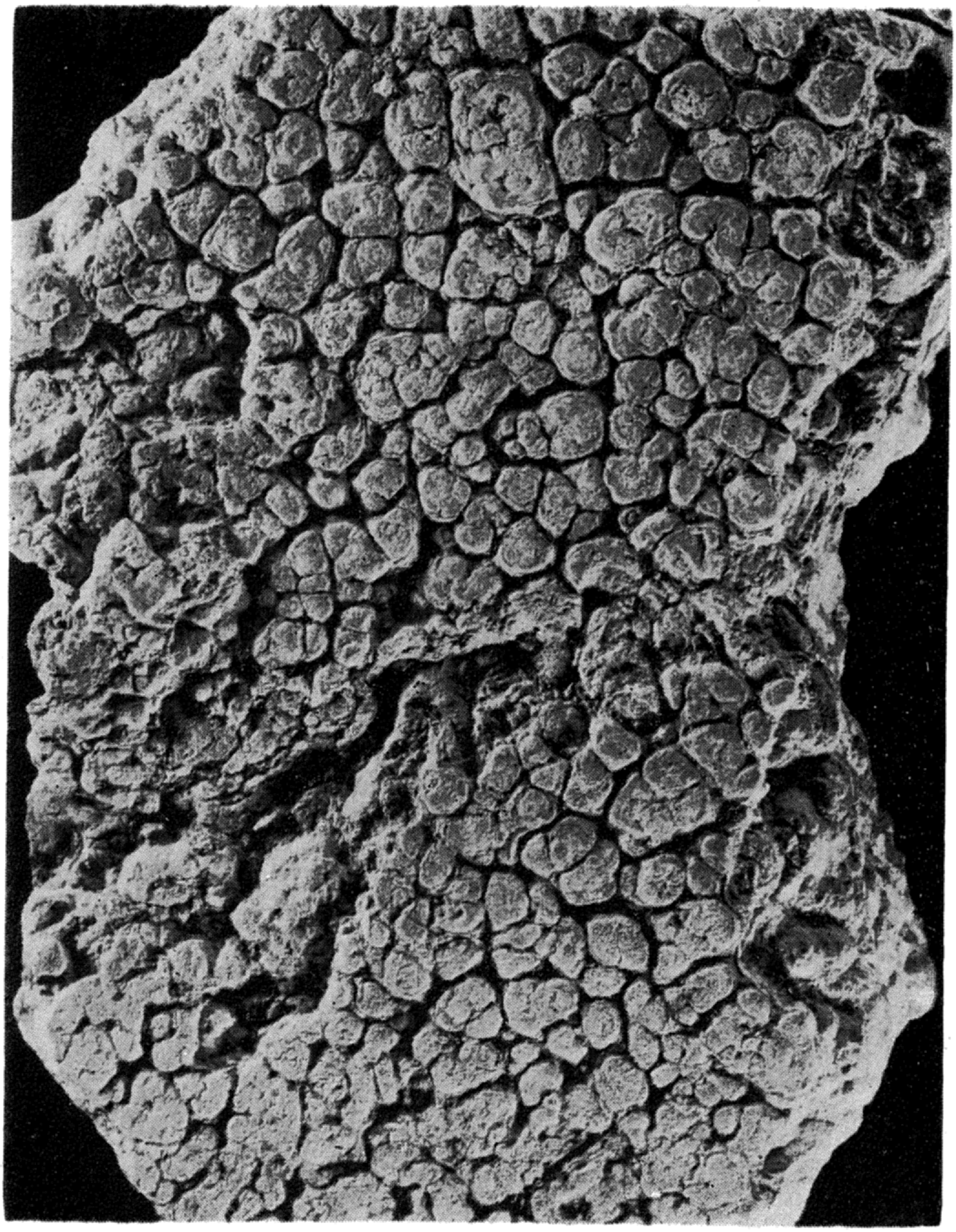
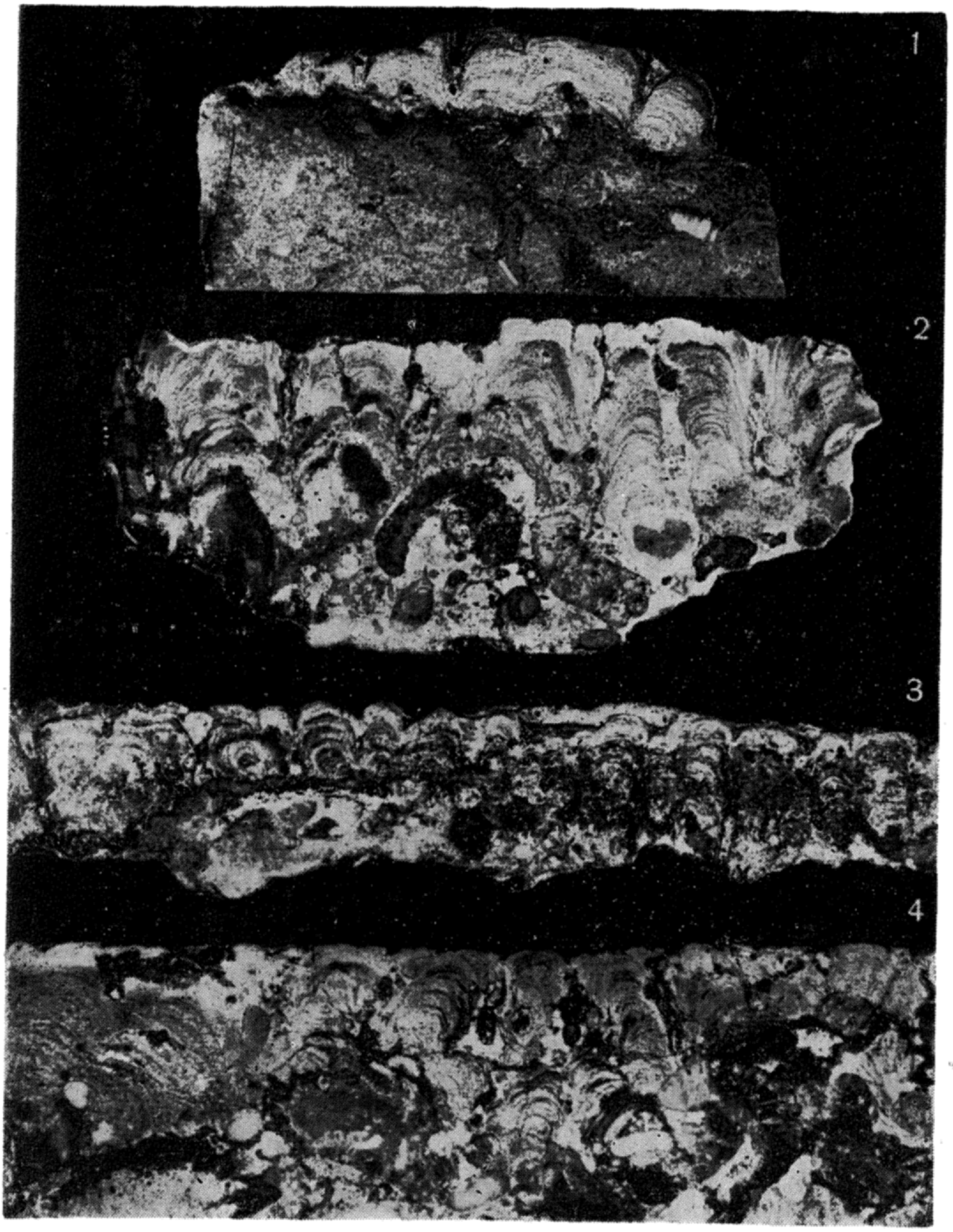
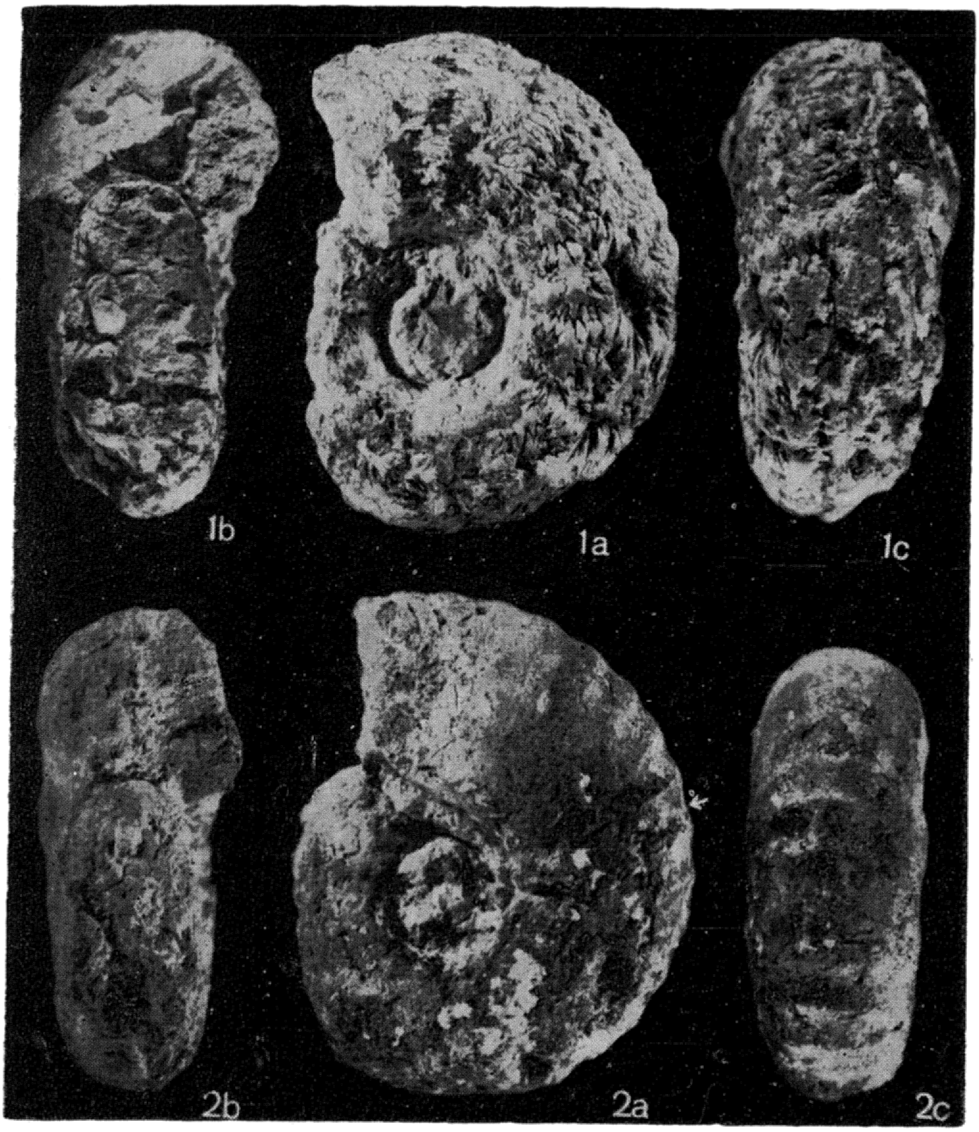


Top view of the polygonal stromatolitic layer; Turonian, Bocieniec; nat. size.



1 — Stromatolitic layer developed on the top surface of sandy-glauconitic limestones; Turonian, Pniaki; nat. size.
2 — Stromatolitic layer developed on uneven surface of the Turonian conglomerate at Bocieniec; nat. size.
3 — Stromatolitic layer; Turonian, Bocieniec; × 1.5.
4 — Stromatolites growing on uneven top surface of the Turonian conglomerate at Bocieniec; nat. size.



1a-c — *Lewesiceras peramplum* (Mantell), inner (juvenile) whorls of the large form; Turonian, Bocieniec.

2a-c — *Lewesiceras peramplum* (Mantell), adult specimen (small form) with a fragment of the final body chamber (arrowed is the end of the phragmocone); Turonian, Bocieniec.

All photos in natural size; taken by B. Drozd, M. Sc.

R. MARCINOWSKI i M. SZULCZEWSKI

STRATYGRAFICZNIE SKONDENSOWANE UTWORY KREDOWE ZE STROMATOLITAMI NA ZACHODNIM OBRZEŻENIU NIECKI MIECHOWSKIEJ

(Streszczenie)

Przedmiotem opracowania są skondensowane stratygraficznie utwory kredowe zachodniego obrzeżenia niecki miechowskiej (fig. 1—2), zawierające horyzont stromatolitowy. Znane już dawniej stromatolity (fig. 6—11 oraz pl. 2—3) charakteryzują się m. in. wysoką selekcją materiału detrytycznego i dużym udziałem nieorganicznej substancji fosforanowej. Powstały one poniżej strefy pływów, w płytkich wodach o wysokiej energii i występują bezpośrednio poniżej podmorskiej powierzchni niedepozycyjnej. Dla określenia pozycji horyzontu stromatolitowego w rozwoju facjalnym sekwencji, dokonano statystycznej analizy mikrofacjalnej kilku wybranych profilów (fig. 3—5 oraz pl. 1). W oparciu o opisanego (fig. 12 oraz pl. 4) amonita *Lewesiceras peramplum* (Mantell) i obserwacje sedymentologiczne ustalono wiek warstwy stromatolitowej w Bocieńcu na turon. Spłycenie, któremu odpowiada warstwa stromatolitowa, i późniejsze warunki niedepozycyjne wiążą się z synsedymentacyjnymi ruchami tektonicznymi o szerszym zasięgu regionalnym.

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