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Coralline algae from the Pińczów Limestones (Middle Miocene; southern slopes of the Holy Cross Mountains, Central Poland) as environmental indicators

ABSTRACT: The applicability of the coralline algae from the Middle Miocene (Badenian) Pińczów Limestones (southern slopes of the Holy Cross Mountains, Central Poland) as environmental indicators is presented and discussed. An integrated analysis of some morphological features (algal forms, shapes, and the nature of interlaminar and internodular sediment) and their relation to the facies pattern enabled the reconstruction of the sedimentary environment for the Pińczów Limestones. This result, combined with the bathymetric interpretation of the foraminifer genus *Amphistegina*, allowed to present a facies model and to distinguish three different varieties of the rhodolith pavement facies. The presented analysis demonstrates also faulty usefulness of the algal taxonomic composition for paleoenvironmental reconstructions.

INTRODUCTION

The widely distributed crustose coralline algae, whose part constitute the lithothamnian algae, are important contributors to the present-day warm-water biocoenoses. They are responsible for the development of such structures as algal ridges (ADEY & BURKE 1976) and rhodoliths, the latter of which due to varying morphology and high preservation potential are recognized tools in paleoecological studies (BOSENCE & PEDLEY 1982, PISERA & STUDENCKI 1989). The Middle Miocene (Badenian) Pińczów Limestones (southern slopes of the Holy Cross Mountains, Central Poland; *see* Text-fig. 1), in which the coralline algae are one of the most common elements of the community, are good research-basis for the valuation of the recognized coralline algae as environmental indicators. The algae of the Pińczów Limestones have been used in the paleofacies discrimination by STUDENCKI (1988a) who, however, based environmental conclusions on requirements of organic biota other than the coralline algae.

Morphological variability observed in recent and fossil material was used by BOSENCE (1976) as a basis of distinguishing four growth-forms of the thalli. In respect to the algal shape, three distinct groups are distinguished: (*i*) spherical, (*ii*) ellipsoidal, and (*iii*) discoidal. The crustose coralline algal thalli may undergo an overturning to produce spherical, ellipsoidal, and a part of discoidal forms, which in literature are called either the rhodoliths, or the nodules, commonly the lithothamnian nodules.

Interpretations of the rhodolith shapes are variable. BOSELLINI & GINSBURG (1971), basing on recent algal community from the Bahamas referred their origin to the wave action in a very shallow (1 to 2m) environment. BOSENCE & PEDLEY (1982) and REZAK & *al.* (1985), however, indicated the possibility of the thalli overturning by bottom currents and thus formation of rhodoliths. The recent current megaripples composed of rhodoliths, with 1 to 2m amplitude and up to 30m length, in waters some tens of meters were reported by REZAK & *al.* (1985), whilst REID & MACINTYRE (1988) mentioned the alive rhodoliths from a depth of about 90m. On the other hand, the rhodoliths may be transported, as interpreted by BOSENCE & PEDLEY (1982) and DULLO (1983) who described them deposited in storm channels from the Miocene deposits of Malta and of the Vienna Basin, respectively.

SCOFFIN & *al.* (1985) stated that the spherical shapes of rhodoliths may be formed, when having been submitted to intermittent rolling only. The rotation could be a result of the basement winnowing from underneath the rhodoliths and their deposition into depressions (*see* MCMASTER & CONOVER 1966). The evidence of such processes was indicated by MINNERY (1990) after the Hurricane Allen in the Gulf of Mexico, in August 1980. The report by MCGRAIL & HORNE (1981) demonstrated that, in spite of high velocity of the upper part of water column, the velocity of the bottom set of the water did not exceed 15cm/s, what was not sufficient for rhodolith overturning, but enough for the winnnowing of the substrate. Another rolling mechanism of the rhodoliths was suggested by FRYDL & STEARN (1978), who showed the life activity of herbivorous and deposit-feeding organisms to be sufficient for the overturning. It may therefore be concluded that the shape of algal thalli may result from variable agents, acting in different hydrodynamic and bathymetric conditions, and being noted from very shallow environments, down to about 150m (GEISTER 1983).

The algal growth-forms are usually related to the hydrodynamic features (*see* BOSELLINI & GINSBURG 1971, BOSENCE 1976), though other posibilities were also pointed as the positive relation between the species possessing the thick perithallus and cell fusion, and the waters enriched with herbivorous organisms (STENECK 1983, 1985); such species are usually characterized by a laminar form of growth.

To summarize, in result of the high environmental plasticity observed in recent crustose coralline algae and numerous factors controlling their development, it is required to consider various aspects to make the algal-based interpretation of any ancient environment. This paper presents an attempt of such an interpretation for the Pińczów Limestones.

GEOLOGIC SETTING OF THE PIŃCZÓW LIMESTONES

The studied sequence of the Pińczów Limestones is exposed betweeen Pińczów and Busko-Spa on the southern slopes of the Holy Cross Mountains, Central Poland (*see* Text-fig. 1). The investigated flat-lying strata (*see* Text-fig. 1*C*) are overlying, with angular unconformity, Upper Cretaceous (Campanian — Maastrichtian) marls. The nannoplankton studies carried out in the neighboring area of the Korytnica Bay indicate the NN5 and NN6 standard nannoplankton zones for the Middle Miocene deposits of the whole region (MARTINI 1977, BAŁUK & RADWAŃSKI 1977), the Pińczów area including (*see* STUDENCKI 1988b).

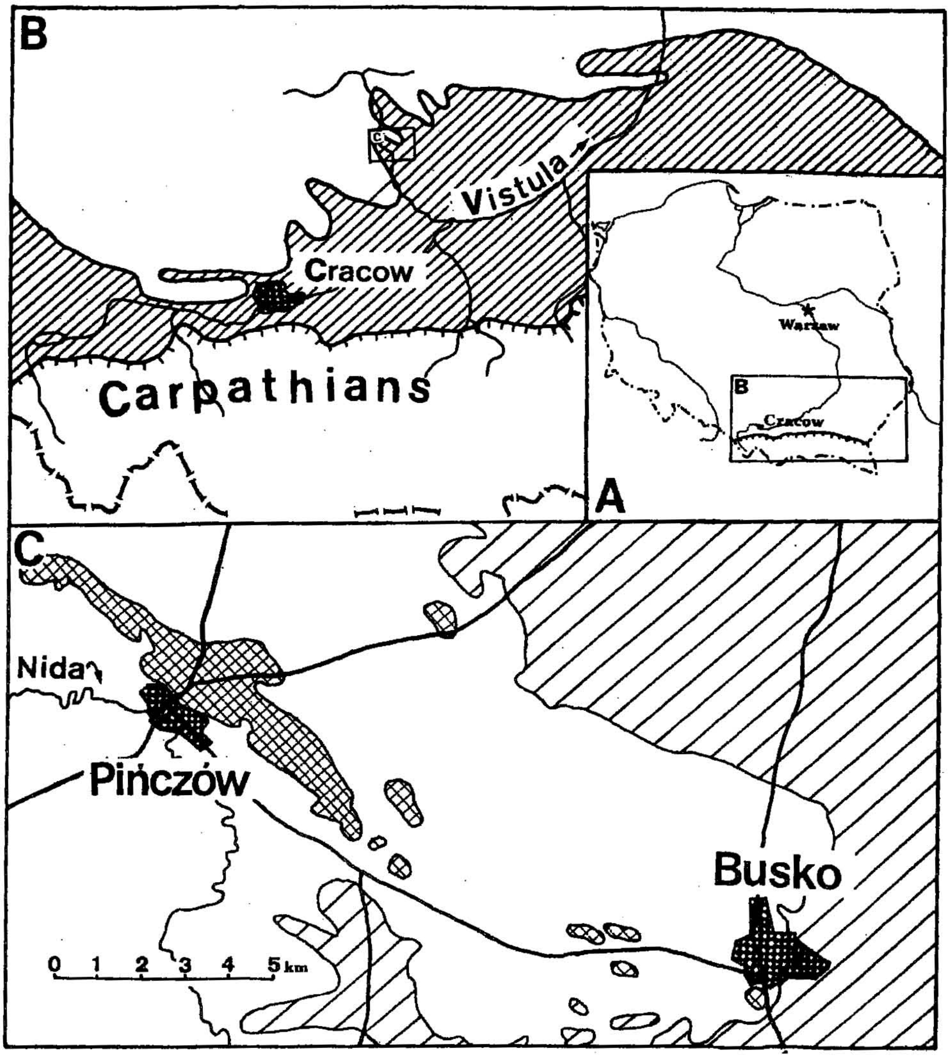


Fig. 1. Geologic setting of the studied area

A — Location of the Fore-Carpathian Depression in Poland

B — Paleogeographic sketch-map of the Middle Miocene (Badenian) transgression in the Fore-Carpathian Depression (*adopted from:* RADWAŃSKI 1977, Fig. 169)

C — Locality map of the studied area, to show present-day exposure areas of the Pińczów Limestones (*checkered*), other Middle Miocene deposits (*hachured*), and pre-Miocene substrate (*blank*)

In the regional lithostratigraphic subdivision, the Middle Miocene (Badenian) Pińczów Limestones have commonly been attributed to the "Lithothamnian Level", whereas all variable deposits beneath to the "Sublithothamnian Level" (KOWALEWSKI 1930), the both of which represent lithofacies units (RADWAŃSKI 1969).

The lowermost part of the Pińczów Limestones is composed of undistinctly, very-thick bedded, fine organodetrital deposits, which pass upwardly into coarse-grained organodetrital limestones (*see* Pl. 1, Figs 1-2). Here and there, the rhodoliths are particularly common and they build the rhodolith pavement. The sequence is interrupted once (in the northern part) or twice (in southern) by marly limestones with abundant bryozoans *Celleporaria*, and thus called the Lower and the Upper Celleporan Bed (*see* Pl. 1, Figs 3-4).

The rich fauna of the Pińczów Limestones gained vast literature (*see* KOWALEWSKI 1930, RADWAŃSKI 1969, BAŁUK & RADWAŃSKI 1977, STUDENCKI 1988a). Separate studies were lately concerned to bivalves (STUDENCKA & STUDENCKI 1988) and some vertebrates (*see* CZYŻEWSKA & RADWAŃSKI 1991). It was STUDENCKI (1988b), who also gave a taxonomic elaboration of the coralline algae.

STUDENCKI (1988a), basing on the analysis of the organic communities, postulated that the Middle Miocene (Badenian) sea became shallow gradually to WNW, showing its evident dependence on the tectonic directions of the Laramide structures in the basement. The analysis of transport directions, mainly within the "Sublithothamnian Level", carried out by the author

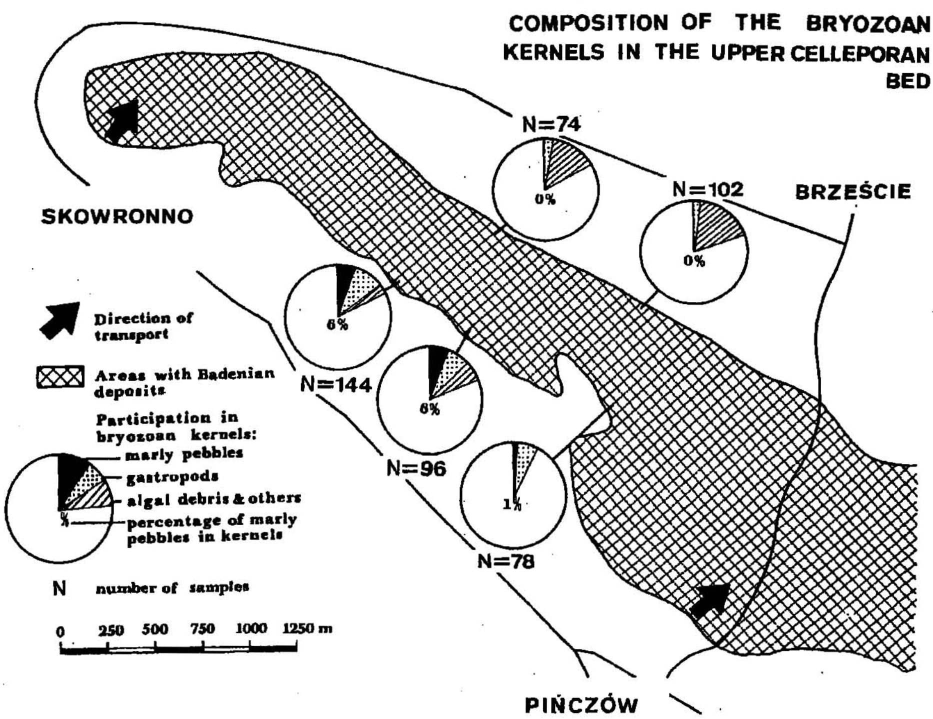
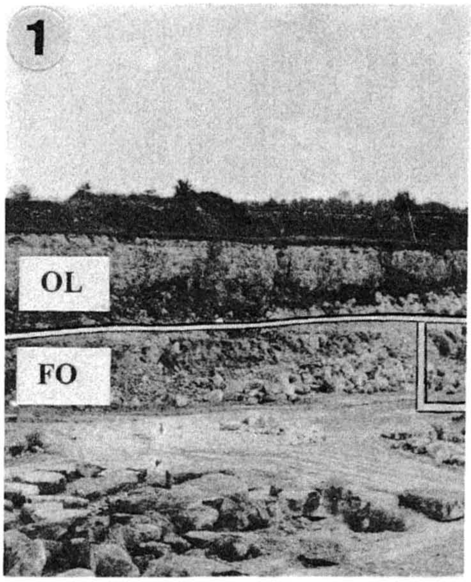
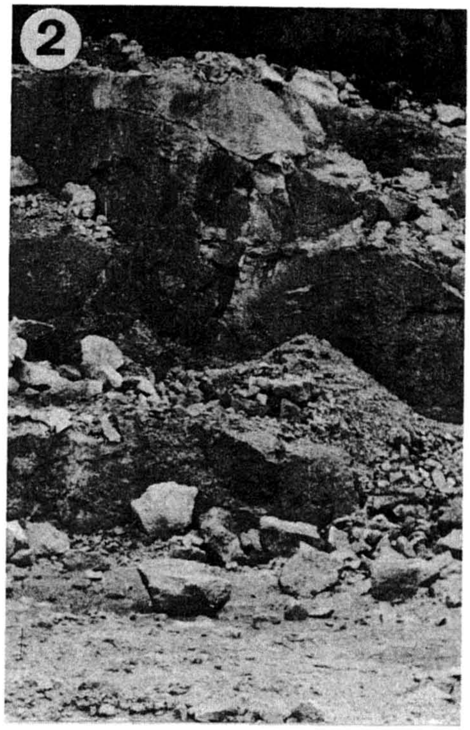
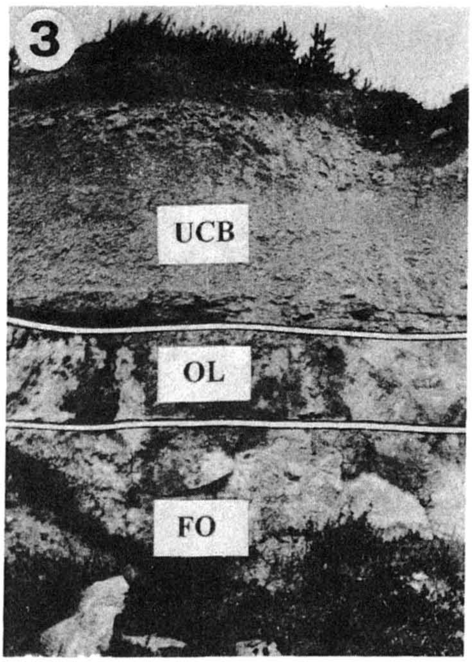
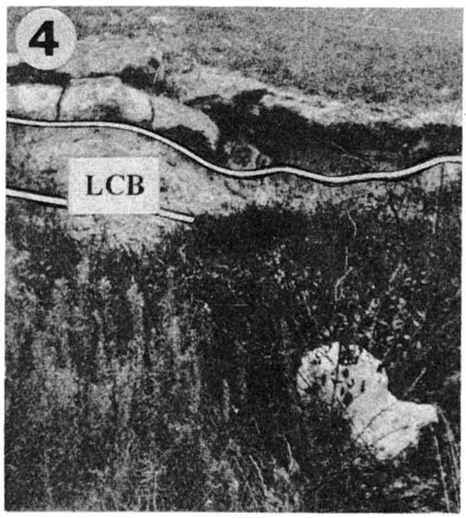


Fig. 2. Composition of the bryozoan kernels in the Upper Celleporan Bed and direction of transport observed in the "Sublithothamnian Level"







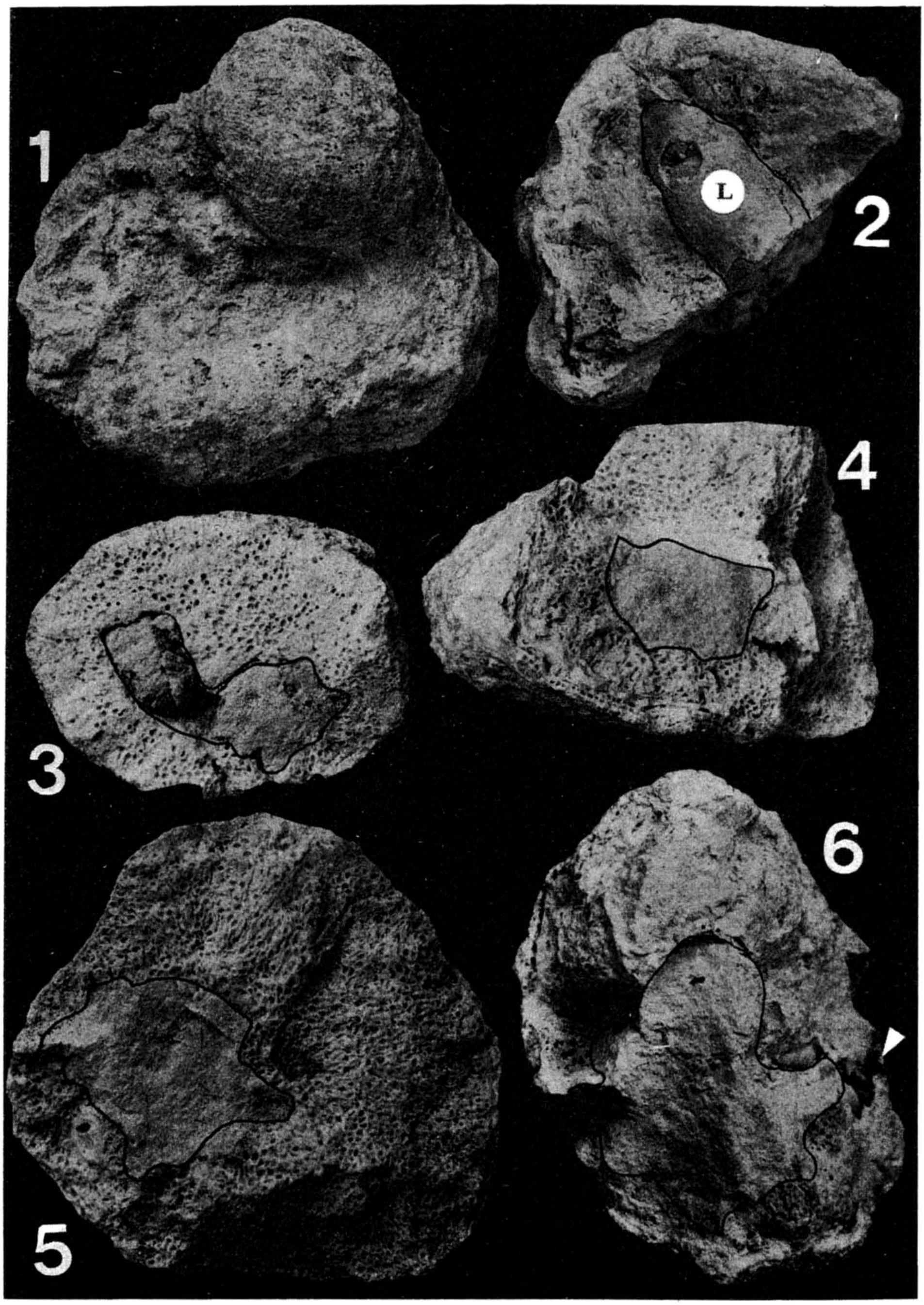


1 — General view of the northern side of the Pińczów Quarry (outcrop *5* in Text-fig. 5; rectangled is a part presented in Pl. 1, Fig. 2); **FO** — fine-organodetrital facies, **OL** — organodetrital facies

2 — Close-up, to show the lower part of the Pińczów Quarry with thick-bedded limestones of the fine-organodetrital facies

3 — Upper Celleporan Bed (**UCB**; outcrop *3* in Text-fig. 5) thickness about 110 cm; **OL** — organodetrital facies, **FO** — fine-organodetrital facies

4 — Lower Celleporan Bed (**LCB**; outcrop *3* in Text-fig. 5) thickness about 80 cm



1 — Celleporan bryozoans encrusted by other bryozoans alternated with coralline algae, × 1.5; Pińczów

2-6 — Clasts from the Cretaceous substrate (Senonian marls) as the kernels of the celleporan colonies, × 2.5; L — boring of the bivalve *Lithophaga* sp., arrowed is the encrusting gastropod *Petaloconchus intortus* (LAMARCK); Pińczów

(DREWNIAK 1990) suggests the second-rate south-north paleotransport direction, with the basin shallowing toward the south, as formerly suggested also by RYSZKIEWICZ (1973). Additionally, the latter trend is supported by the distribution of clasts of the Cretaceous marls (*see* Text-fig. 2 *and* Pl. 2, Figs 2-6) and inoceramid prisms (*see* Pl. 3, Fig. 2), what indicates the areas of the exposed Cretaceous marls in the southern part of the basin. Moreover, the passage from the Upper Celloporan Bed to the rich-in-barnacle sediments southwardly, in the environs of Skowronno (*see* Text-fig. 2), according to observations from the Vienna Basin (Zogelsdorf Formation; *see* NEBELSICK 1989), also indicates the postulated second-rate direction of the paleorelief.

FACIES CHARACTERISTICS

Basing on macro- and microscopic features of the rocks (*see* Text-fig. 3 and Pls 3-5) and on the size and characteristics of organic remains, admixture of quartz, seven variable facies were distinguished within the studied deposits. Some of these facies are adopted after KOWALEWSKI (1930), RADWAŃSKI (1969), and STUDENCKI (1988a), and references to them are given at particular descriptions.

Marly facies (numbered *1*), developed at the bottom of the sequence (KOWALEWSKI 1930, RADWAŃSKI 1969), and characterized by the presence of silt-sized quartz grains and a remarkable amount of small planktic forams, but by a complete lack of coralline algae, is omitted in further discussion.

Sandy-marly facies (numbered *2*) differs from the preceding one by a remarkable content of sand-size quartz (up to 30%), and the presence, in parts, of the detritus of coralline algae. An admixture of algal detritus and its amount in relation to the quartz content allow to distinguish the three following microfacies:

Grainy microfacies (*2A*), characterized by the lack of algal detritus;

Algal-detrital microfacies (*2B*), characterized by an admixture of algal detritus relatively common;

Algal microfacies (*2C*), characterized by the presence of intact rhodoliths, often forming well individualized horizons.

Fine-organodetrital facies (numbered *3*) is represented by foraminiferal mudstones and packstones, with algal detritus being only an accessory element of the deposit (usually much less than 5%); it forms a very thick-bedded unit (*see* Pl. 1, Figs 1-2).

Organodetrital facies (numbered *4*), described by STUDENCKI (1988a), is represented by bryozoan packstones to wackstones, forms a thin- to thick-bedded unit with common detritus of brachiopod and bivalve shells, coralline algae and forams. The latter are the base of the differentiation of the three microfacies:

Foraminiferal microfacies (*4A*) — the type similar to fine-organodetrital facies (*3*), with relatively frequent small planktic forams, but enriched with organic detritus;

Amphisteginal microfacies (*4B*) — the characteristic element is the presence of large benthic forams *Amphistegina mamilla* FICHTEL & MOLL, in places accompanied by *Heterostegina costata* D'ORBIGNY;

Heterosteginal microfacies (*4C*) — the characteristic element is the presence of *Heterostegina costata* D'ORBIGNY; the planktic forams become markedly rarer than in two previous types.

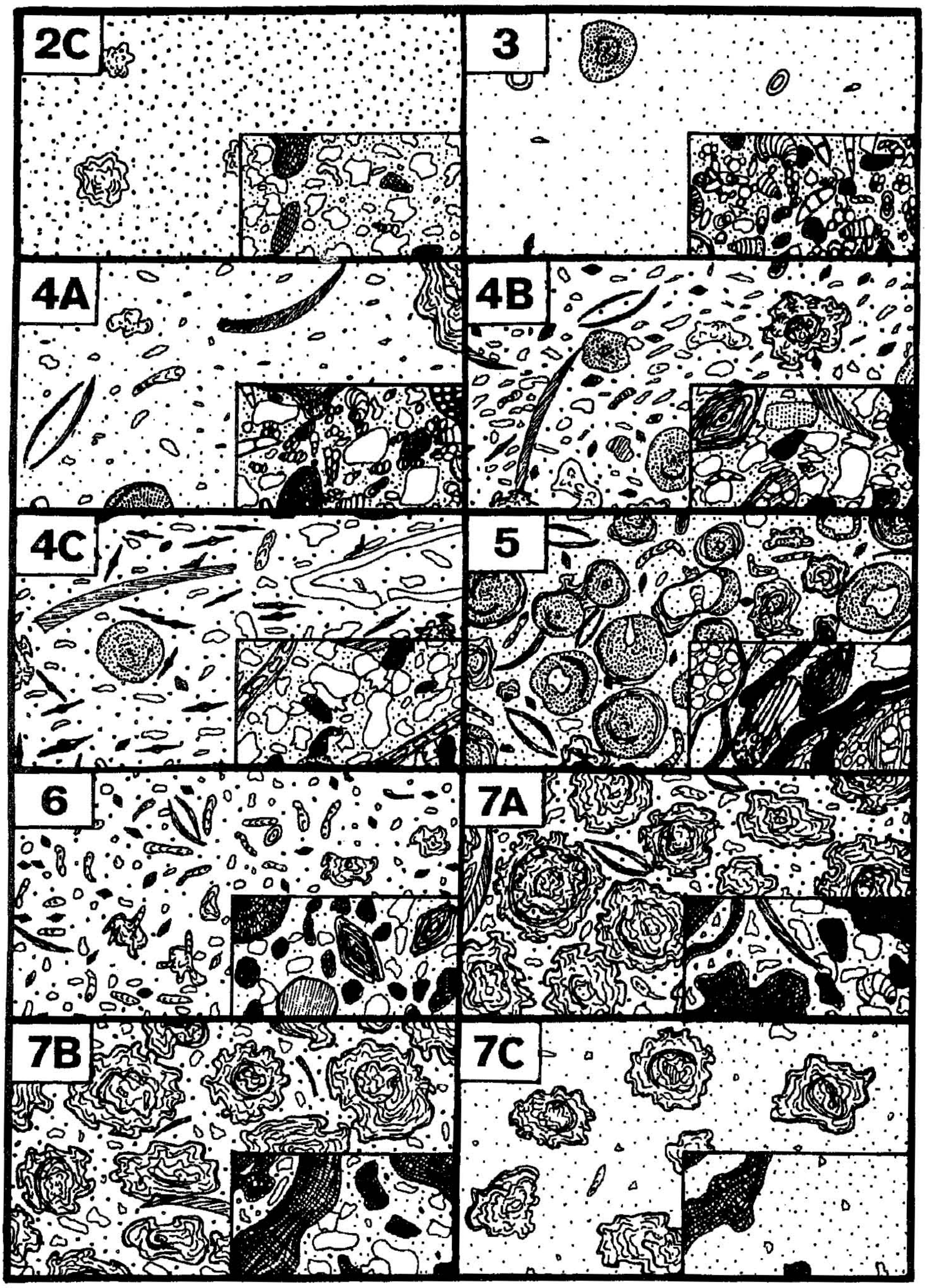
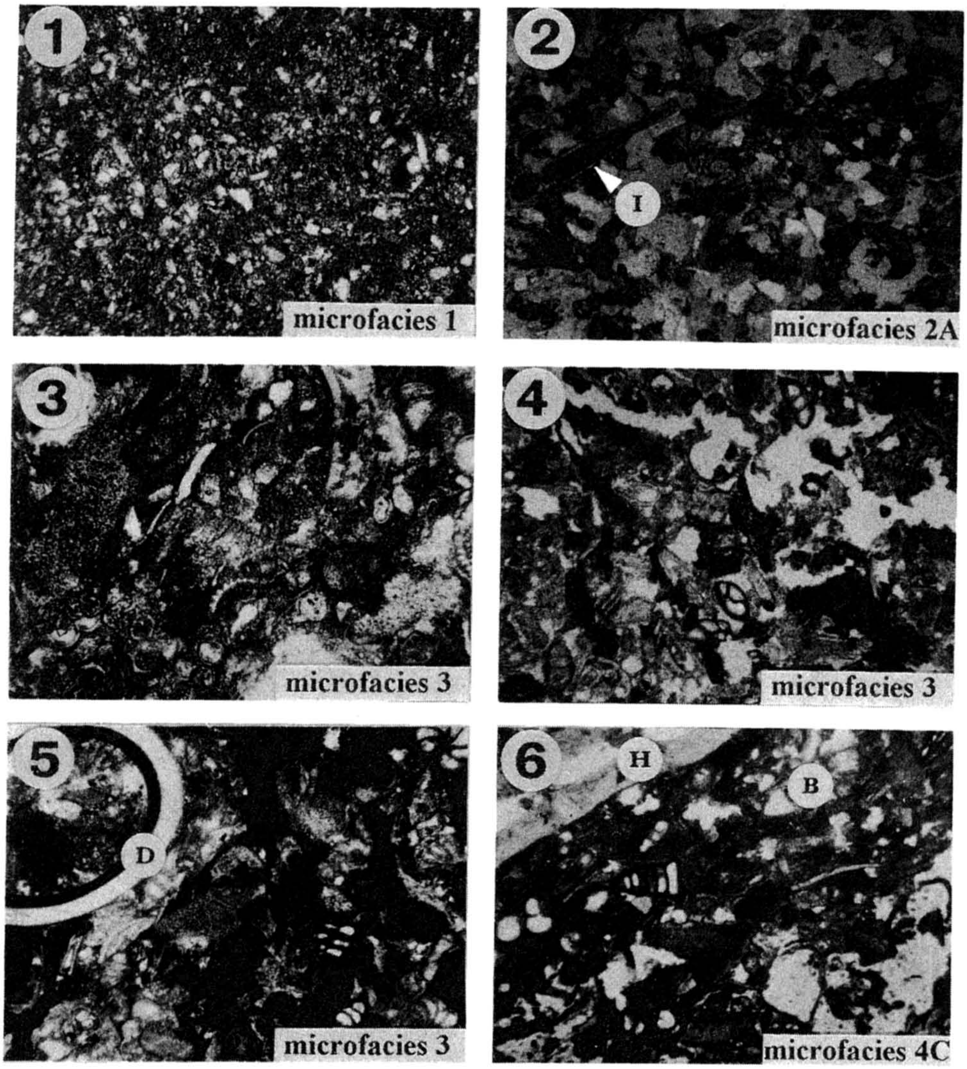


Fig. 3. Typical macroscopic and microscopic views of the facies and microfacies

Length of each sample is about 50 cm, and of insets (microscopic view) about 5 mm; number of the facies and microfacies as in the text and in Text-figs 5-6



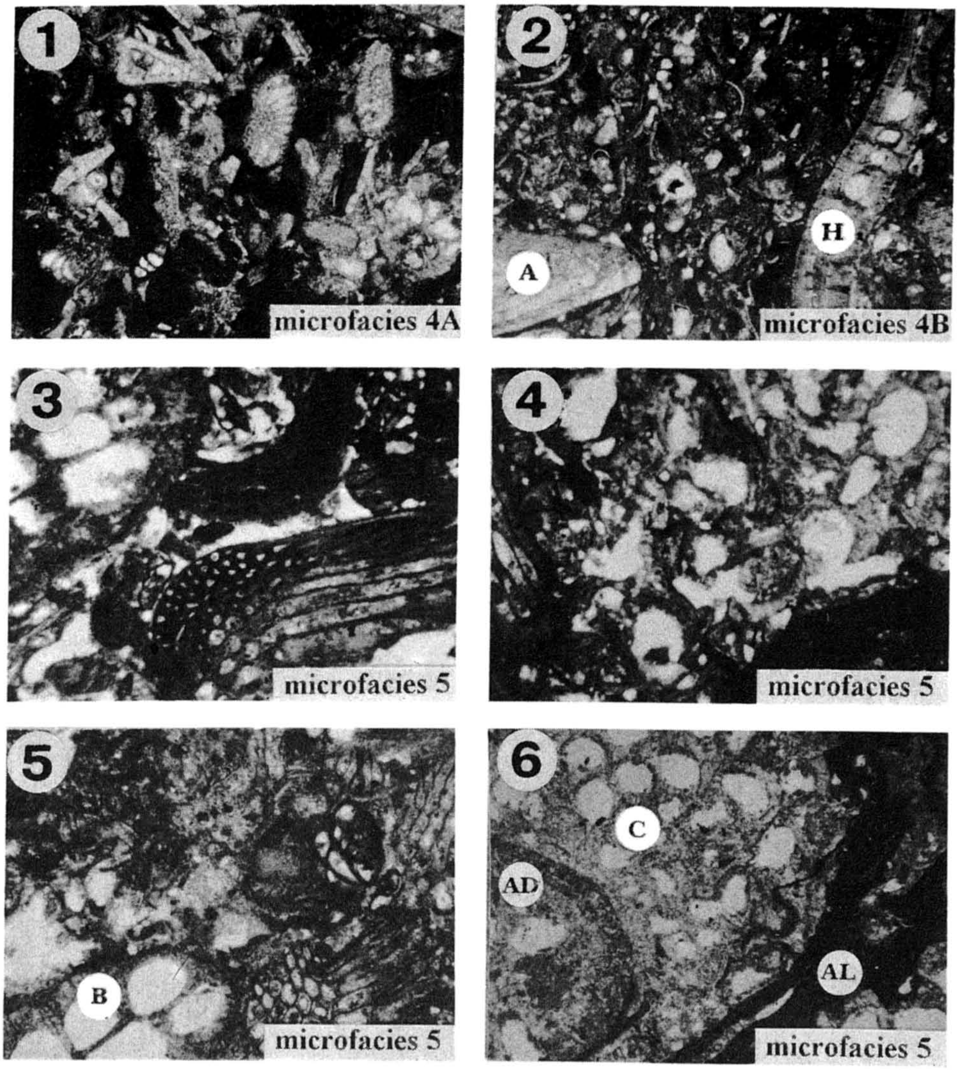
1 — Marly facies; to show the content of fine-grained quartz (about 15%) typical of this facies; × 100, nicols crossed; Pińczów

2 — Grainy microfacies: detrital quartz, and an inoceramid prism (marked **I**); × 100, nicols crossed; Skowronno

3-4 — Fine-organodetrital facies: small planktic forams as dominating component, and debris of coralline algae (black in the photomicrograph), × 30; Pińczów

5 — Fine-organodetrital facies: small forams, algal debris (*black*), and a tube of the polychaete *Ditrupa* (marked **D**), × 30; Pińczów

6 — Organodetrital-heterosteginal microfacies: large forams *Heterostegina costata* D'ORBIGNY (marked **H**), and branching bryozoans (marked **B**), × 30; Pińczów



1 — Organodetrital foraminiferal microfacies of the character intermediate between the organodetrital and fine-organodetrital facies, × 30; Pińczów

2— Organodetrital amphisteginal microfacies with large benthic forams: **A** — *Amphistegina mamilla* FICHTEL & MOLL, **H** — *Heterostegina costata* D'ORBIGNY; × 30; Pińczów

3-6 — Bryozoan debris from algal-bryozoan facies, × 30; *3* and *4* from Pińczów; *5* from Wełecz, **B** — branching bryozoan debris; *6* from Busko, **AD** — erected bilamellar adeoniform bryozoan, **C** — celleporan bryozoan, **AL** — thalli of coralline algae

Algal-bryozoan facies (numbered *5*), described by STUDENCKI (1988a), is characterized by bryozoan remains forming even up to 40% of the rock (Text-fig. 3), and being often wrapped by encrusting coralline algae (*see* Pl. 2, Fig. 1). The forams *Amphistegina* are often its substantial element, and borings of bivalves are common (*see* Pl. 2, Fig. 2). Another kind of this facies is the barnacle facies (*5A*), strongly enriched with detritus of *Balanus* sp.

Algal-amphisteginal debris facies (numbered *6*), described as *the branching algae facies* by STUDENCKI (1988a), has the main components of the rock constantly broken. The debris of the branching coralline algae are relatively common.

Rhodolith pavement facies (numbered *7A*, *7B*, *7C*; defined below), described by STUDENCKI (1988a), is similar to the algal horizons within the algal microfacies (*2C*), from which it differs by a lack of detrital quartz and by a higher abundance of algal thalli; borings of the bivalves *Gastrochaena* and *Lithophaga* are common in particular rhodoliths.

ALGAL MORPHOLOGY

The coralline algae represented in the studied material display a wide range of morphological variability of their growth-forms and shapes. When their share, following BOSENCE'S (1976) classification (Text-fig. 4), is analyzed in all facies types, it is evident that among the intact specimens the III*rd* and IV*th* growth-forms dominate, except the algal-bryozoan (*5*) and the algal-amphistegi-nal debris (*6*) facies. The occurrence of laminar forms besides the algal-bryozoan

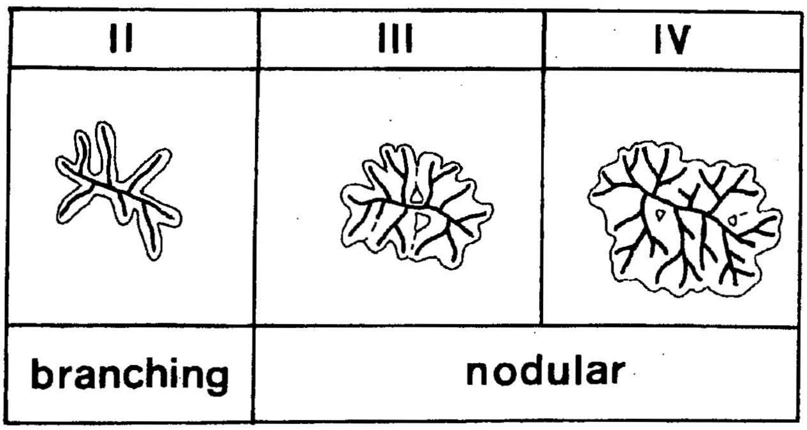


Fig. 4. Algal growth-forms (*adopted from:* BOSENCE 1976)

II — second density algal branching classes

III and IV — third and forth algal branching classes (nodular forms), laminar type of growth is omitted

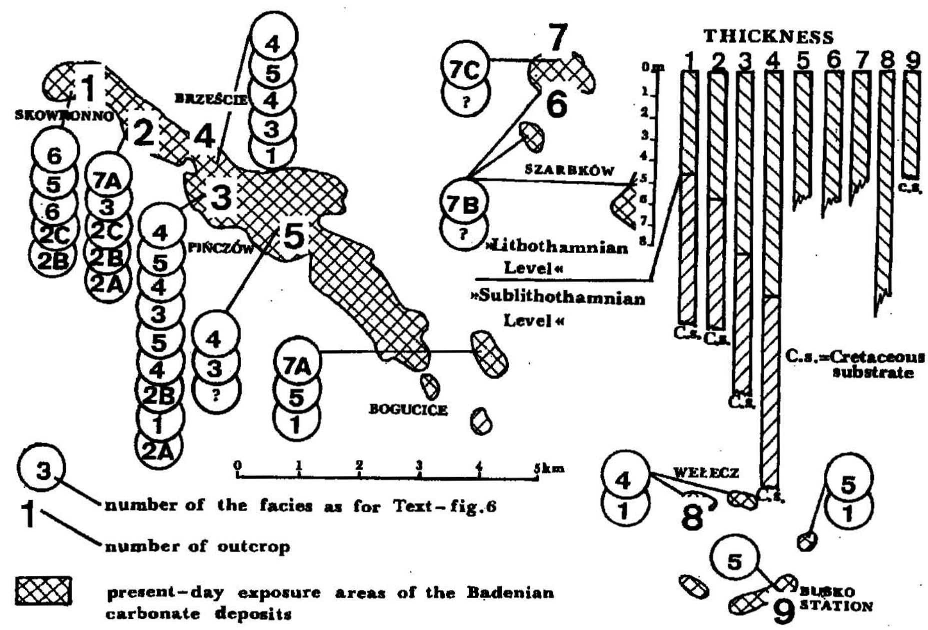


Fig. 5. Locality map, to show the distribution of the facies and microfacies discussed in the text

facies (*5*), where they encrust the spherical elements, is sporadic, and limited to intergrowths within rhodoliths in some kinds of rhodolith pavement facies from environs of Szarbków (for location *see* Text-fig. 5). The algal-amphisteginal debris facies (*6*) is characterized by a more frequent occurrence of laminar forms and of branching types of the II*nd* class. The II*nd* class forms also the secondary rhodolith building elements, and they occur in other facies as detritus.

In the studied deposits the coralline algae are dominantly of spherical shape ("S"). Forms of ellipsoidal shape ("E") are much less abundant, and discoidal shape ("DS") is quite rare (*see* Text-fig. 6).

The spherical shapes of algae are particularly frequent in the algal, the foraminiferal, and the heterosteginal microfacies (*2C*, *4A*, *4C*, respectively), and within the algal-amphisteginal debris, and rhodolith pavement facies (*6* and *7*). In the latter facies, it is mostly a case within the rhodolith pavement facies from Skowronno. The high content of the spherically shaped algae in the algal-bryozoan facies (*5*) is caused by the algal encrusting of the celleporan bryozoans (representing the genus *Celloporaria*), forming nodular colonies (Pl. 2, Fig. 1). The discoidally shaped algae are present in three facies only (*see* Text-fig. 6). These are the fine-organodetrital (*3*), the algal-bryozoan (*5*), and two varieties of the rhodolith pavement facies (*7B, 7C*), that means in deposits from te northern and southern part from the Szarbków environs (*see* Text-fig. 5).

DISCUSSION OF ALGAL DIVERSITY

The shape of the coralline algae, as reviewed in the introduction, does indicate only the mobility of the thalli, regardless of their rotation mechanism. On this basis, the data from the Pińczów Limestones put in order the facies and microfacies with high rotation of rhodoliths as: the algal (*2C*), the heterosteginal (*4B*), the algal-amphisteginal debris (*6*), a part of the rhodolith pavement facies from the Skowronno environs, and the amphisteginal (*4C*),

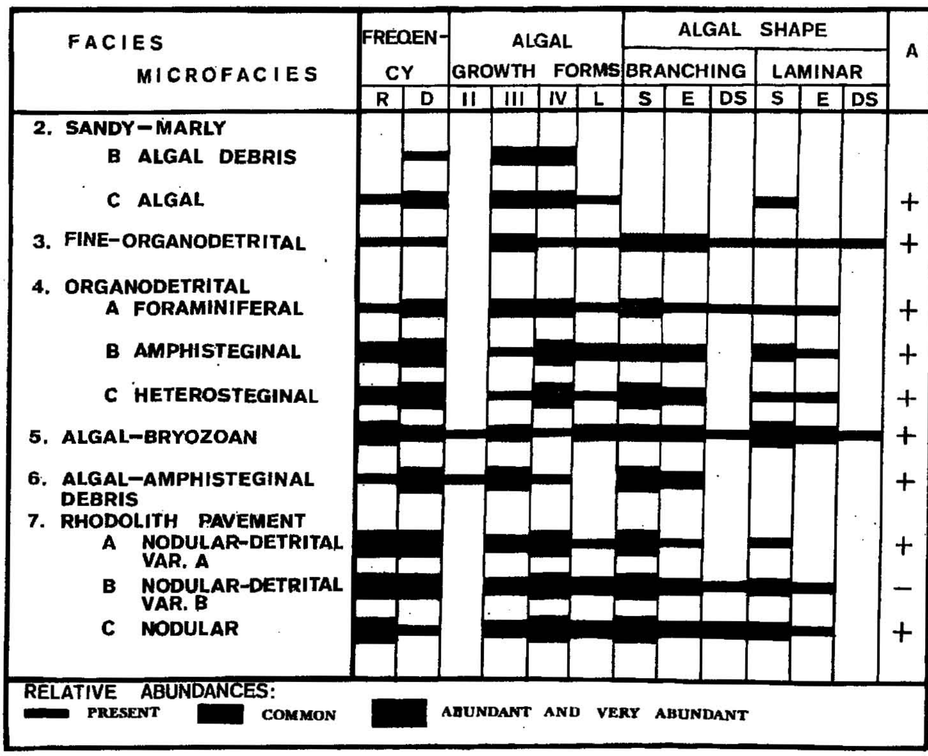


Fig. 6. Relative abundances of the coralline algae and their forms in the particular facies and microfacies

FREQUENCY: R — rhodoliths, D — detritus
ALGAL SHAPE: S — spheroidal, E — ellipsoidal, DS — discoidal
A — accordance (+) or discordance (–) of the sediment between algal crusts and between nodules; L — laminar form of growth; other algal growth-forms as in Text-fig. 4

respectively. Similarity of the rhodolith shape spectrum in the first and last of these facies is thought to be a result of transport of the rhodoliths into the algal microfacies (*2C*) from such an environment as that of the rhodolith pavement facies at Skowronno. The algal shape in the algal-bryozoan facies (*5*) is caused by spherical kernels inside the thalli and thus it does not matter in the reconstruction of the mobility.

The growth-forms of the coralline algae may be used for hydrodynamic analysis only if branching forms (II*nd* class) are neither transported nor crushed. Unfortunately, in the Pińczów Limestones the algal-amphisteginal debris facies (*6*), which is rich in such forms, is dominated by crushed algae. Debris of branching thalli within this facies are probably derived from the rhodolith pavement facies (*7*), as an effect of lower resistance of branched forms on the crushing.

The comparison of the interlaminar sediments documenting hydrodynamics during thalli-growth time and algal shapes registering mobility, permits to determine mechanism of the thallus rotation. When the sediment is fine and algal shape is spherical (high mobility to growth-rate ratio), thalli were overturned by bottom dwellers (*cf.* FRYDL & STEARN 1978) or by intermittent winnowing (*cf.* SCOFFIN & *al.* 1985). A discordance between interlaminar and internodular sediments, and the mainly spherical shape point out the winnowing as the most probable mechanism of rotation. The rhodolith pavement facies from the Skowronno environs, with algal detritus occurring both in the internodular and interlaminar spaces, represented the shallowest part of the basin, only. This very facies, particularly its variety, called the nodular-detrital microfacies var. *A* (numbered *7A*), was a potential source of the detrital material to the surrounding areas, for instance the initial pavement from the environs of Bogucice (*see* STUDENCKI 1988a). The rhodolith pavement facies from the northern part of Szarbków environs is characterized by a small content of algal detritus in interlaminar and internodular sediment. However, southwardly the internodular sediment is markedly enriched with the algal detritus. This fact allows to distinguish the two microfacies: the nodular-detrital var. *B* (numbered *7B*) and the nodular microfacies (numbered *7C*) in the rhodolith pavement facies. A similarity between the interlaminar sediments in both cases suggests the akin quiet conditions during growth period of the algae. The difference of internodular sediment may be interpreted as resulting from an intermittent winnowing of sediment in the area of the nodular-detrital var. *B* microfacies (*7B*). The nodular microfacies (*7C*) was most probably situated deeper in the basin, and thus the original character of the internodular sediment is here preserved (*see* Text-fig. 7). Such model is supported by the bathymetric pattern (deepening to N) indicated for the studied area.

The growth-shapes, forms, character of interlaminar and internodular sediments, and their interrelations enable the ordering of the distinguished

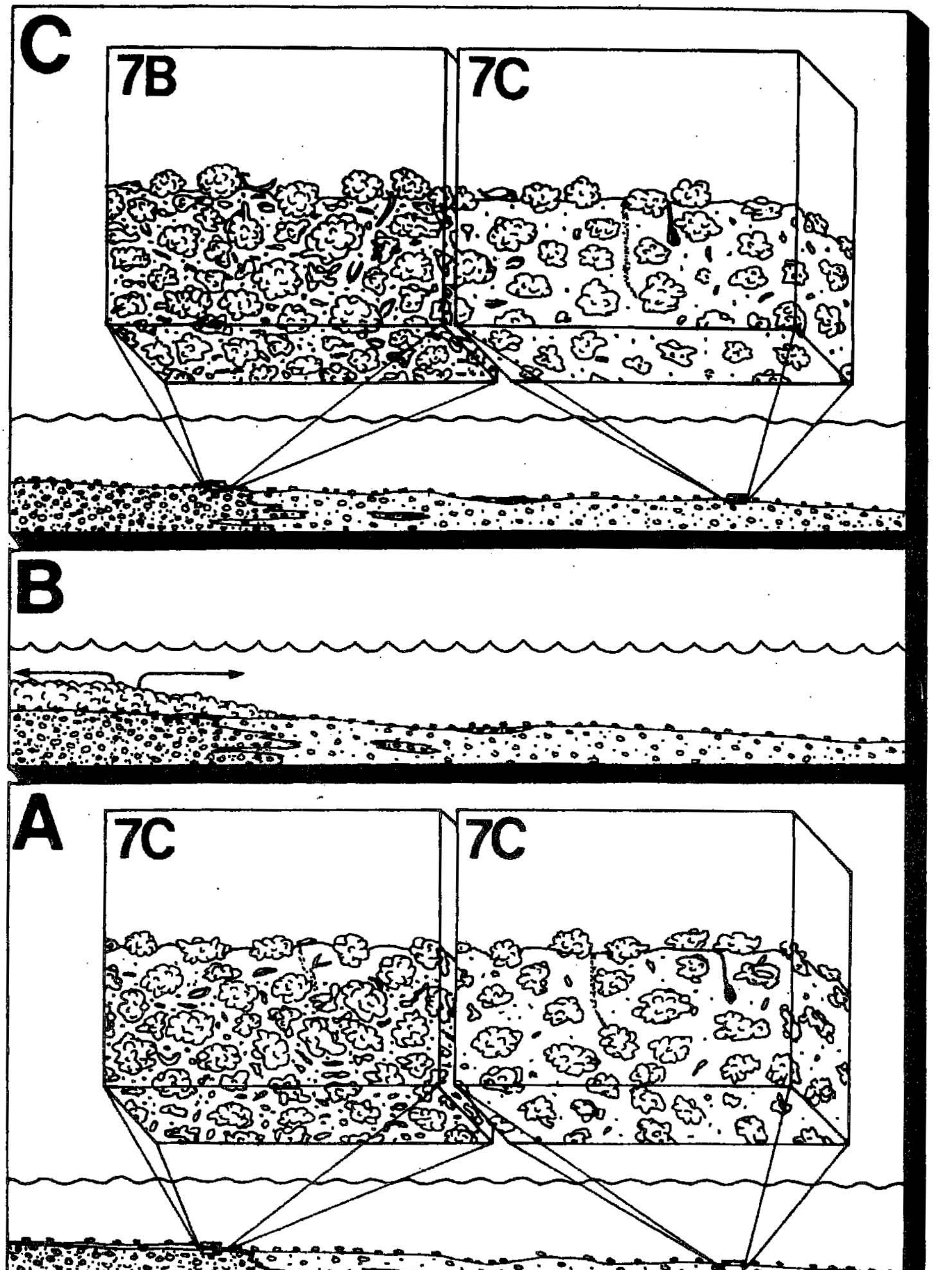


Fig. 7. Model of development of two types of the rhodolith pavement microfacies

A — Primary structure of the sediments; close-up, to show the similarity in the topmost part of both sediments

B — Development of two types of the rhodolith pavement facies during periodic currents; deeper parts are not changed

C — Result of the winnowing: the nodular-detrital var. *B* microfacies (*7B*) in the left, and the nodular microfacies (*7C*) in the right facies types in the rising energy of the environment (*see* Text-fig. 8*A*). The depicted interpretation bases, moreover, on the sediment type and non-algal indications of transport and energy (as *e.g.* crushing of the *Amphistegina* tests in the algal-amphisteginal debris facies). In case of energetic ordering of microfacies within the organodetrital facies the given interpretation is supported by the recognized environmental requirements of the species *Heterostegina costata* D'ORBIGNY. This species, characterizing the most dynamic heterosteginal microfacies (*4B*), is commonly cited from the high energetic environments: RADWAŃSKI (1969, p. 75 and Pl. 26, Figs 1-2) reported a mass occurrence

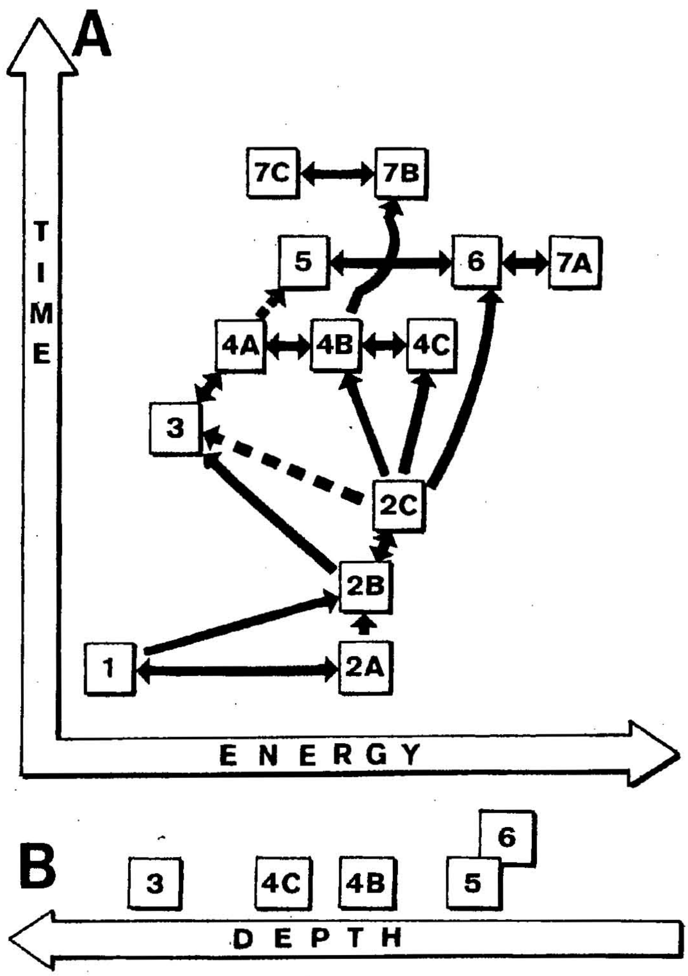
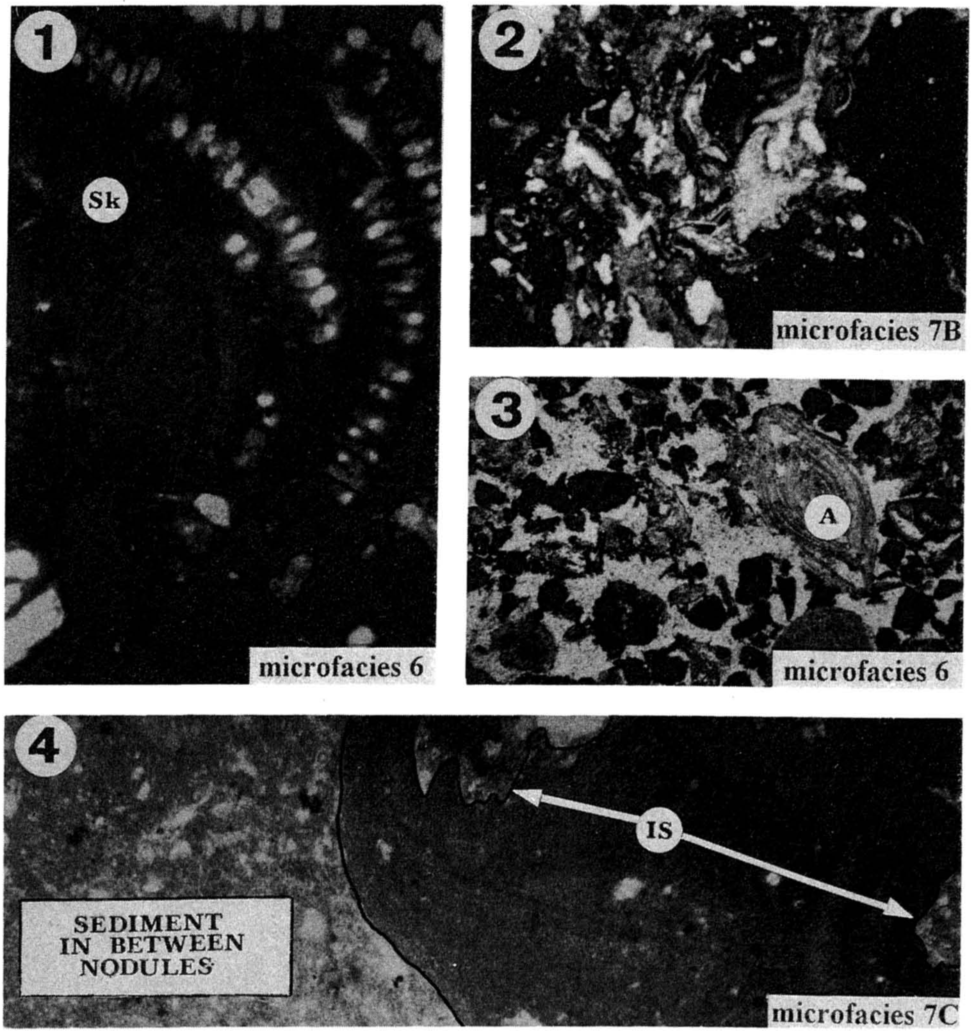


Fig. 8. Scheme illustrating an upward transition of the facies in the Middle Miocene (Badenian) sequence of the Pińczów Limestones in connection with the energy of environment plotted to time of sedimentation (A), and an inferred depth of sedimentation as apparent from the amphisteginal D/T ratio analysis (B)



1 — Algal-amphisteginal debris facies: large fragment of crushed branching alga *Sporolithon keenani* (HOWE), marked **Sk**, in well cemented micrite, × 60; Skowronno

2 — Nodular-detrital microfacies var. *B*: poorly sorted wackstone to packstone between rhodoliths, × 30; Szarbków

3 — Algal-amphisteginal debris facies: very abundant debris of coralline algae (**A** — partly crushed *Amphistegina* test), × 30; Skowronno

4 — Nodular microfacies: fine-sorted wackstone between nodules and as an internal sediment (marked **IS**) amongst the algal thalli, × 60; Szarbków

of this species from the neighboring littoral deposits at Piotrkowice, and DULLO (1983) from the littoral to sublittoral Miocene deposits of the Vienna Basin.

The comparison of hydrodynamic mobility of algae (Text-fig. 8*A*) with the bathymetric relations, is obtained from the analysis of the test shapes of *Amphistegina mamilla* FICHTEL & MOLL (Text-fig. 8*B*). This species, inhabiting the sea grasses, was shown to change markedly its length to thickness ratio (D/T), depending on the depth of water (*see* LARSEN 1976; HALLOCK & HANSEN 1978, 1981). The differences in thickness of the lamellae in the wall of the foraminifer test are caused by the differences in activity of commensal zooxanthellae, whose intensity depends on the light conditions, hence this is related to the depth of the basin. Because various actualistic relations were shown to be a case in the Middle Miocene (Badenian) organic communities of the studied area (*see* BAŁUK & RADWAŃSKI 1977, HOFFMAN & PISERA 1979, CZYŻEWSKA & RADWAŃSKI 1991) the cited relations may be used for interpretation of the Pińczów Limestones. The bathymetric interpretation, inferred from the D/T ratio analysis (*see* Text-fig. 9), points out differences with the algal-based energetic scheme. The obtained results indicate that only the nodular-detrital var. *A* microfacies (*7A*), may be interpreted as the shallow rhodolith pavement. They explain also the occurrence of the branched forms in the shallowest part of the basin. That part of the basin was characterized by branching forms of the coralline algae in the algal-amphisteginal debris facies (*6*), because this area was protected from the open sea by the interfingered and morphologically positive rhodolith pavement, developed as the nodular-detrital var. *A* microfacies (*7A*). The rhodoliths of the nodular-detrital var. *B* microfacies (*7B*) and the nodular microfacies (*7C*) were located further to the ESE, and they are thought to indicate a deeper environment, what as a matter of fact is demonstrated by the analysis of interlaminar and internodular sediments.

NUMBER OF OUTCROP	FACIES: MICROFACIES:	D/T RATIO	V	NUMBER OF SAMPLES
5	FINE-ORAGANODETRITAL *(3)*	2.42	0.2	10
5	ORGANODETRITAL HETEROSTEGINAL *(4C)*	2.35	0.1	15
3	ORGANODETRITAL AMPHISTEGINAL *(4B)*	2.32	0.1	22
1	ALGAL-AMPHISTEGINAL DEBRIS *(6)*	2.25	0.1	32
9	ALGAL-BRYOZOAN *(5)*	2.21	0.1	40
V - variability; number of outcrop as in Text-fig. 5				

Fig. 9. Amphisteginal D/T ratio in some outcrops

N — number of the outcrop as for Text-fig. 5

The density of bivalve borings in the coralline algae, postulated as an indicator of environmental conditions, however, cannot be used for interpretation of the latter, because the quickness of the boring activity of bivalves increases with the decreasing of the rhodolith growth rate, which ranges from 0.04 mm/year by depth 70 m (*see* REID & MACINTYRE 1988) until 2mm/month by depth 1-2m (ADEY & VASSAR 1975).

TAXONOMIC COMPOSITION OF THE CORALLINE ALGAE

STUDENCKI (1988b) in his comprehensive monograph reported 73 species of red algae, representing 12 genera, in the studied area and attributed their distribution pattern to hydrodynamic conditions and the substrate type. Among the forms dependant on hydrodynamic conditions, STUDENCKI (1988b) indicated such species as *Palaeothamnium archaeotypum* CONTI, *Lithothamnion praefruticulosum* MASLOV, and *Lithophyllum albanense* LEMOINE, all of which are participating in the rhodoliths; *Lithothamnion* cf. *nitidum* FOSLIE, and *Mesophyllum* aff. *roveretoi* CONTI, representing the crustose forms accompanying the rhodoliths; and some branching species, for instance *Lithothamnion ramosissimum* GÜMBEL. STUDENCKI (1988b) suggested also the three crustose species, *Lithophyllum lithothamnoides* MASLOV, *Titanoderma nataliae* MASLOV, and *Melobesia* sp., to have been controlled in their distribution by the substrate type, but he left as open the nature of this relationship.

The own studies (DREWNIAK 1990) demonstrated the presence of many species common within different facies types, and occurring both as whole specimens and as a detritus (typically, *Lithothamnion praefruticulosum* MASLOV and *Lithophyllum albanense* LEMOINE). Some species were restricted to distinct microfacies type (*Melobesia* sp.). The specific characteristics of particular facies (*see* Text-fig. 10; nomenclature according to WOELKERING 1988) indicates that, in spite of some taxonomic differentiation of the coralline algae communities, the variation of the dominant forms in particular facies is subtle. Exceptional in this matter is the algal-amphisteginal debris facies (*6*), with dominating branching forms. The other microfacies do not show any bigger difference in their algal taxonomic composition (*see* Text-fig. 10).

Traditionally, the taxonomic composition of the algal assemblages has been considered as depth controlled. However, JOHNSON (1962), ADEY & MACINTYRE (1973) and MINNERY (1990) point out the low efficiency of the existing taxonomy, below the genus level, based mainly on the cell type and reproduction structures. The lack of correspondence between the neo- and paleontological classification should also be taken into account. Moreover, a few recent coralline algae assemblages from the Hawaiian Islands (ADEY & *al.* 1982), Curacao (VAN DEN HOEK & *al.* 1978), Flower Garden Bank (MINNERY 1990), and from the Aqaba Bay (AL-RIFAIY & CHERIF 1988) proved changes of dominant elements at the same depth in the different areas. ADEY & BURKE

(1976) demonstrated that this change may occur in distance of some tens of kilometers.

The value of actualistic taxonomic data is lowered also due to a want of convincing arguments for the really recent age of the analyzed assemblages from *i.a.* the Caribbean Sea (MINNERY 1990), the conditions of which strongly changed 500 y. BP. Moreover, the original distribution pattern may to a great extent be obliterated by taphonomic processes, what in the studied material is well seen on the example of *Sporolithon keenani* (HOWE) and *Lithothamnion ramosissimum* GÜMBEL, which are common as detritus even in assemblages generally poor in intact branching forms in rhodoliths (*see* Text-fig. 10). Therefore, unexcepting the encrusting species (like *Lithophyllum lithothamnoides* MASLOV, *Titanoderma natalie* MASLOV, and *Melobesia* sp.), the distribution of which is dependant on the type of substrate, the taxonomic composition of any red algal assemblage represents a rather faulty indicator of environmental conditions (*see* also PISERA & STUDENCKI 1989).

FACIES: MICROFACIES:	N	GF	SPECIES OF CORALINACEAE
SANDY-MARLY		R	*Lithophyllum albanense* LEMOINE
		B	*Sporolithon keenani* (HOWE)
ALGAL DEBRIS	*(2B)*		*Lithophyllum* sp.
			Mesophyllum sp.
ALGAL	*(2C)*	R	*Lithophyllum albanense* LEMOINE
		R	*Mesophyllum* aff. *roveretoi* CONTI
		R	*Lithothamnion praefruticulosum* MASLOV
			Mesophyllum sp.
		R	*Mesophyllum* aff. *roveretoi* CONTI
FINE-ORGANODETRITAL	*(3)*	R	*Lithophyllum albanense* LEMOINE
			Lithothamnion sp.
ORGANODETRITAL		R	*Lithothamnion praefruticulosum* MASLOV
		R	*Mesophyllum* aff. *roveretoi* CONTI
FORAMINIFERAL	*(4A)*	R	*Lithophyllum albanense* LEMOINE
AMPHISTEGINAL	*(4B)*	R	*Lithothamnion* cf. *nitidum* FOSLIE
HETEROSTEGINAL	*(4C)*	R	*Palaeothamnium archaeotypum* CONTI
		+R	*Lithophyllum prelichenoides* LEMOINE
		B	*Lithothamnion ramosissimum* GÜMBEL
		R	*Lithophyllum albanense* LEMOINE
		R	*Lithothamnion praefruticulosum* MASLOV
ALGAL-BRYOZOAN	*(5)*	L	*Lithophyllum lithothamnoides* MASLOV
		+R	*Lithophyllum prelichenoides* LEMOINE
		B	*Sporolithon keenani* (HOWE)
			Lithothamnion sp.
		B	*Sporolithon keenani* (HOWE)
		B	*Lithothamnion ramosissimum* GÜMBEL
ALGAL-AMPHISTEGINAL DEBRIS	*(6)*	R	*Lithothamnion gaschei* MASLOV
		L	*Melobesia* sp.
RHODOLITH PAVEMENT		R	*Lithothamnion praefruticulosum* MASLOV
		R	*Lithophyllum albanense* LEMOINE
NODULAR-DETRITAL VAR. *A*	*(7A)*	R	*Lithothamnion* cf. *nitidum* FOSLIE
NODULAR-DETRITAL VAR. *B*	*(7B)*	+R	*Mesophyllum* cf. *ingestum* CONTI
NODULAR	*(7C)*	L	*Lithophyllum lithothamnoides* MASLOV
		B	*Lithothamnion ramosissimum* GÜMBEL

N - number of facies as used in the Text
GF - growth-forms: B branching, R rhodolith, L laminar
+ species are not self-existing:
(IInd algal branching class after BOSENCE 1976)
(IIIrd and IVth)
(encrusting)

Fig. 10. Abundances of crustose coralline species in the studied facies

CONCLUSIONS

The integrated algal morphologic interpretation makes possible to present a facies reconstruction of the studied basin (Text-fig. 11), where in the shallowest part the algal-amphisteginal debris facies (*6*) was located, and protected from the open sea by the rhodolith pavement, situated further to ESE (*see* Text-fig. 11). Only this pavement, positive in morphology, and distinguished as the nodular-detrital var. *A* microfacies (*7A*), was a source of detrital

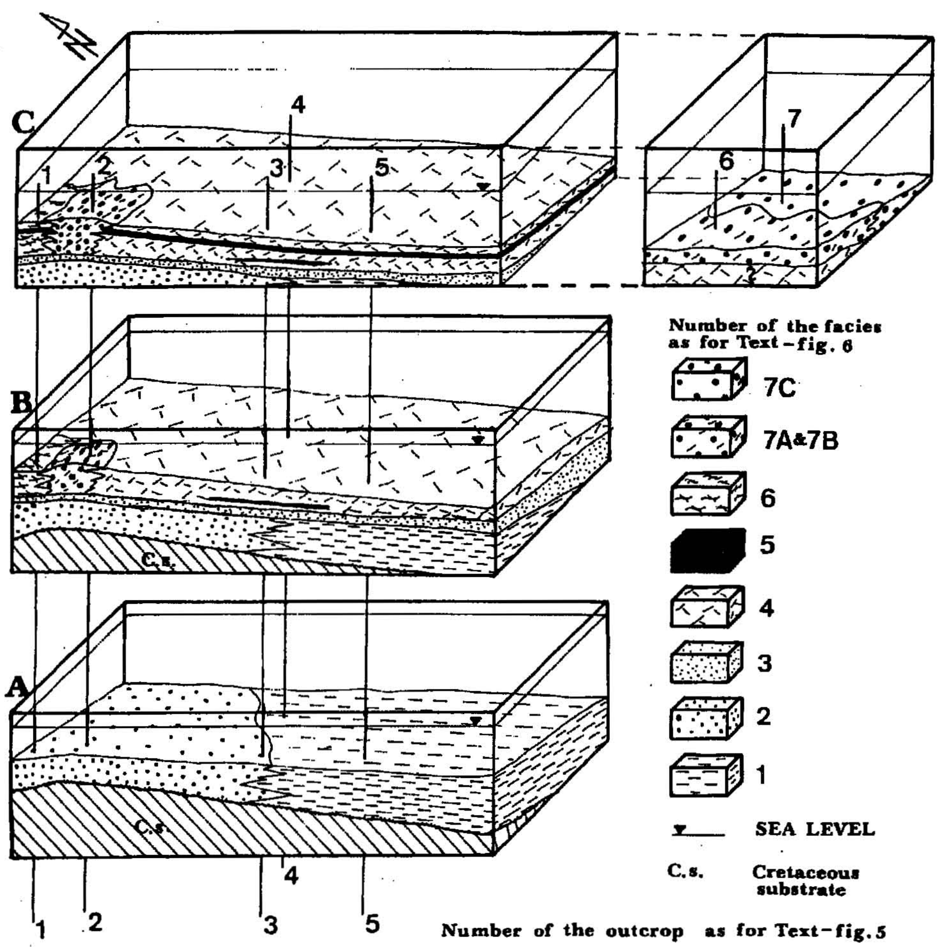


Fig. 11. Facies distribution trough time of deposition of the studied Middle Miocene (Badenian) sequence of the Pińczów Limestones:

A — During sedimentation of the "Sublithothamnian Level"
B — Mid-time of the "Lithothamnian Level"
C — Late time of the "Lithothamnian Level"

material for neighboring facies, such as the algal-amphisteginal debris facies (*6*), or some horizons of rhodoliths in the sandy-marly facies (*2*), precisely in the algal microfacies (*2C*).

As it is showed, the coralline algae characterized by the wealth of easily identified and well preservable morphological variants are, when carefully treated, important parameters. However, the studies on the coralline algae display that the common views on transferring the selected characteristics of the group directly onto the specific environmental traits should be revised. It seems that the vastly used parameters, as growth-forms and shapes or the taxonomic composition, are influenced by too many factors to bear univocal environmental self-dependent significance, and have to be propped by examination of a more complex set of algal features. Particularly effective are coralline algae in the assessment of the hydrodynamics of the basin, inferred from an integrated analysis of the algal growth shapes and forms, and a comparison of internodular and interlaminar sediments. Other algal features, such as their taxonomic composition or their damage by bivalve borings in the rhodoliths do not indicate precisely the environmental conditions.

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A. DREWNIAK

LITOTAMNIA Z WAPIENI PIŃCZOWSKICH JAKO WSKAŹNIKI ŚRODOWISKA

(Streszczenie)

Przedmiotem niniejszej pracy jest ocena przydatności litotamnii (krasnorostów z rodziny Corallinaceae) z wapieni pińczowskich jako wskaźników środowiska. Na tle facjalnego i mikrofacjalnego zróżnicowania osadów (*patrz* fig. 1-5 *oraz* pl. 1-4) przedstawiono analizę morfologii plech tych glonów (ich kształtu, form wzrostu) oraz dokonano porównania osadu uwięzionego w obrębie plech z osadem otaczającym (*patrz* fig. 6 *oraz* pl. 5). Umożliwiło to rozpoznanie mechanizmu obrotu plech i formowania rodolitów, oraz przedstawienie hydrodynamiki środowiska (*patrz* fig. 7). Zestawiając wyniki analizy morfologii plech z innymi wskaźnikami środowiskowymi (np. zróżnicowanie szerokości/grubości skorupek otwornic z rodzaju *Amphistegina*) odtworzono relacje batymetryczne i energetyczne pomiędzy wyróżnionymi facjami (*patrz* fig. 8-9), stwierdzając małą przydatność składu taksonomicznego litotamnii do takich rekonstrukcji (*patrz* fig. 10). W rezultacie przedstawiono ogólny obraz facjalny (*patrz* fig. 11) dla obszaru sedymentacji wapieni pińczowskich.
