acta geologica polonica

Vol. 35, No. 1-2 Warszawa 1985

ANDRZEJ PISERA

Paleoecology and lithogenesis of the Middle Miocene (Badenian) algal-vermetid reefs from the Roztocze Hills, south-eastern Poland

ABSTRACT: The Middle Miocene (Badenian) algal-vermetid reefs of the Roztocze Hills (Lublin Upland, south-eastern Poland) are built mostly of laminar crusts of coralline algae, shells of sessile gastropods *Petaloconchus intortus* (LAMARCK), and various amount of detrital internal sediments. The secondary encrusters of a reef frame are bryozoans, serpulids, foraminifers, and cirripedes *Verruca*. Seven species of coralline algae are common among 21 species found in reef deposits. Corallines show most species in common with the Ukraine and only some with the Vienna Basin. Of the two ecological assemblages recognized, viz. the reef assemblage and the epi-reef assemblage, the first one inhabited the reef during its growth, and was structured mainly by the presence of hard bottom with abundant fissures and cavities. The second one inhabited the surface of the already dead reef, and it was structured by the presence of hard bottom and ubiquitous noncalcifying submarine flora. The reef has developed on positive elements of the sea bottom in extremely shallow water, under high hydrodynamic conditions, normal salinity, and climate comparable to the present-day eastern part of the Mediterranean. Intensive submarine cementation has initiated the diagenetic evolution of reef rocks. Late diagenetic features in the investigated reefs are attributed to changes in local continental (Upper Miocene till Holocene) environments associated with wandering level of local ground-water tables.

INTRODUCTION

The algal-vermetid reefs from the Roztocze Hills, Lublin Upland in south-eastern Poland, have received considerable attention because of their abundant fauna. However, no detailed characterisation of their genesis and associated fauna is available.

The reef deposits occur in a zone 20 km long and few hundred meters wide, at the south-western part of the Lublin Upland (*see* Text-fig. 1). The reefs from a few groups of outcrops in the vicinity of Węglinek, Kamienna Hill, Łychów, and Radwanówka (*see* Text-fig. 2).

The first report on the algal-vermetid reefs (then called the lithothamnian limestones with *Haliotis*) from the Roztocze Hills was made by KOWALEWSKI (1925). More detailed characteristics, with the recognition of algae and vermetid gastropods was given by KRACH (1962a) and BIELECKA (1967). The present author (PISERA 1978) presented short petrographic and paleoecological analysis; HAŁAS & *al.* (1979) investigated the isotopic composition of some reef samples from Kamienna

Hill. Recently KRACH (1981) described molluscs from the reef and inter-reef deposits and their paleoenvironments.

Outside Poland, Badenian algal-vermetid reefs crop out in the western Ukraine (TEISSEYRE 1895, 1900; KOROLYUK 1952). Description of coralline algae and of the facies relationships of these deposits was given by MASLOV (1962). JANAKEVITSCH (1977) described Badenian algal-vermetid reefs from Moldavia, and included descriptions of the associated macrofauna and their autoecological characteristics.

GEOLOGICAL AND STRATIGRAPHIC SETTING OF THE ALGAL-VERMETID REEFS

Following the Alpine orogenesis, the complex system of the circum and inter Alpine-Carpathian basins, called the Paratethys, originated in Europe (Text-fig. 1*A*). In Badenian time part of this sea entered the area of the Fore-Carpathian Depression

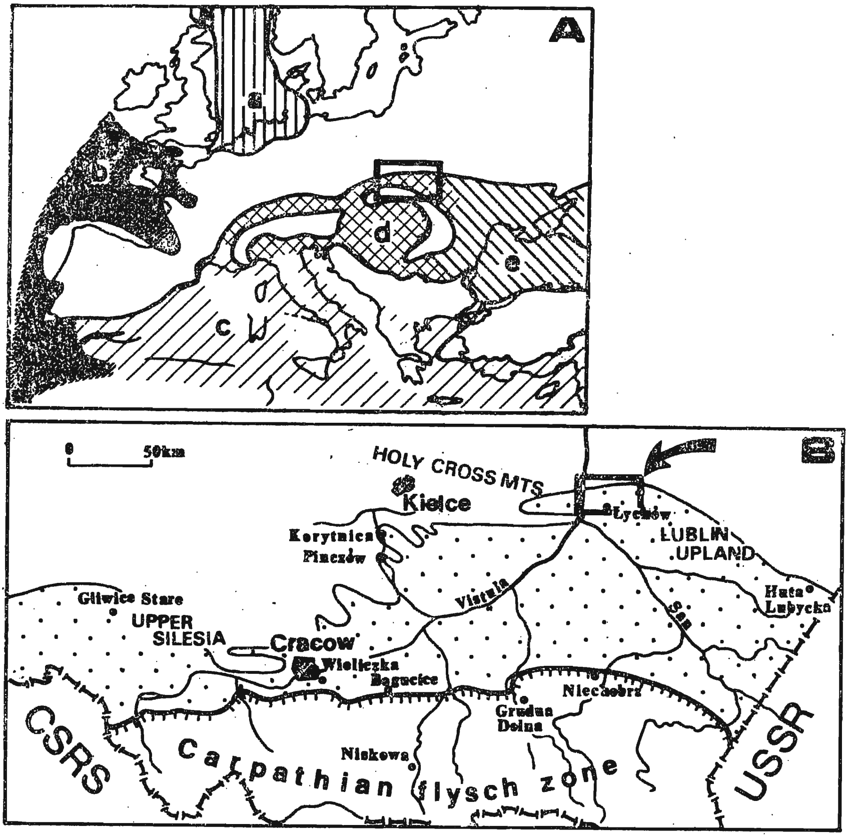
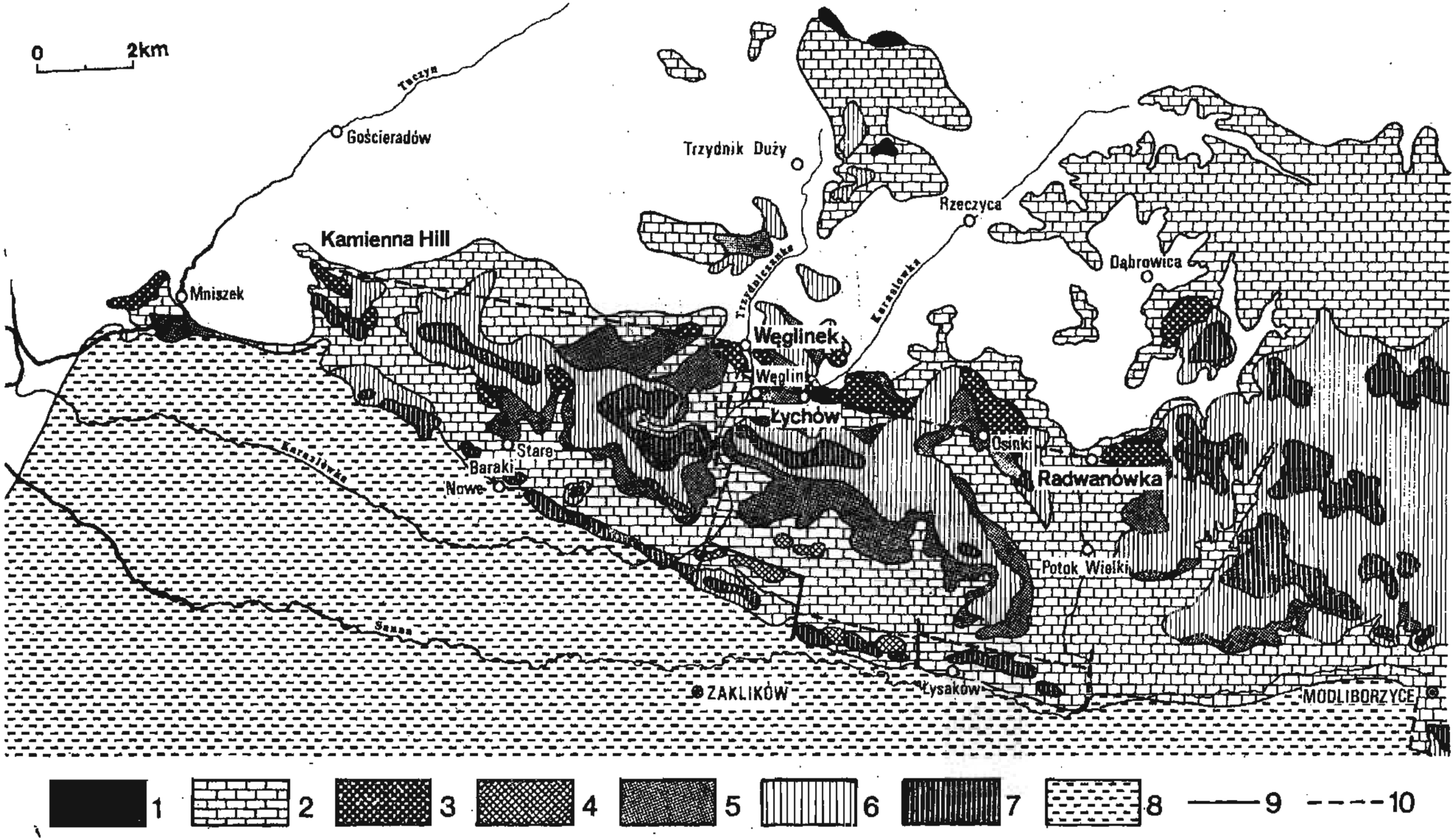


Fig. 1. Paleogeographic setting of the studied area

A — Marine basins in the Middle Miocene of Europe: **a** — North Sea Basin, **b** — Atlantic gulfs, **c** — Mediterranean Basin, **d** — Paratethys basins, **e** — Euxinian Basin; rectangled is the area presented in Text-fig. 1*B* (*adopted from:* BAŁUK & RADWAŃSKI 1977, Fig. 1*A*)
B — Extent of the Middle Miocene (Badenian) sea in the Fore-Carpathian Depression (*stippled*); rectangled is the area presented in Text-fig. 2 (*adopted from:* RADWAŃSKI 1977b, Fig. 169)

Geological map of the studied area (without Quaternary cover; Upper Cretaceous substrate is blank)



1 — quartz sands and clays with brown-coal intercalations, 2 — lithothamnian biocalcarenites and marls with lithothamnians, 3 — algal-vermetid reefs, 4 — oyster reefs, 5 — lithothamnian conglomerates and quartz sands, 6 — lithothamnian biocalcarenites, 7 — cryptalgal-serpulid reefs, 8 — clays of the Fore-Carpathian Depression, 9 — detected faults, 10 — supposed faults (*after* BIELECKA 1967; *simplified*)

in Poland. The deposits under study follow the north-eastern shore of this sea along the southern slopes of the Lublin Upland (Text-fig. 1*B*). The algal-vermetid reefs in the Roztocze region now occur at the tops of hills and are surrounded by stratified coralline algal biocalcarenites, marls and sands of Badenian to Lower Sarmatian age (Text-fig. 2). A complex facies mosaic does not allow detailed correlations of reef deposits with bedded ones (PISERA 1978, KRACH 1981). However, both contain abundant fauna and clearly are of shallow water origin (RADWAŃSKI 1977b, HOFFMAN & *al.* 1978, PISERA 1978). The outcrop zone of such sediments is about 30 km wide and spreads from NW to SE. To the south it is now limited by a fault zone, south of which Badenian sediments are covered by thick clay deposits (Sarmatian) of the Carpathian Foredeep (BIELECKA 1959, 1967). Faulting (partly synsedimentary?) modified the primary distribution of Miocene sediments of the study area (BIELECKA 1967, MUCHOWSKI 1970). The reef limestones are associated with upthrown sides of faults (BIELECKA 1967) which formed morphologically positive elements during sedimentation. In the tectonic troughs reefs are absent but biodetrital and marly sediments predominate, indicating tectonic control of sedimentation (MUCHOWSKI 1970). The tectonic style is controlled by two, more or less perpendicular fault systems oriented NW-SE and NE-SW (Text-fig. 2). West of the investigated area, on the southern slopes of Holy Cross Mts the reefs are absent and the facies pattern is controlled by differences in the substrate during the Badenian transgression (BAŁUK & RADWAŃSKI 1968, 1977; RADWAŃSKI 1969, 1973, 1977a, b; STUDENCKI 1979).

The Upper Cretaceous substrate in the study area is formed by marls and siliceous chalk. In the depressions of the substrate, glauconitic sands, probably of Oligocene age (BIELECKA 1967) may be found in some places. Thickness of the Miocene sediments varies, caused in part by post Miocene erosion as well as by primary relief. On the elevations of the Upper Cretaceous substrate it is about 10—20 m, and about 50—70 m in the depressions (BIELECKA 1967). The Badenian sequence (Text-fig. 3) begins with sands and clays with brown-coal intercalations which typically occur in the depressions of the substrate. Coralline algal biocalcarenites occur stratigraphically higher and pass gradually into marls with coralline algae. Locally, in a lower part of sequence oyster bioherms are present. The algal-vermetid reefs are the stratigraphical equivalents of upper part of sands and lower part of biocalcarenites (Text-fig. 3) and occur only in some places, probably on the elevations of the Upper Cretaceous substrate. The marls are covered with a thin, 20—30 cm thick, but very characteristic marl and silt layers containing molluscs the so called "*Ervilia* Bed" of BIELECKA (1967). Atop this bed lie 1 to 4 meters of coralline algal conglomerates and sands with pebbles of reworked Mesozoic and Badenian sediments. The whole described sequence is considered to be of Badenian age. Higher, coralline algal biocalcarenites appear once more and contain a considerable admixture of quartz. They are the stratigraphic equivalents of cryptalgal-serpulid reefs (PISERA 1978). These sediments, considered as of Sarmatian age, terminate the Miocene marine sequence in the study area.

The Badenian age of the algal-vermetid reefs is well-established (BIELECKA 1959, 1967; AREŃ 1962; KRACH 1962a, b) only their position within Badenian is under discussion. Recent investigations of planktic foraminifers indicate the

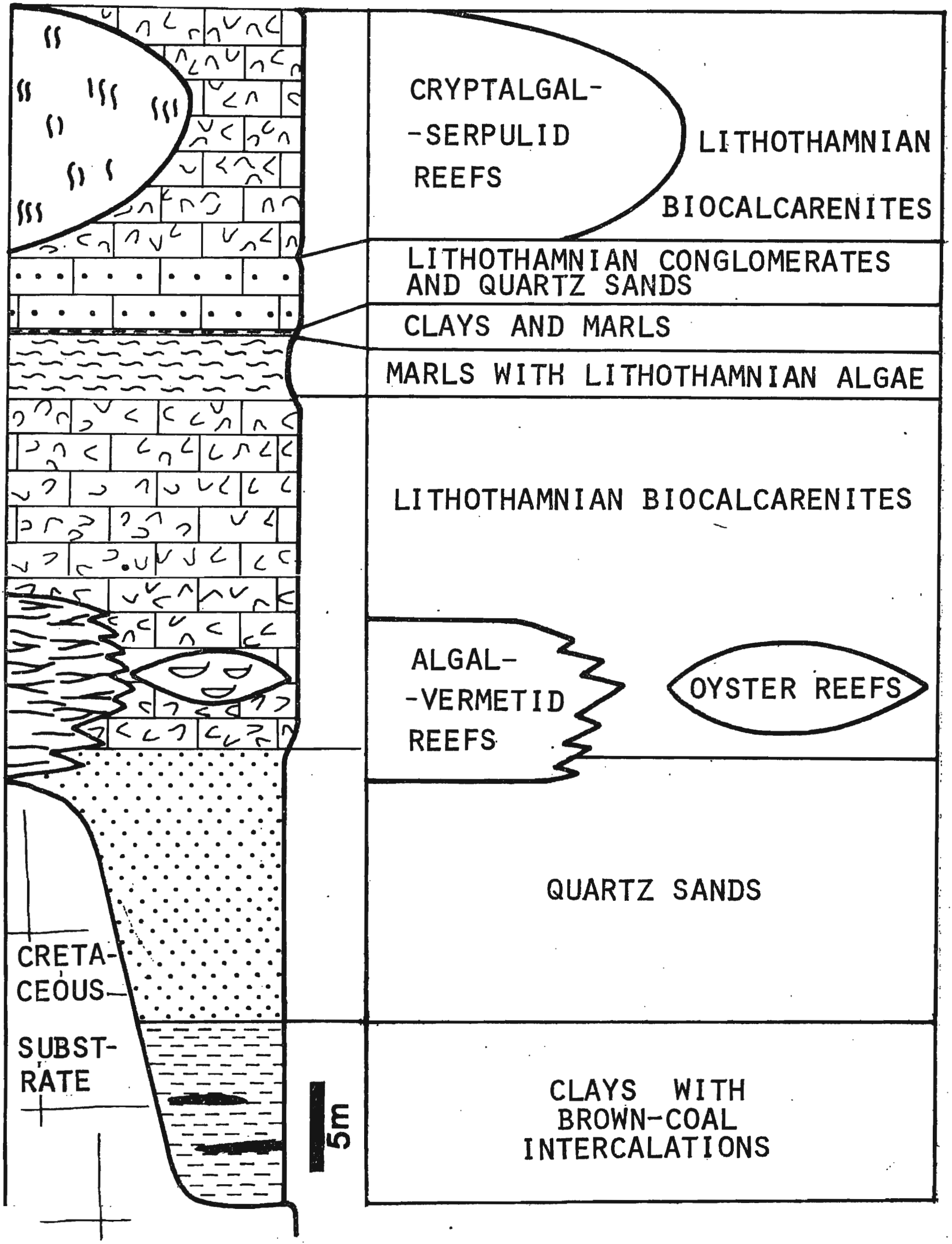


Fig. 3. Synthetic litostratigraphic column of the studied Miocene deposits

absence of the Early Badenian strata in this region (SZCZECHURA 1982, SZCZECHURA & PISERA 1985), so the Late Badenian age of these reefs is only an inference.

METHODS OF INVESTIGATION

For paleontological and paleoecological purposes 27 bulk samples were collected in the field. The macrofauna was identified and counted in the laboratory. The taxic composition of samples is presented as percentages because samples were of different size. The total bulk sample collection contained over 14 000 individual moluscs and over 13 000 of other fauna. Additionally, more than 800 specimens of molluscs and over 600 specimens of other fauna were collected from outcrops.

Based on the frequency of molluscan taxa all samples were grouped into associations. Depending on criteria used in the procedure it was possible to distinguish several homogeneous associations or smaller number but more varied structurally. Because the patchiness of occurrence of sessile invertebrates, which dominate our samples, is a common feature (PIANKA 1974, OSMAN 1977, BOUCOT 1981,) it seems more reasonable to accept a smaller number of associations but more varied internally. If one uses the trophic nucleus concept (*see* FÜRSICH 1977, BOSENCE 1979), two spatially different associations viz. reef and epi-reef may be recognized in the investigated material. The first aim, historically, of fossil assemblage analysis was the reconstruction of environmental conditions (*see* FAGERSTROM 1964, SCOTT 1970, ZIEGLER 1974, BOUCOT 1981, DODD & STANTON 1981 and others); later work also emphasized the reconstruction of biological interactions among members of the assemblage and attempted to document community evolution. Regardless of HOFFMAN'S (1979) challenges to the community approach the analysis of fossil assemblages as a tool for environmental condition reconstructions remains a legitimate enterprice (HOFFMAN 1979, DODD & STANTON 1981).

Petrographic investigations were carried out on more than 100 thin sections and 150 polished surfaces. The *SEM* observations of the broken surfaces were made. Uncovered thin sections were stained with FEIGEL'S solution, Alizaryne Red-S and potassium ferrycyanide (*see* EVAMY 1969). Additional information on minerals present were provided by *X*-ray analysis. The spectrographic analysis of strontium, magnesium and manganese contents of selected samples were also prepared.

GENERAL CHARACTERISTICS OF ALGAL-VERMETID REEFS

The outcrops of algal-vermetid reefs in the Roztocze Hills are grouped at Węglinek, Łychów, Radwanówka, and Kamienna Hill (*see* Text-fig. 2), where the reef bodies are locally exposed.

WĘGLINEK

The reef limestones crop out in numerous small quarries on the hill west of the village (Text-fig. 5). The visible thickness is about 5—6 m but real thickness may be estimated as 10 to 15 m. BIELICKA (1967) observed reef limestones resting on the Cretaceous surface or over a thin layer of glauconitic sand. To the south coralline algal biocalcarenites and marls with abundant bryozoans and brachiopods cover reef limestones. To the north, at a distance of several meters and at the same level as the reef, coralline algal biocalcarenites with quartz can be observed. The reef outcrops cover the area of 100 m of radius. In some parts, synsedimentary depressions existed, and are now filled with biodetrital sediment indicating local relief about 50—70 cm.

The reef limestones are very porous (Pl. 1, Fig. 1; Pl. 2; Pl. 3, Fig. 1), are non stratified and have a yellow-green colour caused by algae and glauconite. They may be generally classified as algal-vermetid and algal biolithites. Coralline algae forming laminar thalli preserved in situ in growth position, account for up to 70% of the rock, usually however, they do not exceed 40—50% (Pl. 6,

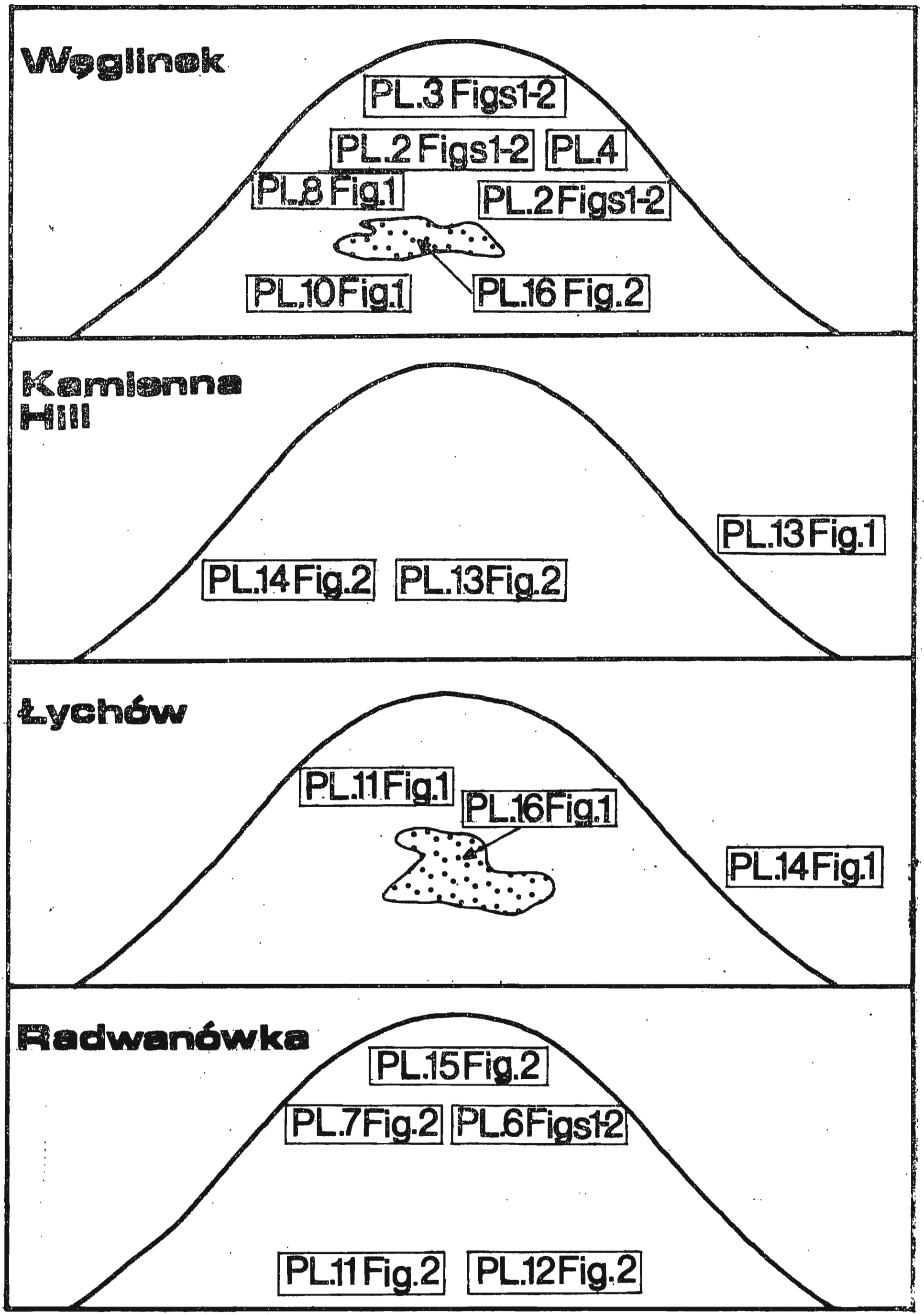


Fig. 4. Spatial distribution of typical rock samples in relation to the investigated reef bodies

Figs 1—2; Pl. 7, Fig. 2; Pl. 8, Figs 1—2). Their importance varies considerable and may, in some parts of the reef, be less than 20% of the rock. Algal thalli are 0.5—3 mm thick and build a complex construction with extremely abundant primary growth pores in which detrital sediment has collected. As a result of the superimposing of several thalli of the same or different species more complex algal lamina also occur (Pl. 6, Fig. 1; Pl. 9, Fig. 1; Pl. 11, Figs 1—2). Similar algal structures were described from the Tortonian of Malta (PEDLEY 1979, BOSENCE & PEDLEY 1979, 1982; BOSENCE 1983a,b) as a Crustose Pavement facies. They differ, however, in their taxonomical composition of algae and in the absence of vermetids there. Algal reefs with vermetids are also known from the Ukraine (KOROLYUK 1952, MASLOV 1962) and Moldavia (JANAKEVITSCH 1977) and are of similar construction. At Węglinek the most common algal species is *Lithothamnium lacroixi* LEMOINE, the next most abundant is *Lithophyllum albanense* LEMOINE; together they account for 75% of the algae. Less common species include, in decreasing frequency *Lithothamnium praefruticulosum* MASLOV, *L. ishigakiensis* JOHNSON, *L. microphyllum* MASLOV and *Dermatolithon ucrainicum* MASLOV. Sporadic occurrences of *Archaeolithothamnium lvovicum* MASLOV, *Paleothamnium archaeotypum* CONTI, *Lithothamnium saxorum* CAPEDER and *Jania dniestrovica* MASLOV were also noted. Laminar algal thalli dominate in the lower part of the reef (Pl. 10, Fig. 1), towards the top their morphology becomes more complex as thick laminae with stubby branches and very uneven sufrace appear. Coralline algae found in internal sediments are branching in form, and are often different species. However, the branched forms of *Lithophyllum albanense* LEMOINE and *Lithothamnium microphyllum* MASLOV which occur in the reef framework as laminar forms were also noted. Other species are poorly preserved and belong to the genus *Lithothamnium*, probably to the species *Lithothamnium corallinaeformae* LEMOINE.

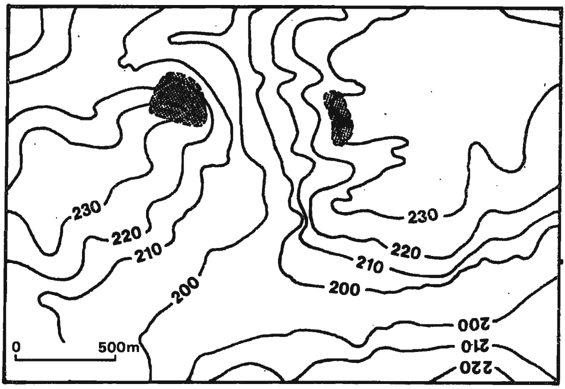


Fig. 5

Topographical situation of the algal-vermetid reef (*stippled*) in the Węglinek area

Sessile vermetid gastropods are of great importance in the reef construction (Pl. 8, Fig. 2). They are irregularly distributed in the rock, usually in patches. In some parts they are totally absent. Incrustations of cheilostomate bryozoans (Pl. 4; Pl. 5, Fig. 1), sometimes up to few centimeters thick were also noted. In thin sections sessile foraminifers were observed as a common component. The walls of synsedimentary cavities are usually encrusted with serpulid tubes.

In the reef body occurs a ubiquitous and highly diverse molluscan fauna. Part of the shells are incorporated into the reef frame (Pl. 2, Fig. 2; Pl. 3, Fig. 1), but most occur, however, as disorderly accumulations in a differently sized synsedimentary cavities (Pl. 3, Fig. 2; Pl. 4; Pl. 5, Fig. 2). In the outcrops the most common gastropods are (in decreasing order of abundance) *Astraea mammillaris* (EICHWALD), *Bittium reticulatum* (DA COSTA), trochids, *Haliotis* sp., and among the bivalves *Pycnodonte navicularis* (BROCCHI), *Chlamys multistriata* POLI, *Lima lima* (LINNAEUS), *Venus cincta* EICHWALD, arcids and different boring taxa. Also common are small brachiopods. In the detrital sediments cyclostomate and cheilostomate bryozoans as well as cirripedes are very common. Most of molluscan shells are preserved with their original aragonitic mineralogy.

The detrital internal sediment occurring in the reef body was deposited in synsedimentary cavities and is represented by biomicrites and biocalcarenites in the whole reef sequence (Pl. 4; Pl. 17, Fig. 2). The detrital sediment also includes a significant admixture of quartz, especially in the lower part of the reef (Pl. 10, Fig. 1). In the central part of the reef, large meter-sized cavities exist that are now filled with bryozoan-foraminifer biocalcarenites containing coralline algae (Pl. 16, Fig. 2). The degree of cementation of the reef rock varies and changes even over the distance of a few centimeters. Biomicrites are usually well lithified and biocalcarenites are usually poorly cemented. In well cemented biocalcarenites aragonitic shells are absent.

The reef construction was well lithified already during sedimentation, as is indicated by the numerous bivalve borings (Pl. 5, Fig. 1; Pl. 7, Fig. 1; Pl. 8, Fig. 1) and absence of compactional features. Early cementation is also confirmed by a vertical neptunian dyke (Pl. 1, Fig. 2) about 5 cm thick and 3 m long. The infilling consists of two vertically disposed generations of sediment composed of coralline algal biomicrites, identical with internal sediment of the reef. The first generation was apparently lithified at the moment of the second opening and infilling with the sediment. Similar neptunian dykes but of larger size have been described from the Devonian reefs of the Holy Cross Mts by SZULCZEWSKI (1971, 1973).

KAMIENNA HILL

The reef limestones are exposed in this region in several small quarries situated along a topographic scarp running from NW to SE (Text-fig. 6). The coralline algal biosparites overlie reef limestones. They are transgressive in relation to the substrate and extend further to the north than the reef limestones. The contact between biosparites and reef limestones is of sedimentary origin but sharp. At this boundary, fossiliferous lenses occur in fissures and depressions of the reef body. The most common species of molluscs in these accumulations are (in decreasing frequency) *Pycnodonte navicularis* (BROCCHI), *Chlamys multistriata* POLI, *Haliotis* sp., *Barbatia barbata* (LINNAEUS), *Lima lima* (LINNAEUS), *Astraea mammillaris* (EICHWALD) and trochids. Except for species with calcitic shells preservation is as casts and molds.

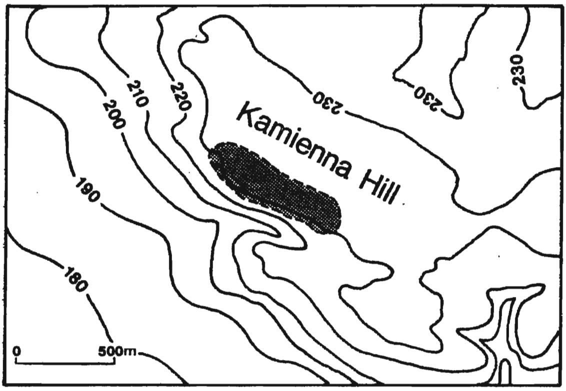
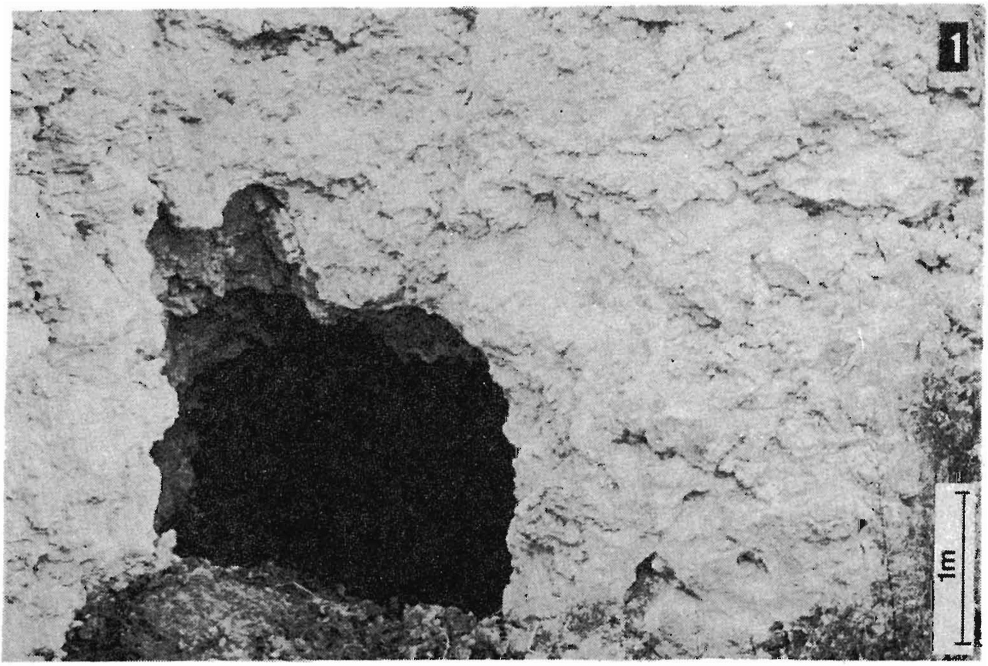


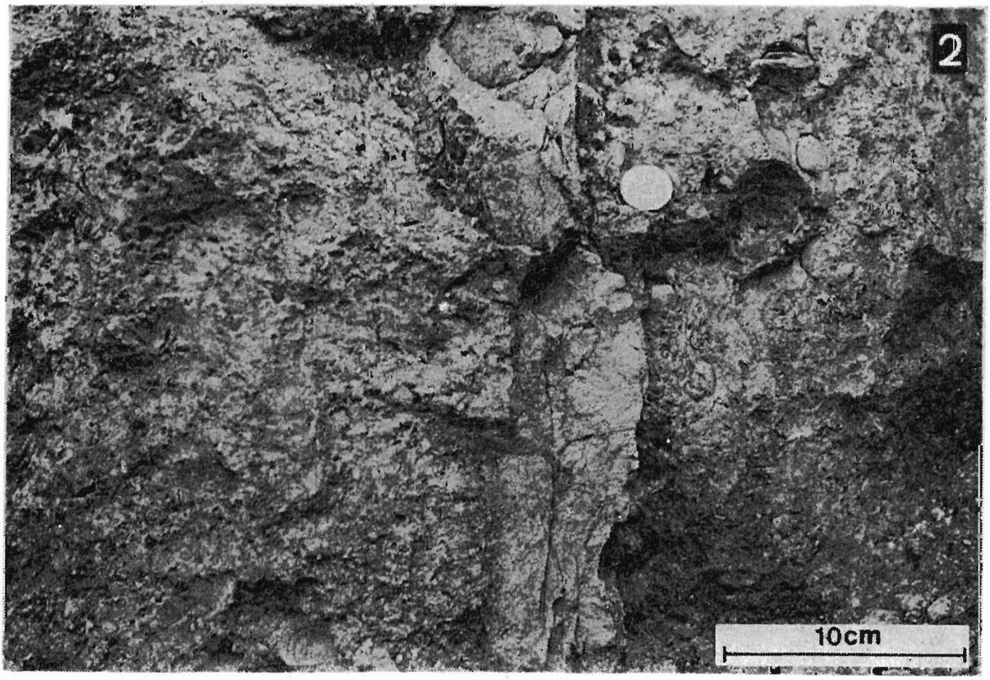
Fig. 6

Topographical situation of the algal-vermetid reef (*stippled*) in the Kamienna Hill area

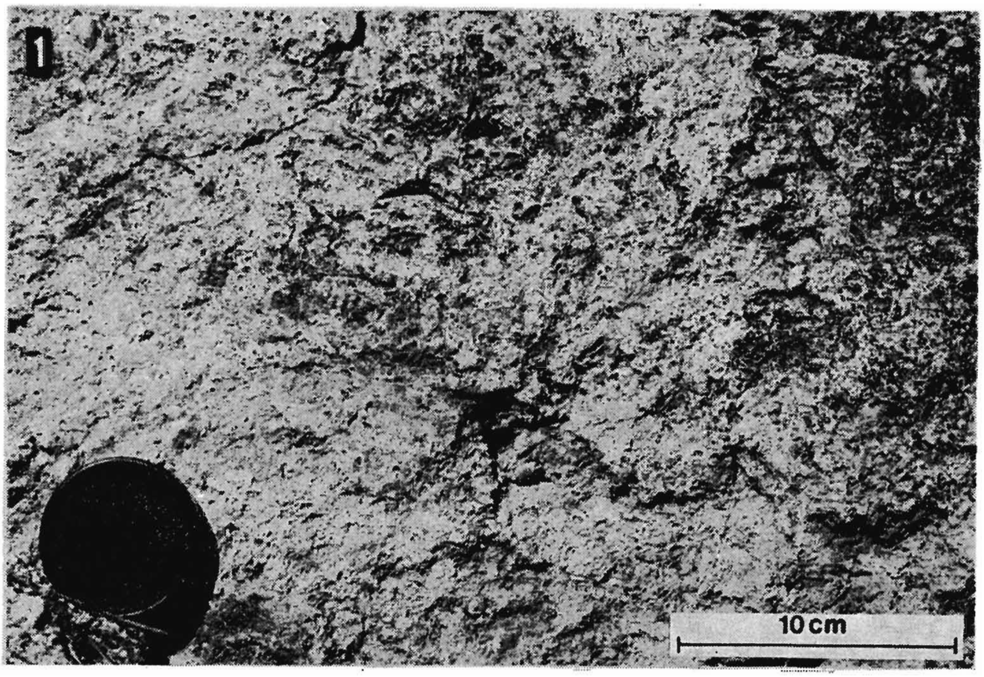
The thickness of the reef limestones visible in the outcrops is about 6 m but the base is not exposed. The reefs probably rest directly on the Cretaceous substrate as it may be recognized on the geological map presented by BIELECKA (1967).

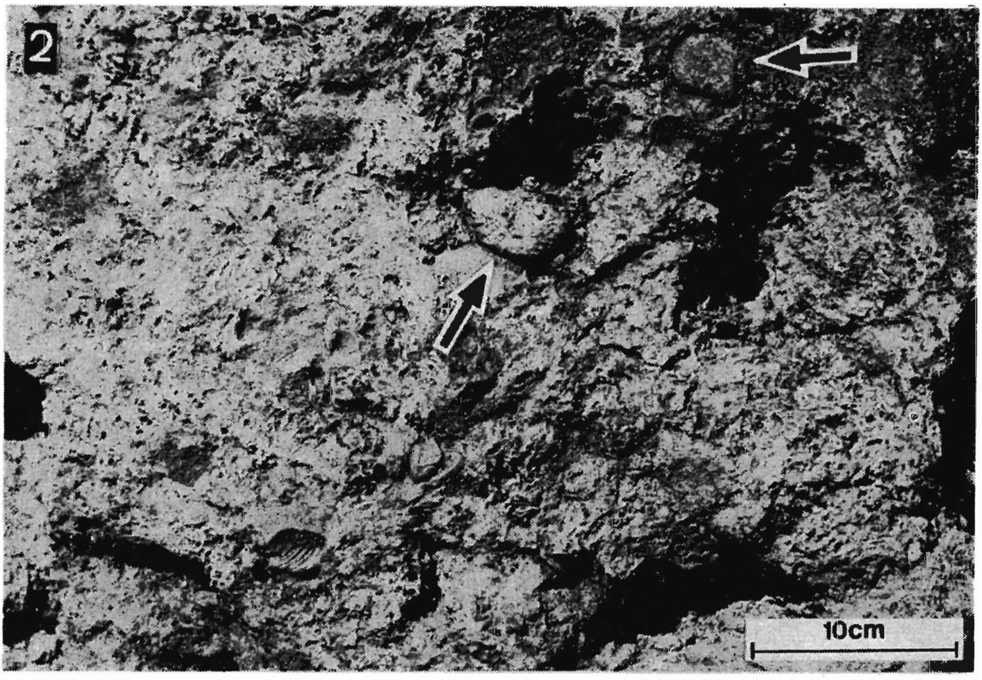
The reef limestones may be classified as coralline algal biolithites (biosparites) (Pl. 13, Fig. 2; Pl. 14, Fig. 1). Algae are dominated by *Lithothamnium lacroixi* LEMOINE and *L. ishigakiensis* JOHNSON. In some places *Lithothamnium saxorum* CAPEDER and *Lithophyllum albanense* LEMOINE are common. Uniformly distributed are *Melobesia badji* MASLOV and *Dermatolithon ucrainicum*



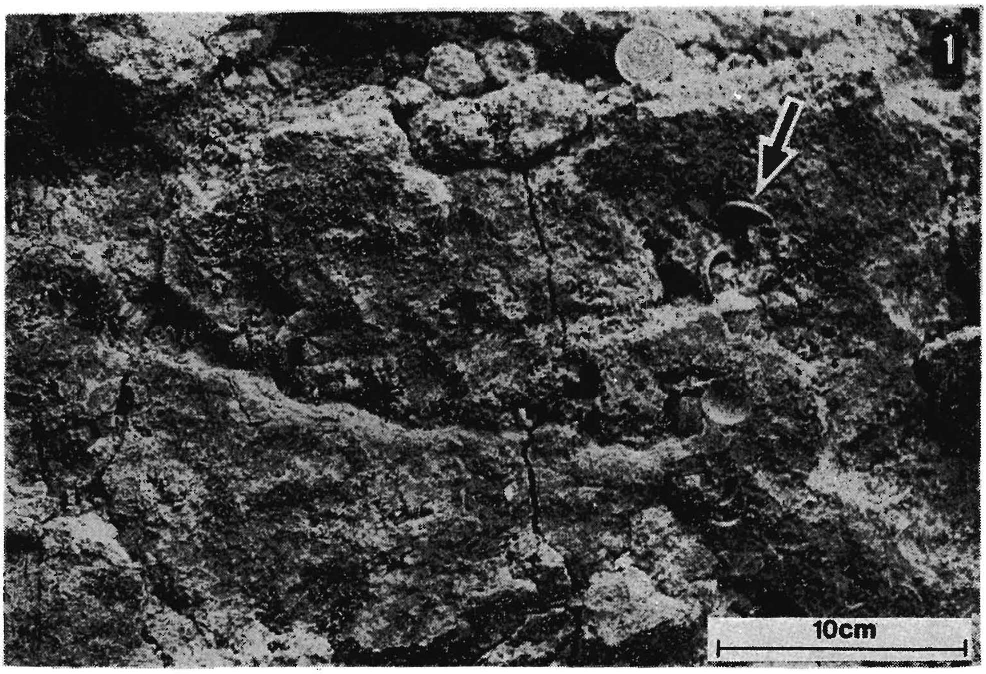


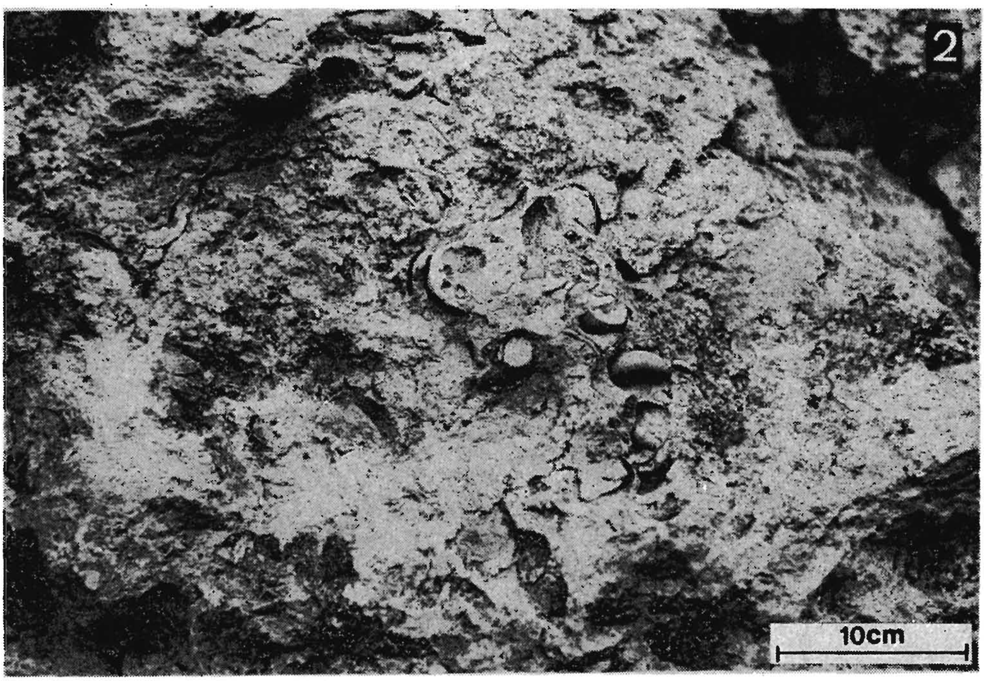
1 — Algal-vermetid reef exposed at Węglinek
2 — Neptunian dyke in the reef limestones, Węglinek





1 — Details of the algal-vermetid reef, to show its porosity; Węglinek
2 — Details of the algal-vermetid reef rock: molluscs incorporated into reef framework are arrowed; black points represent the vermetid shells; Węglinek

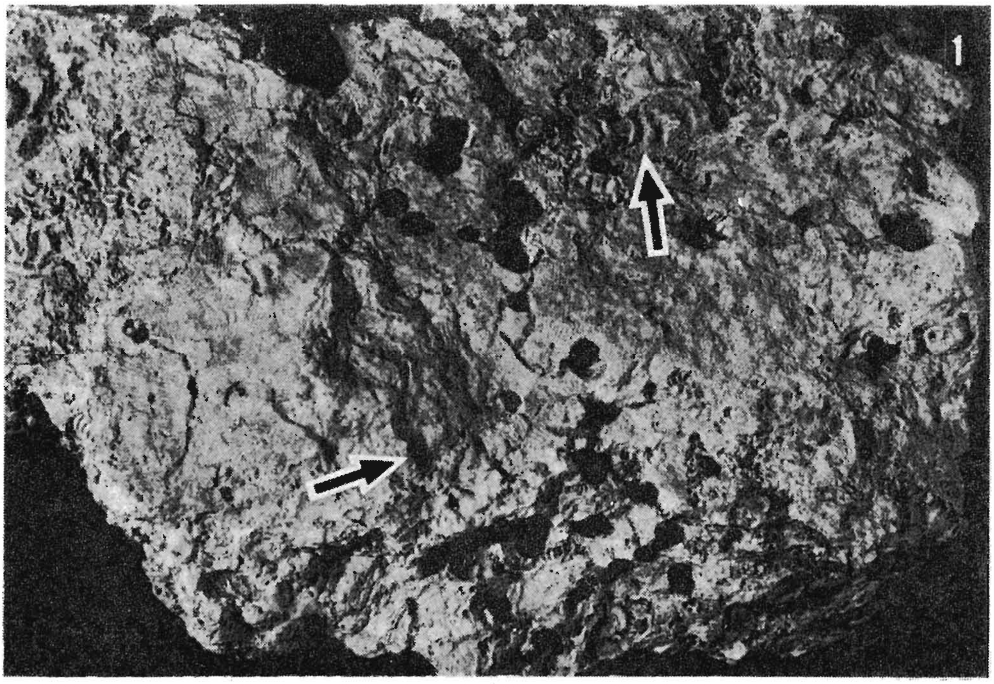


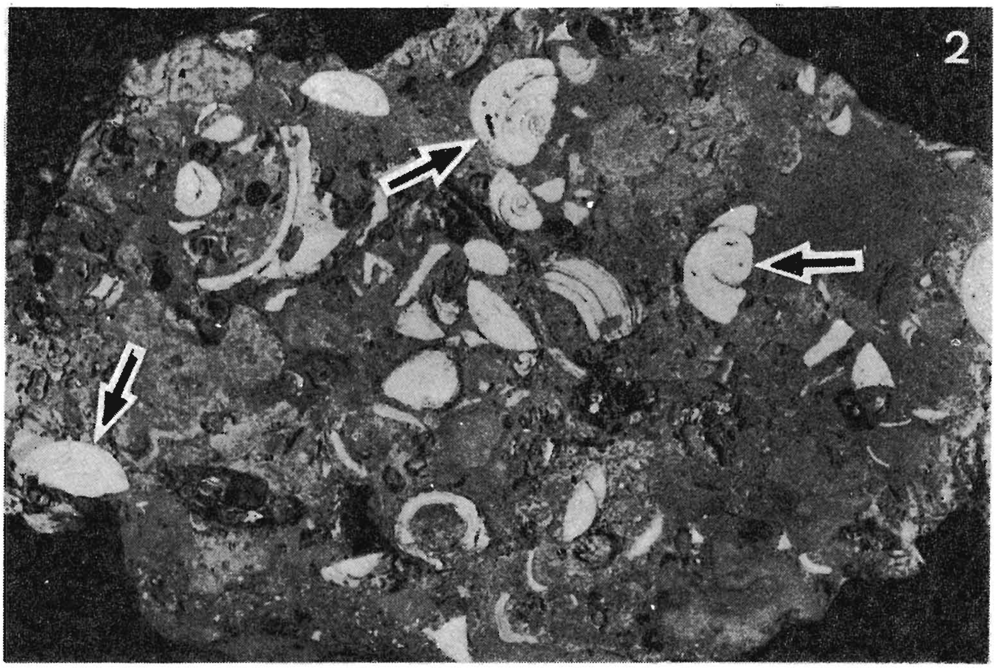


1 — Porosity of the algal-vermetid reef limestones; molluscs incorporated into reef frame are arrowed; Węglinek

2 — Biomicrites infilling large primary cavity in the reef body; abundant molluscs preserved as molds; Węglinek

Algal-vermetid biolithite and biomicrite (with abundant mollusc shells) infilling primary cavity; aragonitic shells (*white*) are still preserved, cavity wall is encrusted by bryozoans and sessile foraminifers *Nubecularia*; Węglinek

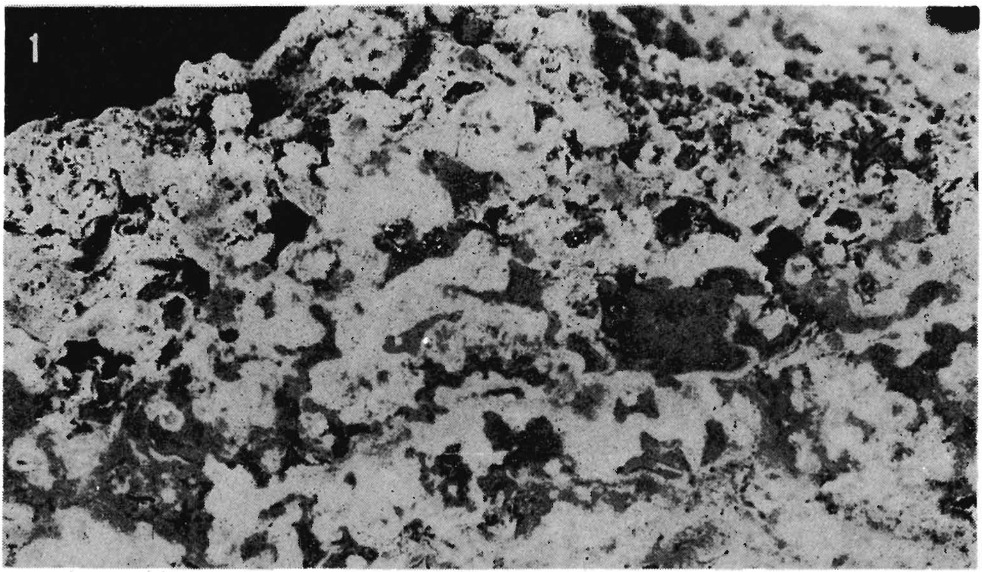




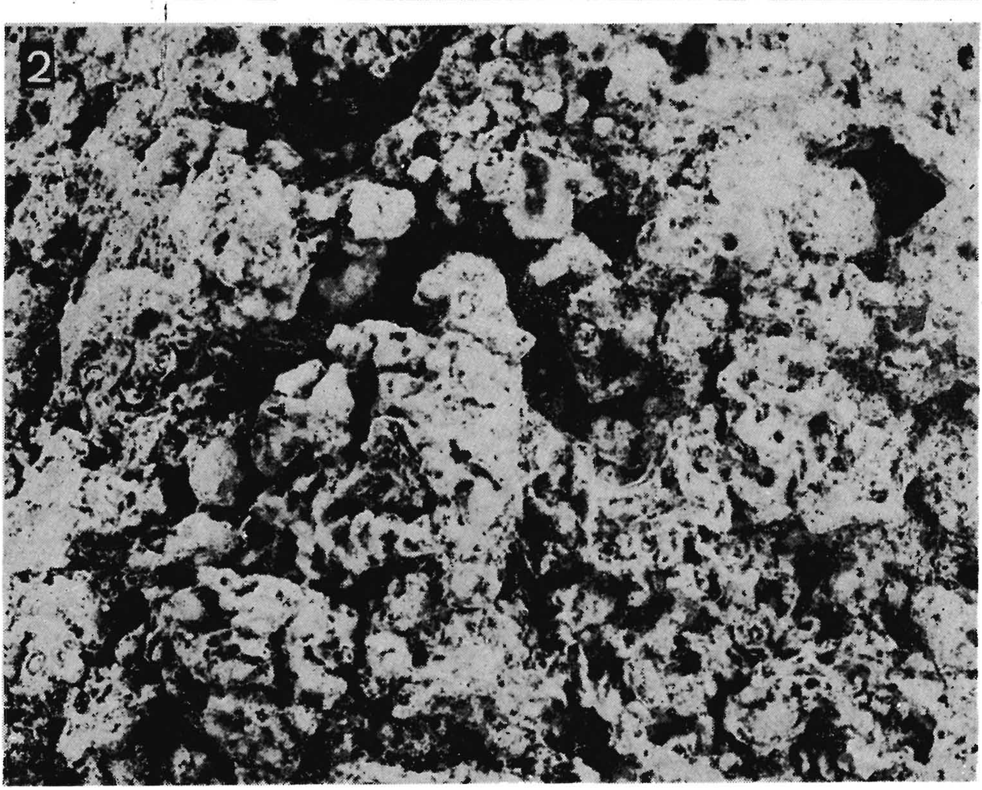
1 — Growth surface of the reef rock (encrusted with bryozoan *Schizoporella*) showing attachment scars of the vermetids (*arrows*) and bivalve borings (*black holes*); Węglinek

2 — Biomicrite with abundant opercula of *Astraea mammillaris* (EICHWALD); polished surface, ×2; Węglinek

1

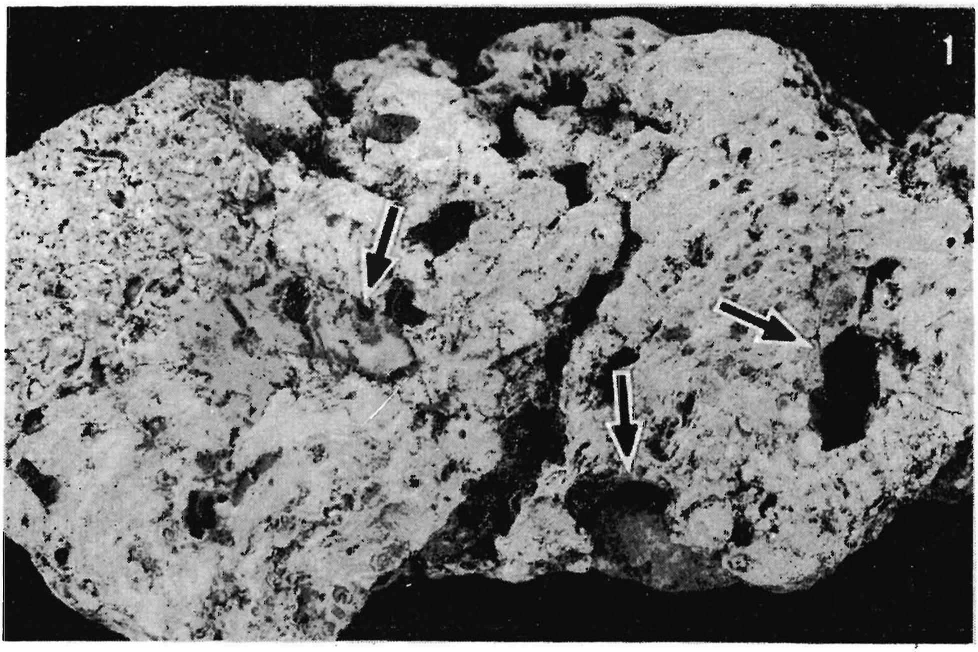


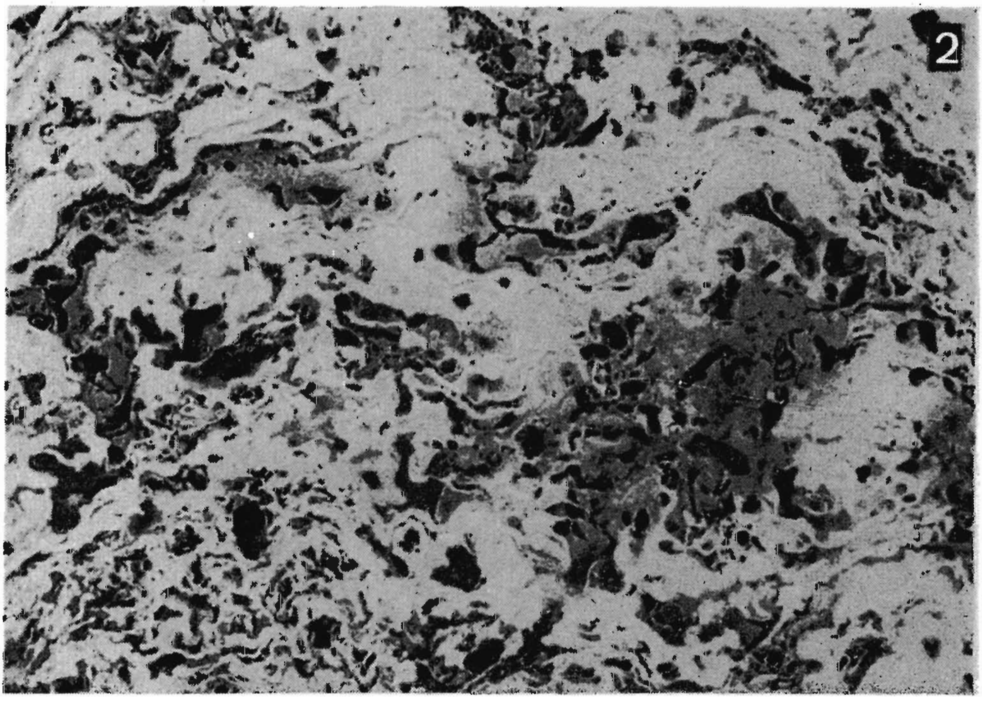
2



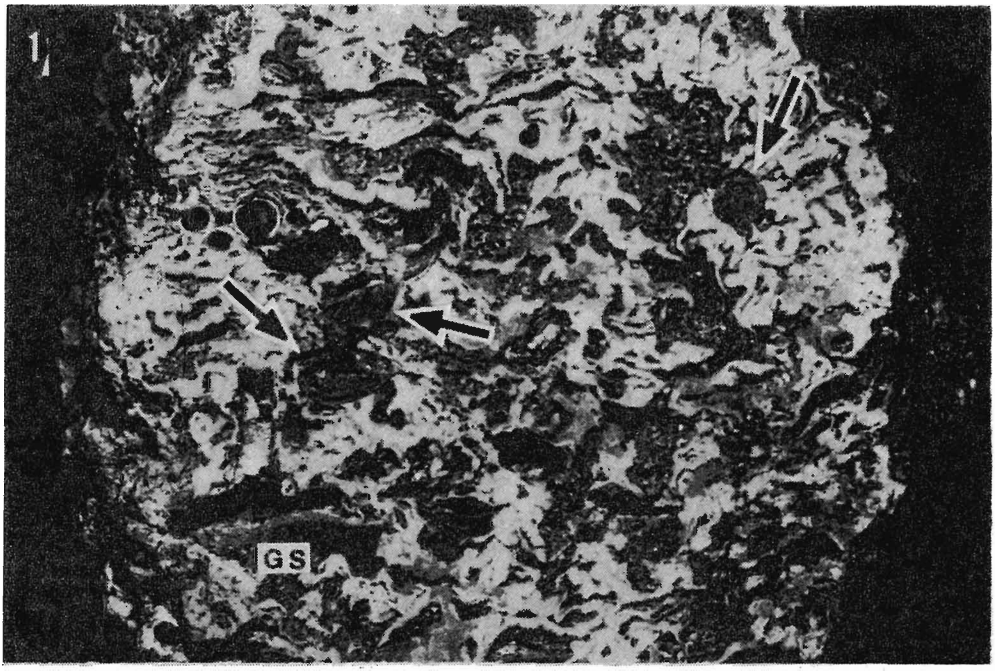
1 — Algal biolithite from Radwanówka, polished surface (*see also* Fig. 2); algal thalli white, internal sediments grey; polished surface, ×1.5

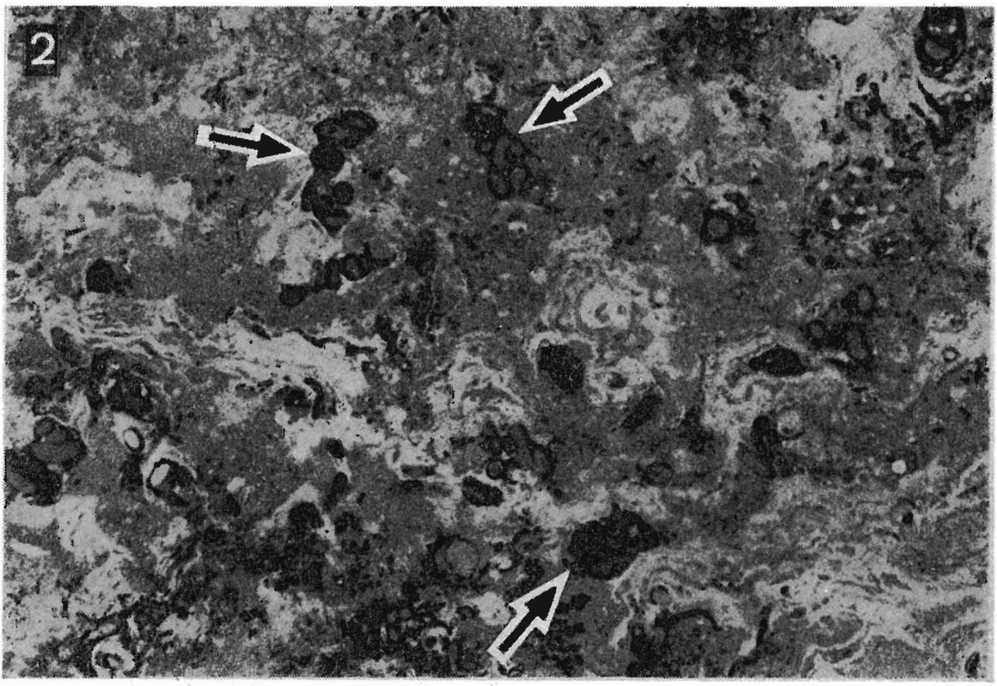
2 — Cavernous growth surface of the algal biolithe from Radwanówka, presented in Fig. 1; polished surface, ×1.5





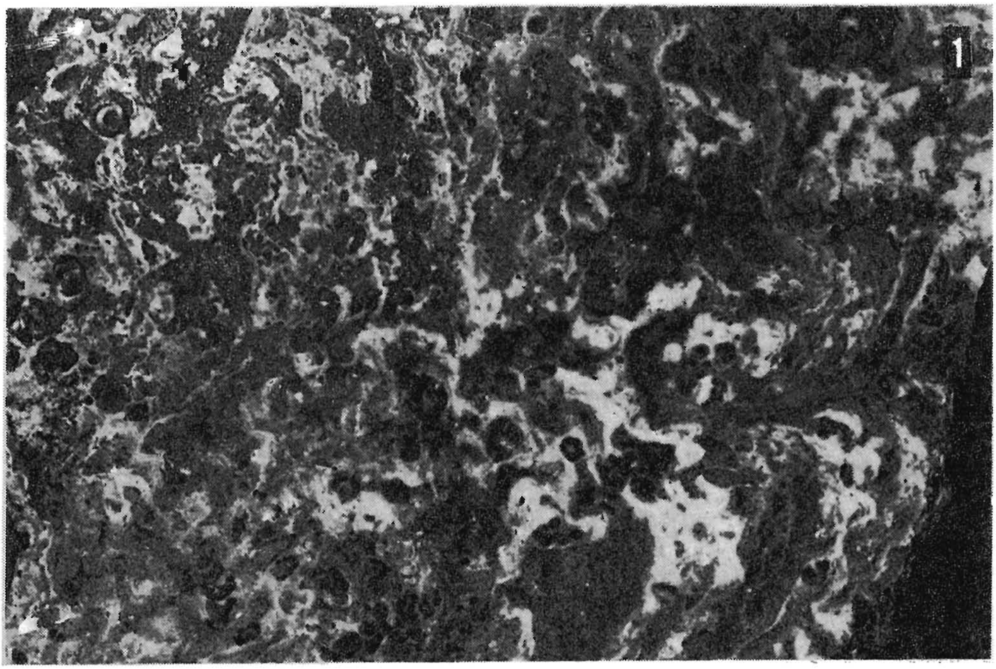
1 — Bivalve borings (*arrowed*) in the algal-vermetid reef rock; polished surface; Radwanówka
2 — Algal-vermetid biolithite showing large primary (mainly *GF*) porosity and small amount of internal sediment; polished surface, ×1.5; Radwanówka

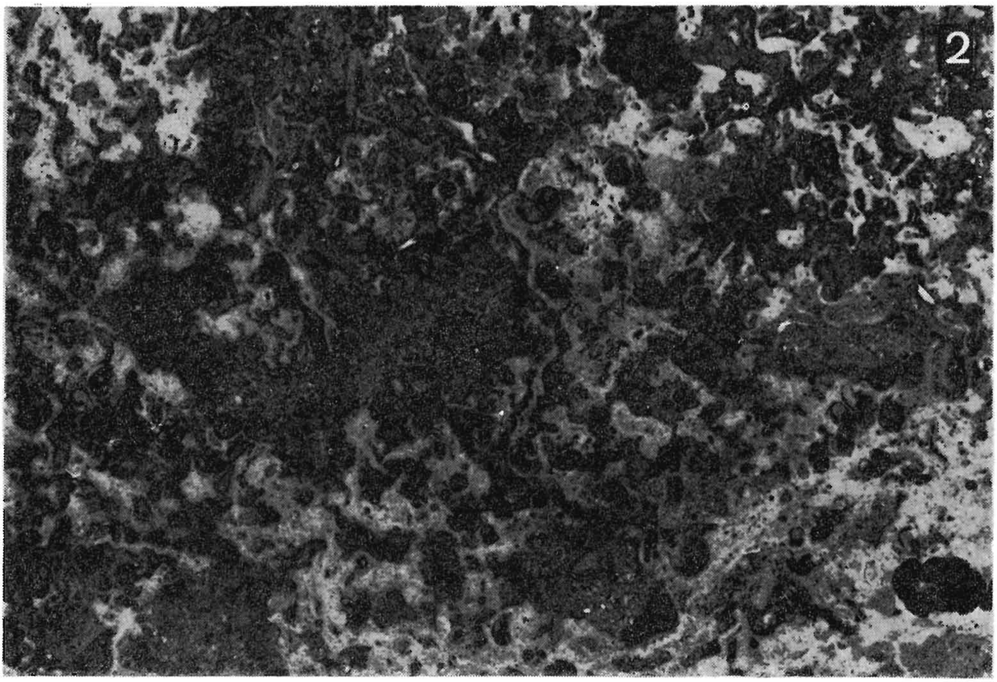




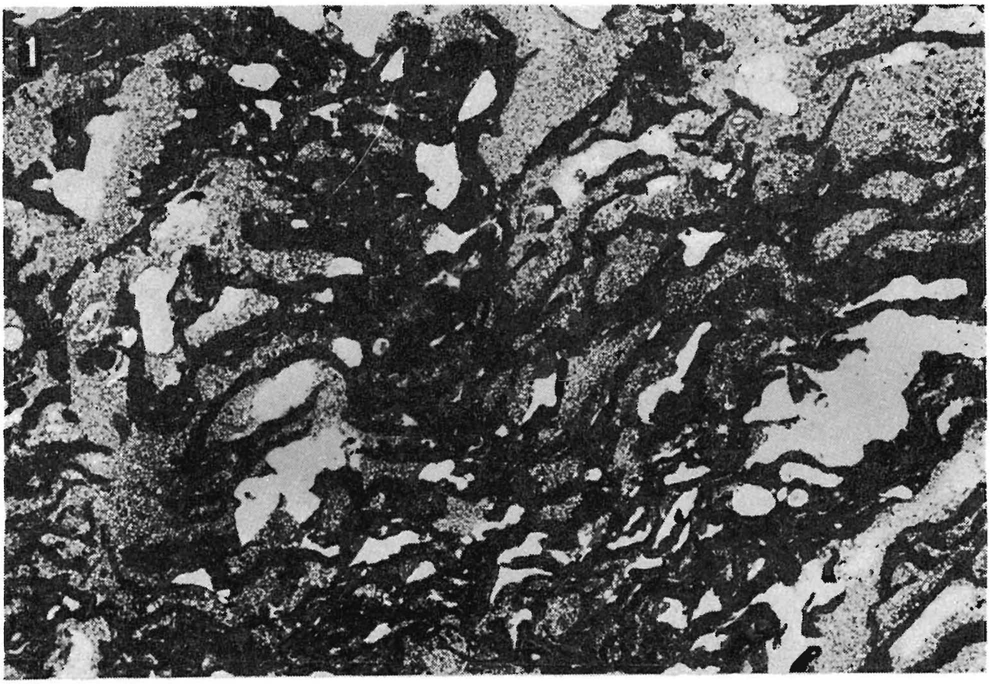
1 — Internal sediments (*grey*) infilling primary cavities in the algal framework: geopetal structures (*GS*) are indicated, bivalve borings of framework are arrowed; polished surface, ×2; Węglinek

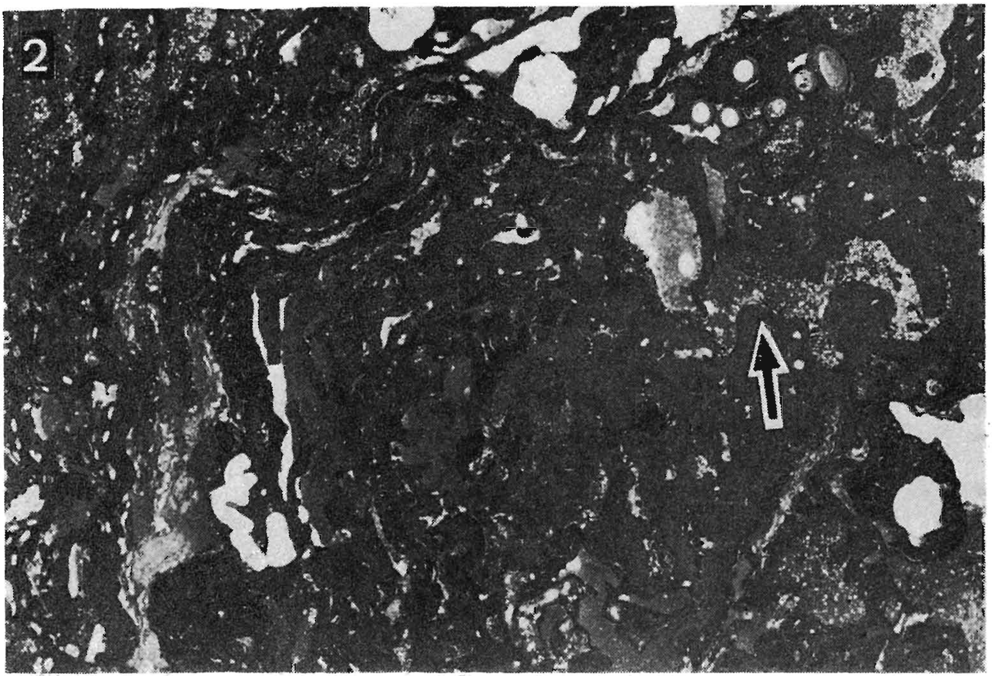
2 — Reef rock with subordinate amount of algal framework (*light grey*); molds of vermetid shells are arrowed; polished surface, ×2; Węglinek





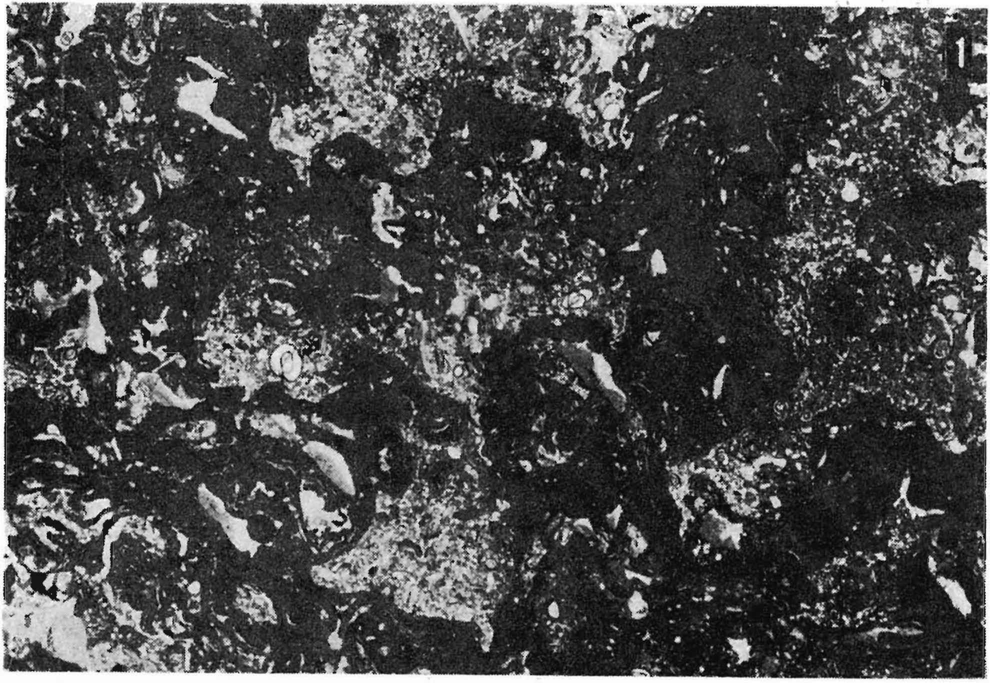
Badenian and Recent algal-vermetid biolithites (polished surfaces) from Radwanówka (Fig. 1) and Bermuda (Fig. 2), to show algal framework (*white* or *light grey*), internal sediment (*dark grey*), and pores of different origin (*black*)

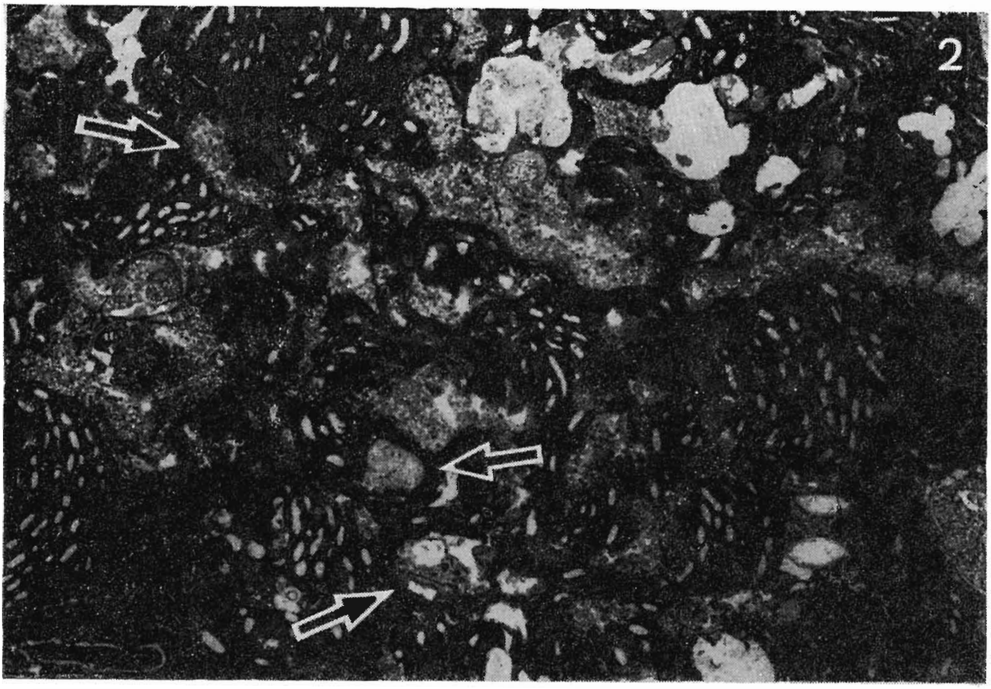




1 — Algal biolithite showing laminar form of algal thalli (*black*) and internal sediment (carbonate sandstone); thin section, ×5; Węglinek

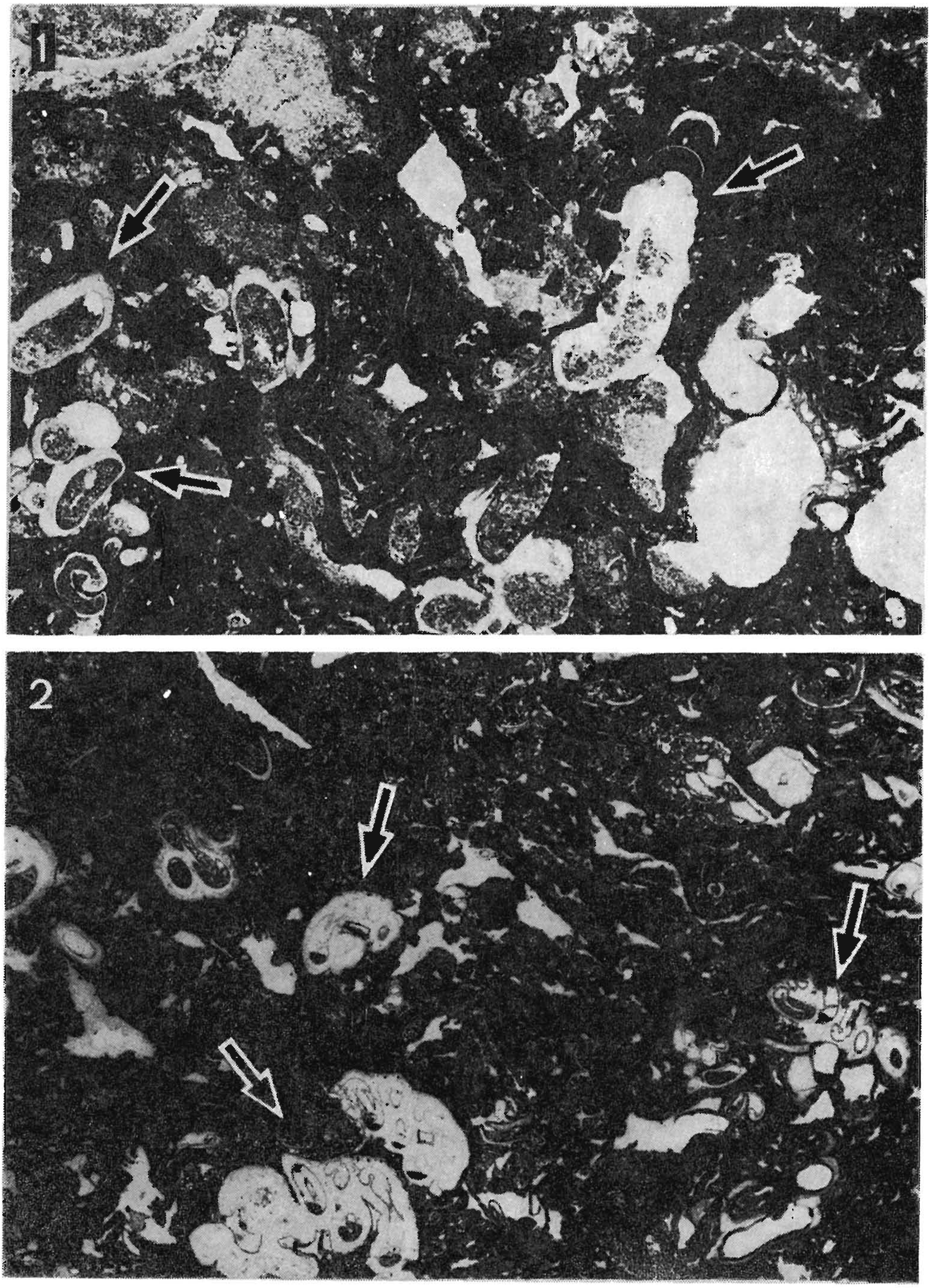
2 — Algal biolithite showing micritic internal sediment which changes its character in one cavity (*arrowed*) from sandstone to pelloidal biomicrite (quartz present in subordinate amounts); thin section, ×5; Węglinek



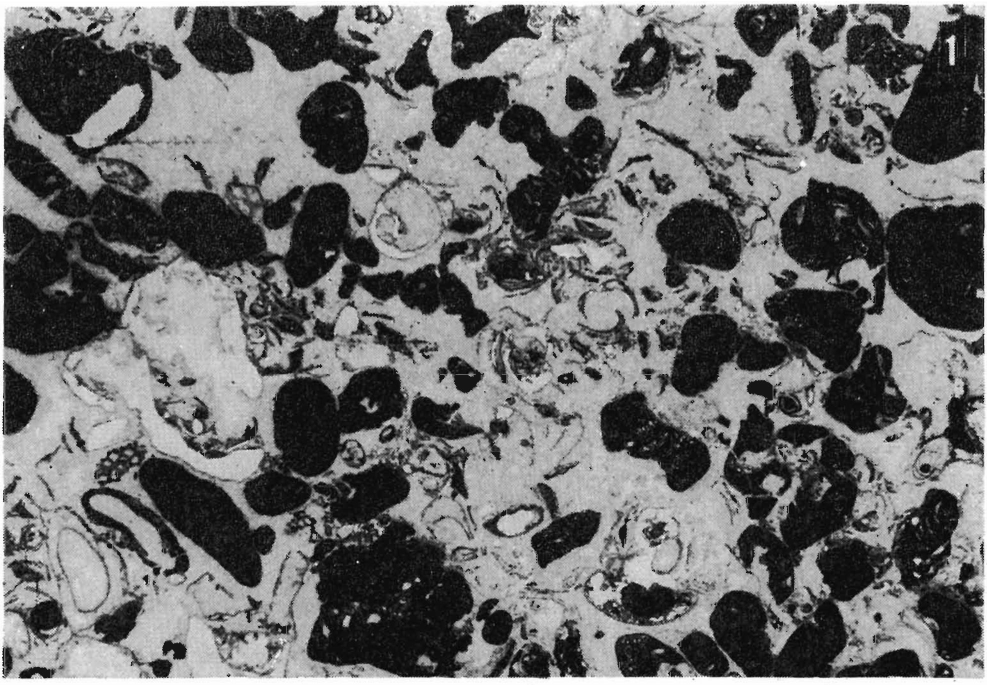


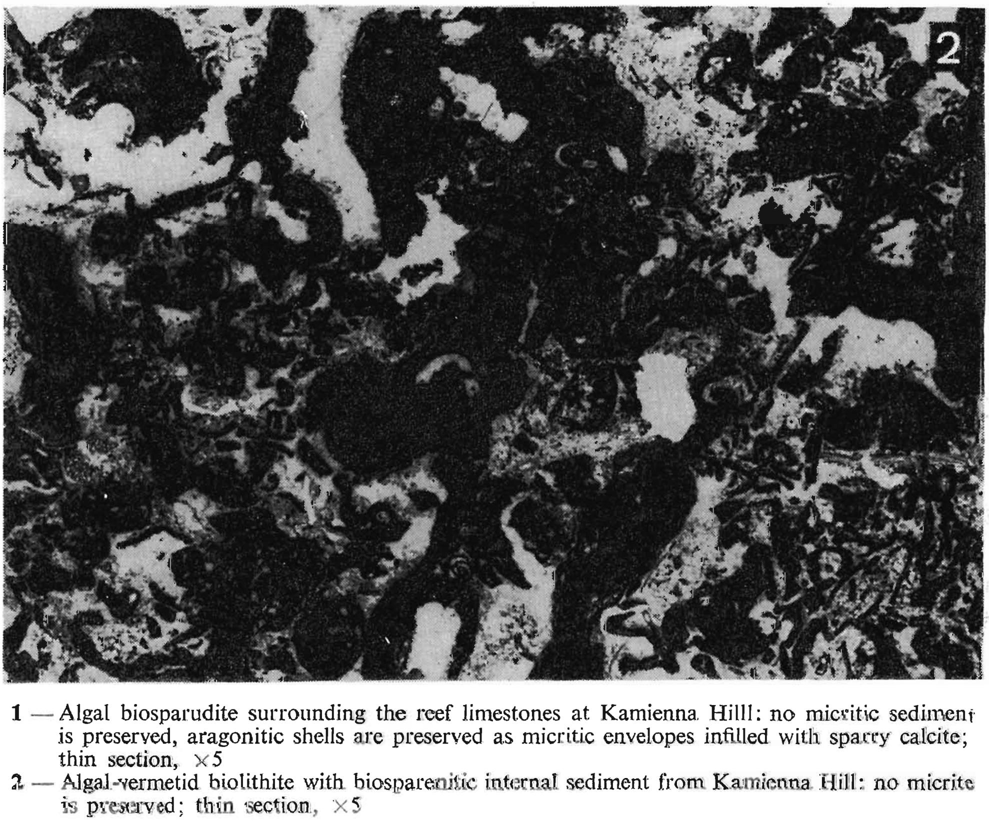
1 — Algal biolithite showing the complex structure of algal framework (*dark*) and biomicritic internal sediment with quartz; thin section, ×5; Łychów

2 — Algal-vermetid biolithite with frame composed of algal thalli provided with knoby protuberances; abundant conceptacles of algae are visible; clionid borings are arrowed, ×5; Radwanówka



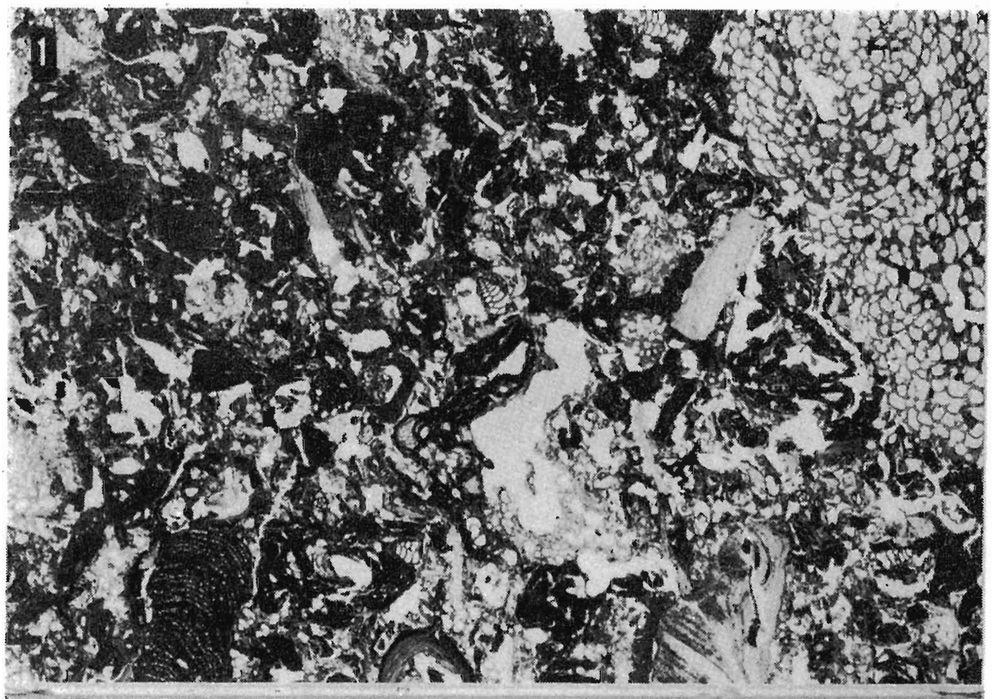
Badenian and Recent algal-vermetid biolithites (thin sections, ×5), from Bermuda (Fig. 1) and Radwanówka (Fig. 2), to show algae (*black*), internal sediment (*grey*), and some vermetids (*arrowed*)

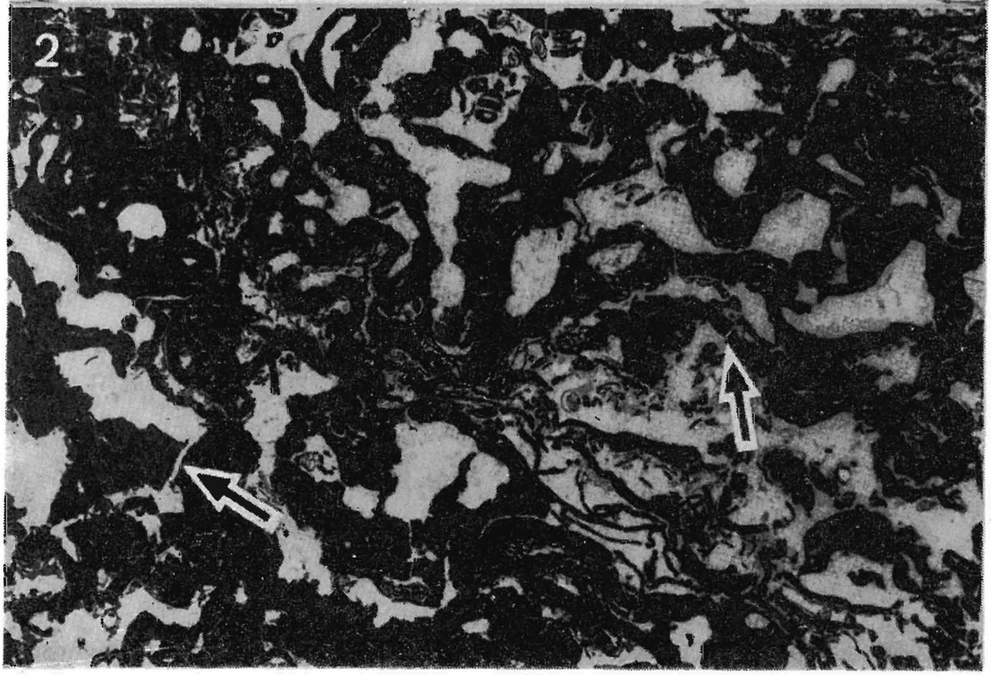




1 — Algal biosparudite surrounding the reef limestones at Kamienna Hilll: no micritic sediment is preserved, aragonitic shells are preserved as micritic envelopes infilled with sparry calcite; thin section, ×5

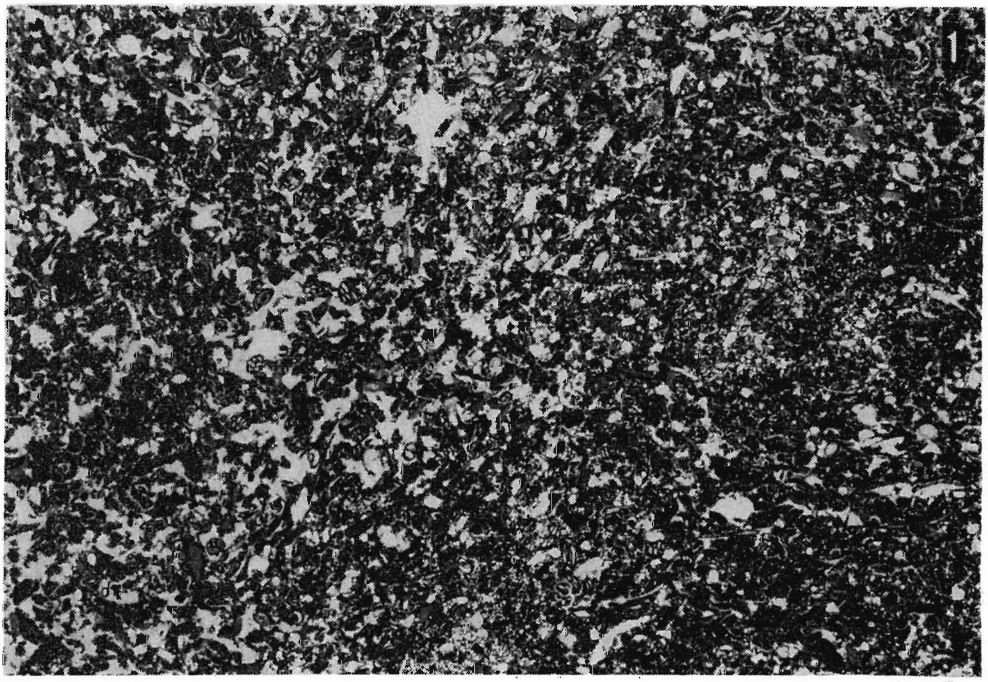
2 — Algal-vermetid biolithite with biosparenitic internal sediment from Kamienna Hill: no micrite is preserved; thin section, ×5

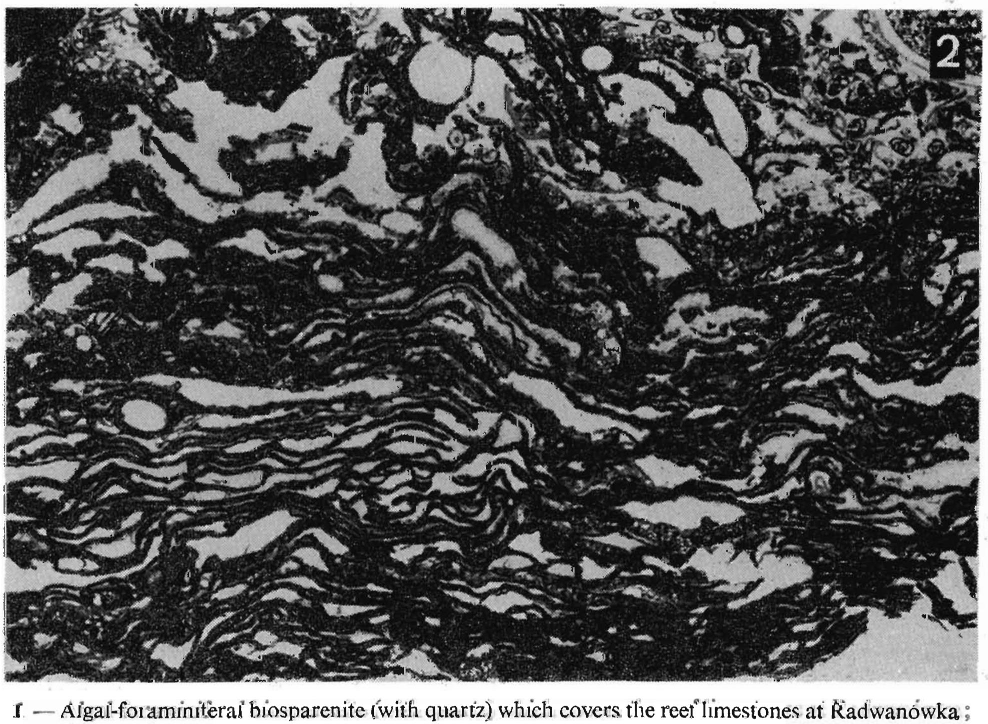




1 — Algal-foraminiferal biorudite (with bryozoans and oysters) from reef talus; thin section, ×5; Łychów

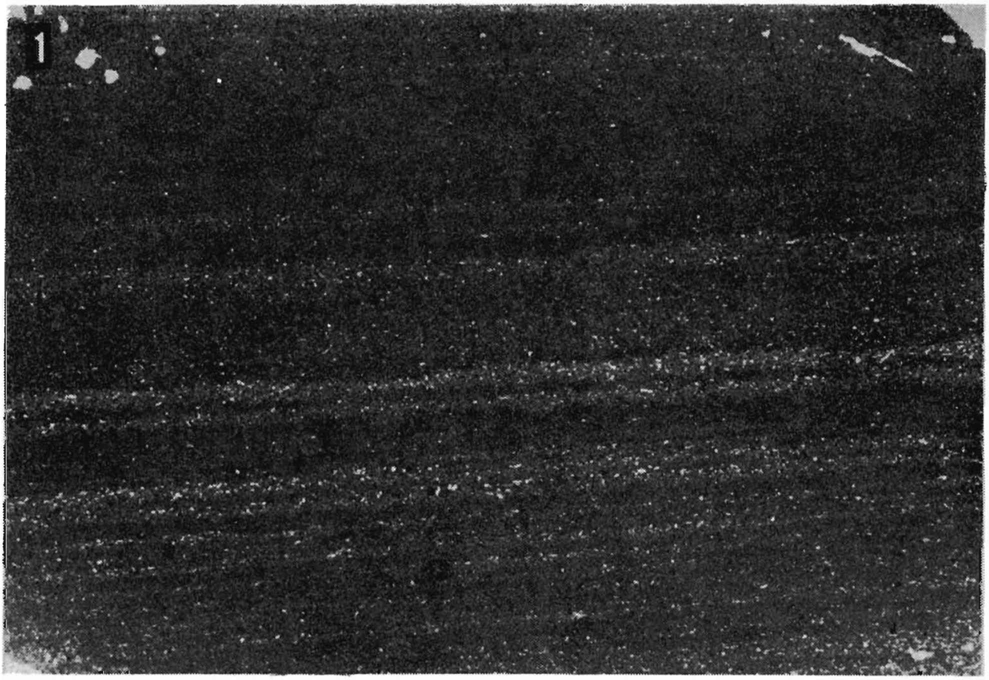
2 — Algal biolithite showing the complex structure of algal frame and compactional cracks (*arrowed*) of algal thalli; all pores are infilled by sparry calcite; thin section, ×5; Kamienna Hill

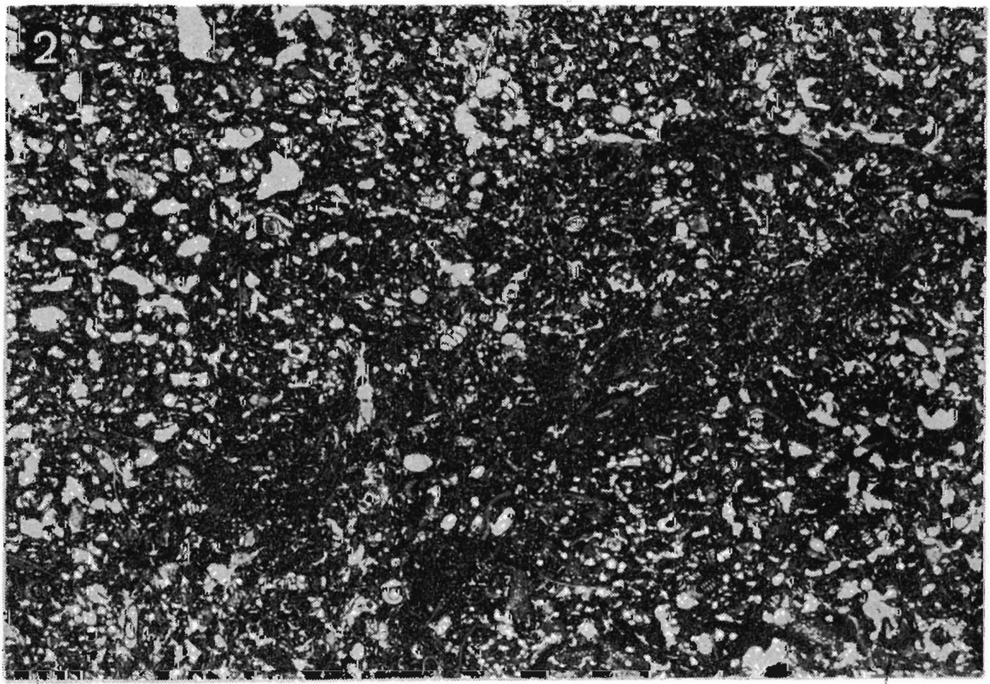




1 — Algal-foraminiferal biosparenite (with quartz) which covers the reef limestones at Radwanówka; thin section, ×5

2. — Laminar crusts of algae forming upper parts of reef rock at Radwanówka, to show pores (*white*) and subordinate internal sediments; thin section, ×5





Internal sediments from large cavities

1 — Micrite laminated with detrital quartz; thin section, ×5; Łychów
2 — Algal-bryozoan-foraminiferal biocalcarenite with quartz showing inter- and intragranular porosity; thin section, ×5; Węglinek

MASLOV. *Lithothamnium praefruticulosum* MASLOV, *Lithophyllum* cf. *rotundum* (CAPEDER), *Archaeolithothamnium lvovicum* MASLOV and *Lithothamnium microphyllum* MASLOV are very rare.

In the biosparenites overlying the reef are common but unrecognizable *Lithothamnium* spp., quite common *Lithophyllum albanense* LEMOINE and very rare *Mesophyllum* cf. *roveretoi* CONTI, *Lithophyllum prelichenoides* LEMOINE as well as fragments of *Jania* sp.

Of great importance, especially in the upper portion of the reef, are vermetids. They are distributed quite irregularly, being absent in some places.

Porosity, high in the upper portion of the reef is strongly reduced towards the bottom where most of pores are infilled with calcite sparite (Pl. 14, Fig. 2). Internal sediments are developed as biomicrites and biosparites with quartz (Pl. 13, Fig. 2), sometimes even calcareous sandstones. The larger-sized cavities contain coralline algal biosparudites with poorly sorted biogenic material (Pl. 13, Fig. 1). The micritic matrix is only partly preserved in the upper part of the reef, that towards the bottom is neomorphosed. The aragonitic shells are dissolved or sparitized so that only micritic envelopes infilled with sparite are visible (Pl. 13, Fig. 1). In some places, especially in the southern part of area, pockets of biosparudites with numerous trochid molds are common.

The taxic composition of macrofauna is the same as at Węglinek but the frequency is much lower, except for accumulations in the upper part. The lowered abundance is probably caused by the absence of large primary cavities, so common at Węglinek, which served as suitable microenvironment to numerous molluscs.

ŁYCHÓW

The reef limestones crop out in few small pits at 230 meters altitude (Text-fig. 7). The bottom of the Miocene sequence is not exposed but observed thickness is about 5 m. The reef limestones are orange to yellow in colour, well lithified and have low porosity. They may be classified as algal-vermetid biolithites. The importance of coralline algae is variable but they may account for up to 70% of the rock, however, they usually comprise only 40%. The algal growth-forms are very complex with thick and irregular lamina. Dominating species are *Lithothamnium lacroixi* LEMOINE and *Lithophyllum albanense* LEMOINE. Common are *Lithothamnium microphyllum* MASLOV, *Archaeolithothamnium lvovicum* MASLOV and *Dermatolithon ucrainicum* MASLOV, *Lithophyllum corculumis* MASLOV and *L.* cf. *duplex* MASLOV are rare. Vermetids, preserved as calcitic molds are very common and widespread. The associated molluscan fauna is similar, though less abundant, to that present at Węglinek. The internal sediments are well lithified and may be classified as biomicrites or micrites with quartz. (Pl. 16, Fig. 1). To the south, the reef limestones are covered by coralline algal biocalcarenites with quartz. The contact between them is sharp. These sediments are composed of detritus of *Lithothamnium* sp. and *Lithophyllum prelichenoides* LEMOINE, miliolid

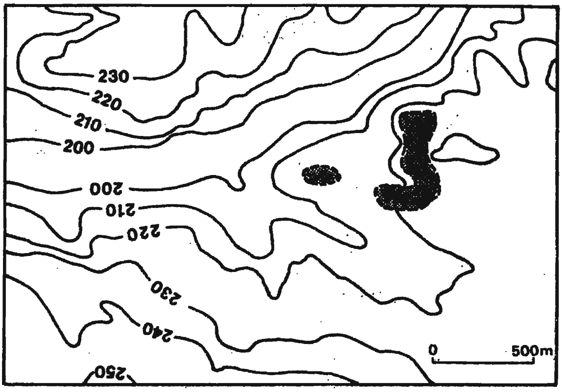


Fig. 7

Topographical situation of the algal-vermetid reef (*stippled*) in the Łychów area and arenaceous foraminifers, serpulid tubes and echinoid fragments. The rare macrofauna is represented by *Pycnodonte* sp. and scallops.

In the outcrops situated at a few meters distance from the reef and a little lower, strongly porous unbedded biorudites and biocalcarenites (Pl. 14, Fig. 1) are exposed. They contain oysters and scallops. The bioclasts are mainly coralline algae, bryozoans, serpulid tubes as well as numerous foraminifers. Aragonitic shells are totally absent — this apparently caused by diagenetic factors. The bioclasts show no sorting or rounding and are up to few centimeters in diameter. All these facts suggest that they represent the reef talus.

RADWANÓWKA

The outcrops of the reef limestones are visible east of the Potok-Stany village, on the slope of hill 244.2 m (Text-fig. 8). In the vicinity of these limestones, west of them and few meters lower, yellow-green marls with coralline algae are exposed. To the east, at the same level as well as over the reef, coralline algal biosparenites crop out. To the south, lower than the reef, coralline algal biocalcarenites with oysters and scallops were observed. It seems that marls and biocalcarenites with molluscs are stratigraphical equivalents of the reef limestones and the biosparenites which partly cover the reef are of course younger. In the other areas of this region exposures of the reef limestones are not presently accessible.

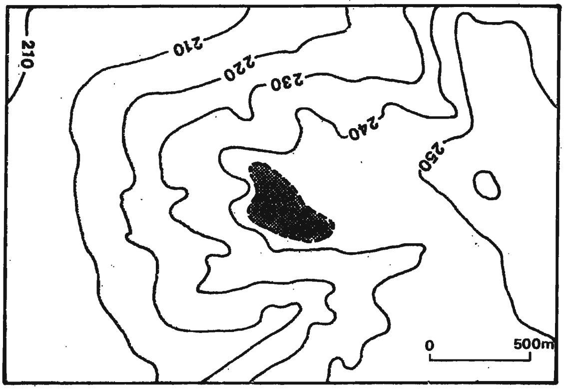


Fig. 8

Topographical situation of the algal-vermetid reef (*stippled*) in the Radwanówka area

The thickness of the Miocene sediments visible at the outcrops is about 8 m but the reef limestones account for only 6 meters. Coralline algal biosparenites with quartz fill depressions in the uneven surface of the reef. They consist of small, up to 3 cm of diameter, rhodoliths. An abundant fauna of molluscs, but preserved only as molds, occurs in the lower part. The boundary of the reef limestones and overlying biosparenites is irregular and sharp but clearly of sedimentary origin. The reef surface has numerous cavities and fissures filled with poorly cemented biocalcarenites and calcareous sands with quartz. These cavities contain very abundant trochid and rissoid gastropods. Sometimes one may also find pebbles and blocks of the reef limestones that have been bored by bivalves. The upper parts of the reef are often encrusted with sessile foraminifers *Nubecularia* which are present throughout the whole reef body but never in such quantities. The thickness of biocalcarenites is about 2 meters.

The reef limestones are unbedded, porous, yellow-green in colour and may be classified as coralline algal biolithites with vermetids (*see* Pl. 6; Pl. 7, Fig. 1; Pl. 9, Fig. 1; Pl. 11, Fig. 2; Pl. 12, Fig. 2). The most abundant algal species are *Lithothamnium praefruticulosum* MASLOV, *L. lacroixi* LEMOINE and *Lithophyllum albanense* LEMOINE. In the upper portion of the reef *Lithothamnium ishigakiensis* JOHNSON, *Mesophyllum* cf. *schenki* HOWE and *Archaeolithothamnium* sp., are also common. Rare species are *Dermatolithon ucrainicum* MASLOV, *Melobesia badji* MASLOV and

Lithothamnium microphyllum MASLOV. Specimens of *Paleothamnium archaeotypum* CONTI are very rare. The thin laminar thalli dominate in the upper part of the reef (Pl. 15, Fig. 2), towards the bottom they become more complex and thicker (Pl. 6, Fig. 1; Pl. 11, Fig. 2). The molluscan fauna of the reef is very similar to the one present at Węglinek but the absence of *Astraea mammillaris* (EICHWALD), so common at the other outcrops, is notable.

The internal sediments are not of as great importance as at the Węglinek section. Especially lacking are large primary cavities filled with internal sediment. No aragonitic shells are preserved, only molds or sparitized forms are present. The internal sediments are more important in the lower part of the reef, towards the top their abundance is less so that they do not completely infill the growth cavities among the algal thalli. The internal sediment is comprised of abundant quartz grains, bioclasts and glauconite. The role of the vermetids varies considerable, they are most common in the middle portion of the reef.

PALEONTOLOGICAL AND PALEOECOLOGICAL ANALYSIS OF REEF ORGANISMS

GENERAL REMARKS

The frame-forming organisms of the reefs, the coralline algae, are preserved *in situ* in growth position, in the form of thin laminar or leaf-shaped thalli. Usually, even very delicate branches are preserved (*see* Pl. 21, Fig. 3). The particular cells are readily visible, as micritization was not pervasive, micrite only infills the interior of cells (*see* Pl. 39, Fig. 3). Except for the Węglinek section, where part of biogenic aragonite is preserved, most of fossils occur as molds or impressions. It is thought that all fauna is preserved *in situ* and was not transported from other environments. This is indicated by the absence of breakage, rounding and abrasion of shells, the common preservation of articulated shells of bivalves and brachiopods as well as by the presence of all growth stages of fossils. No exotic elements are present which may have come from other environments and the assemblages are coherent in their ecological character. As the reef formed a positive element during sedimentation no mechanical mixing of faunal elements is to be expected inside the reef body but may be expected in the perireef sediments. Only very strong storms could introduce exotic faunal elements but no sedimentological evidence of such events is apparent. Part of the fauna occurs as diverse and abundant accumulations but they probably represent only the uneven primary distribution of fauna which inhabited the fissures and depressions of the reef body.

CORALLINE ALGAE

The basis of the taxonomic investigations were the petrographic thin sections. Thus, proper orientation of section of algal thalli were not always available and some determinations were only possible to the genus level or are uncertain. The taxonomy is based on JOHNSON (1962, 1963), MASLOV (1956, 1962), ADEY (1965) and ADEY & MACINTYRE (1973). The key of POIGNAT (1979) was also very helpful. The main characters in classification of fossil coralline algae are hypo- and perithallus structures, type of sporangial organs and cell sizes (MASLOV 1962, WRAY 1977).

The crustose coralline algae are the main biogenic component of the reef limestones investigated here and account for up to 70% of the rock. Usually in one thin section different species and genera of algae are visible. These algae form the typical reef framework. Segmented red algae of the genus *Jania*, are rare and equamariacean algae are very rare.

Only a few of the above described algal species are real frame-builders in the Roztocze reefs, others occur as more or less accessory species. Those taking part in the frame formation are *Lithopyllum albanense* LEMOINE, *Lithothamnium ishigakiensis* JOHNSON, *L. praefruticulosum* MASLOV, *L. lacroixi* LEMOINE, *Mesophyllum* cf. *schenki* HOWE and sometimes also *Lithothamnium saxorum* CAPEDER. *Dermatolithon ucrainicum* MASLOV and *Melobesia badji* MASLOV are common encrusters in some samples but unimportant volumetrically and can not be regarded as frame-builders.

As one may expect, the coralline algal flora from the algal-vermetid reefs from the Badenian of Roztocze is most similar to the one described from analogous sediments of the Ukraine by MASLOV (1956, 1962). Most species were also mentioned by GOLONKA (1981) from the coralline algal limestones of Badenian age from the Rzeszów region (Carpathians in Poland). Most species have, however, wide geographical distribution and occur in the whole Mediterranean region. Only two species (apart from wide-ranging *Lithophyllum prelichenoides* LEMOINE), i.e. *Lithothamnium ishigakiensis* JOHNSON and *Mesophyllum* cf. *schenki* HOWE occur outside this region. Rather surprising are substantial differences between the algal flora of the Vienna Basin (CONTI 1946) and that of the Polish Badenian.

SYSTEMATIC ACCOUNT

Family **Corallinaceae** (LAMOUROUX) HARVEY, 1849
Subfamily **Melobesioideae** LEMOINE, 1939
Genus *Archaeolithothamnium* ROTHPLETZ, 1891
Archaeolithothamnium lvovicum MASLOV, 1956
(Pl. 17, Figs 1—4)

1956. *Archaeolithothamnium Keenanii* var. *lvovicum* sp. nov.; V.P. MASLOV, pp. 151—152, Text-fig. 75, Pl. 53, Fig. 2; Pls 54—55.
1962. *Archaeolithothamnium keenanii* var. *lvovicum* MASLOV; V.P. MASLOV, pp. 46—47, Text-fig. 21.

DESCRIPTION: Encrusting thallus with weakly developed hypothallus; hypothallial cells rectangular (5—7μm × 13—18μm). Perithallus with cells arranged in a regular pattern, cells square (9—11μm × 9—14μm). Ubiquitous oval sporangia (35—55μm × 60—95μm) arranged in regular rows.

REMARKS: MASLOV (1956, 1962) described this form as a subspecies of *Archaeolithothamnium keenani* HOWE. Features of hypothallus and of perithallus, the cell sizes of the investigated specimens are identical as given by MASLOV. The size of sporangia are more variable but are usually also similar to those given by MASLOV. Recently, MASTRORILLI (1973) included *Archaeolithothamnium keenani* var. *lvovicum* MASLOV into the synonymy of his species *Archaeolithothamnium pseudokeenani* from the Oligocene of Liguria and Piemont. However, the cell and sporangia sizes differ considerably from those given by MASLOV (1956, 1962).

OCCURRENCE: Badenian of the Ukraine; probably also Badenian deposits from the Carpathians in Poland (*see* GOLONKA 1981).

Archaeolithothamnium sp.
(Pl. 27, Figs 1—2)

DESCRIPTION: Encrusting thallus with small mamellons. Hypothallus thin, typical of the genus; perithallus thick, with cells arranged in a regular pattern; cells of perithallus square to rectangular (7—13μm × 7—9μm). Conceptacles oval in shape and elongated on sides, measuring 120—150μm × 205—250μm.

REMARKS: General morphological features allow the attribution of the investigated specimens to the genus *Archaeolithothamnium*. The absence of sori and the presence of conceptacles may indicate that the investigated specimens belong to the genus *Lithothamnium* but as conceptacles may also occur as sexual organs which may be found in *Archaeolithothamnium* our attribution could be correct.

Genus *Paleothamnium* CONTI, 1945
Paleothamnium archaeotypum CONTI, 1945
(Pl. 18, Figs 1—2)

1962. *Paleothamnium* sp.: V.P. MASLOV, pp. 56—57, Text-fig. 33.
1972. *Paleothamnium archaeotypum* CONTI; F. ORSZAG-SPERBER & A.F. POIGNAT, p. 117, Pl. 2, Figs 1—3.
1973. *Paleothamnium archaeotypum* CONTI; A. SCHALEKOVA, p. 214, Pl. 71, Fig. 12; Pl. 76, Fig. 1.
1977. *Paleothamnium archaeotypum* CONTI; F. ORSZAG-SPERBER, A.F POIGNAT & A. POISSON, p. 286, Pl. 3. Fig. 3

REMARKS: The character of perithallus and sori of the investigated specimens well agree with those given by other authors for *P. archaeotypum* CONTI. However, no hypothallus was observed in the present study. Perithallial cells (9μm × 17—22μm) do not differ in their size from those given in other papers, the same concerns heterocysts (590μm × 120μm).

OCCURRENCE: Miocene of the Ukraine, Italy, Austria, and Czechoslovakia.

Genus *Lithothamnium* PHILIPPI, 1837
Lithothamnium praefruticulosum MASLOV, 1956
(Pl. 20, Figs 1—3)

1956. *Lithothamnium praefruticulosum* sp. nov.; V.P. MASLOV, p. 149, Pl. 52, Fig. 13.
1962. *Lithothamnium praefruticulosum* MASLOV; V.P. MASLOV, p. 68, Pl. 16, Figs 1, 3.
1967a. *Lithothamnium praefruticulosum* MASLOV; V.I. MASTRORILLI, pp. 266—267, Pl. 3, Fig. 3.
1983a. *Lithothamnium praefruticulosum* MASLOV; D.W.J. BOSENCE, pp. 153—156. Text-fig. 4, Pl. 16, Figs 1—2.

REMARKS: Noncoaxial hypothallus with rectangular cells (7—9μm × 18—25μm); perithallus thick, up to several hundred micrometers, with common conceptacles (180μm × 590μm); perithallial cells square to rectangular (9μm × 9—19μm), in the conceptacles area strongly elongated (9—11 μm × 22—27 μm).

OCCURRENCE: Oligocene of Italy; Miocene of Malta; Badenian of the Ukraine.

Lithothamnium lacroixi LEMOINE, 1917
(Pl. 18, Figs 1—2)

1917. *Lithothamnium lacroixi* sp. nov.; M. LEMOINE, pp. 269—271, Text-figs 17—18.
1962. *Lithothamnium* aff. *lacroixi* LEMOINE; V.P. MASLOV, pp. 63—64, Text-fig. 38.

DESCRIPTION: Noncoaxial, thick hypothallus with rectangular cells (7—9µm × 13—22µm). Perithallus with most cells of rectangular shape (9µm × 13—15µm), near the boundary with hypothallus, however, they are nearly square (5—9 µm × 5—9 µm). Pertithallus very thick, weakly zoned with mamellons; conceptacles common (180—200µm × 290—360µm).

REMARKS: The cell conceptacle sizes as well as growth form well agree with characteristics of the species *Lithothamnium lacroixi* LEMOINE. The species *Lithothamnium taurinense* CAPEDER is similar in many aspects, differing only in the larger size of conceptacles and stronger zonation.

OCCURRENCE: Miocene of Martinique, Badenian of the Ukraine.

Lithothamnium saxorum CAPEDER, 1900
(Pl. 18, Figs 3—4)

1956. *Lithothamnium saxorum* CAPEDER; V.P. MASLOV, pp. 134—144, Text-fig. 64, Pl. 45, Fig. 2; Pl. 46, Figs 1—2.
1962. *Lithothamnium saxorum* CAPEDER; V.P. MASLOV, p. 69, Text-fig. 45.
1963. *Lithothamnium saxorum* CAPEDER; F.J. SOUAYA, p. 1209, Pl. 161, Fig. 1.
1977. *Lithothamnium* sp. cf. *Lithothamnium saxorum* CAPEDER; B. BUCHBINDER, p. 420, Pl. 1, Fig. 6.

REMARKS: Noncoaxial hypothallus 130—160µm thick, built by rectangular cells (7—11 µm × 13—31µm). Perithallus thin, up to 300µm with rectangular cells (9—11µm × 13—31µm), weakly zoned. Rare conceptacles measure 120—170µm × 330—380µm.

OCCURRENCE: Miocene of Egypt and Italy; Tortonian of Israel; Badenian of the Ukraine.

Lithothamnium ishigakiensis JOHNSON, 1964
(Pl. 21, Figs 1—3)

1964. *Lithothamnium ishigakiensis* n. sp.; J.H. JOHNSON, pp. 6—7, Pl. 3 Figs 1—2.

DESCRIPTION: The investigated specimens occur in the form of thin 100 to 200µm thick crusts with very thin perithallus, sometimes, the overgrowths of singular thalli form more thick encrustations. Noncoaxial hypothallus has rectangular cells measurring 7—9µm × 18—22µm, values close to the holotype; perithallial cells are square to rectangular (9—13µm × 9—11µm). Conceptacles are rare and measure 220µm × 470—660µm.

REMARKS: The investigated specimens agree well with those illustrated and described by JOHNSON (1964), only conceptacles are rare in contrast to the holotype. Some similarity exists also with the species *Lithothamnium saipanense* JOHNSON (*see* Pl. 49, Fig. 3 *in* JOHNSON 1957; *and* Pl. 2, Fig. 1 *in* JOHNSON 1964), cell sizes, however, are different. The species *Lithothamnium maemogensis* of JOHNSON (1964) differs in having a thicker perithallus and differently shaped conceptacles.

OCCURRENCE: Eocene of Guam.

Lithothamnium microphyllum MASLOV, 1956
(Pl. 19, Figs 3—4)

1956. *Lithothamnium microphyllum* sp. nov.; V.P. MASLOV, pp. 150—151, Text-fig. 74, Pl. 53, Fig. 1.
1962. *Lithothamnium microphyllum* MASLOV; V.P. MASLOV, p. 67, Text-fig. 43, Pl. 16, Fig. 4.
1967a. *Lithothamnium microphyllum* MASLOV; V.I.MASTRORILLI, pp. 264—265, Pl. 8, Fig. 4.

REMARKS: The structure of perithallial tissue with nearly square cells (5—7µm × 7µm) as well as the shape and size of conceptacles (100 µm × 140 µm) agree well with previous descriptions. In the investigated specimens weak zonation is also visible, but no hypothallus was observed.

OCCURRENCE: Oligocene of Italy; Badenian of the Ukraine.

Genus *Mesophyllum* LEMOINE, 1928
Mesophyllum cf. *roveretoi* CONTI, 1943
(Pl. 22, Fig. 4)

cf. 1946. *Mesophyllum Roveretoi* CONTI; S. CONTI, pp. 48—49, Pl. 4, Fig. 1*a*, Pl. 8, Fig. 2*a*.
cf. 1967a. *Mesophyllum roveretoi* CONTI; V.I.MASTRORILLI, pp. 249—296, Pl. 14. Figs 1—4.
cf. 1972. *Mesophyllum roveretoi* CONTI; F. ORSZAG-SPERBER & A.F. POIGNAT, p. 122, Pl. 1, Fig. 3.
cf. 1973. *Mesophyllum roveretoi* CONTI; A. SCHALEKOVA, p. 215, Pl. 72, Fig. 1.

REMARKS: Coaxial hypothallus with rectangular cells (9—11µm × 18—22µm) and grid-like perithallus with cells measuring 7—9µm × 9—14µm. The investigated specimens agree well with those hitherto described, especially those by ORSZAG-SPERBER & POIGNAT (1972). Some differences may be noted in comparison to the Oligocene forms illustrated by MASTRORILLI (1967). The absence of well preserved conceptacles and the scarcity of material do not allow a precise identification.

OCCURRENCE: Miocene of Italy and Austria; Badenian of Czechoslovakia.

Mesophyllum cf. *schenki* HOWE, 1934
(Pl. 22, Figs 1—3)

cf. 1934. *Mysophyllum schenki* sp. n.; M.A. HOWE, p. 51, Pls 52—53.
cf. 1953. *Mesophyllum schenki* HOWE; J.H. JOHNSON & W.A. STEWART, p. 135, Pl. 15, Fig. 1.
cf. 1956. *Mesophyllum schenki* var. *corticesum* MASLOV; V.P. MASLOV, pp. 162—164, Pls 65—67.
cf. 1962. *Mesophyllum schenki* var. *corticesum* MASLOV; V.P. MASLOV, p. 76, Text-fig. 54, Pl. 15, Fig. 1.
cf. 1970. *Mesophyllum schenki* HOWE; G. VANNUCCI, p. 341, Pl. 2, Figs 3—4.

REMARKS: Coaxial hypothallus with rectangular cells (5—9µm × 13—22µm); perithallial cells square (5—9µm × 5—9µm); conceptacles are common (110—130µm × 220—290µm). Cell sizes agree well, as does the general structure, with the features of *Mesophyllum schenki* HOWE, only the size of conceptacles is smaller. The specimens described by MASLOV (1956, 1962) as var. *corticesum* show no substantial differences from typical *M. schenki* HOWE.

OCCURRENCE: Eocene of New Mexico and California; Oligocene (?) of Italy.

Mesophyllum sp.
(Pl. 28, Figs 1—3)

DESCRIPTION: Distinctly coaxial hypothallus 170µm thick with rectangular cells (7—9µm × × 22µm); perithallus several hundred µm thick, with rectangular cells (7—9µm × 15—22µm), distinctly zoned ; conceptacles common, large, measuring 215—240 µm × 420—455 µm.

REMARKS: The investigated specimens are close to *Mesophyllum savornini* LEMOINE but cell sizes and the size of conceptacles are different. Limited material does not allow specific identification.

Genus *Lithophyllum* PHILIPPI, 1837
Lithophyllum albanense LEMOINE, 1923
(Pl. 23, Figs 1—4)

1923. *Lithophyllum albanense* sp. nov.; M. LEMOINE, p. 281, Text-figs 8—9.
1956. *Lithophyllum albanense* LEMOINE; V.P. MASLOV, p. 155, Text-figs 78—79, Pl. 40, Figs 40—41.
1962. *Lithophyllum albanense* LEMOINE; V.P.MASLOV, pp. 78—79, Text-fig. 55, Pl. 22.

1963. *Lithophyllum albanense* LEMOINE; F.J. SOUAYA, p. 1210, Pl. 162, Fig. 1.
1964b. *Lithophyllum albanense* LEMOINE; J.H. JOHNSON, p. 482. Pl. 3, Fig. 2.
1972. *Lithophyllum albanense* LEMOINE; F. ORSZAG-SPERBER & A.F. POIGNAT, p. 118, Pl. 3, Fig. 1.
1977. *Lithophyllum albanense* LEMOINE; B. BUCHBINDER, pp. 422—423, Pl. 162, Figs 2—3.
1983a. *Lithophyllum albanense* LEMOINE; D.W.J. BOSENCE, p. 160, Text-fig. 7, Pl. 17, Figs 1—4.

REMARKS: The investigated specimens agree well with those already described. No measurements of hypothallial cells were possible because of oblique sectioning. The rest of characters are, however, unequivocal. Perithallial cells are very irregular from rectangular to square (13μm×22μm up to 22μm×21μm). Predominate rectangular perithallial cell measures 13—22μm×18—22μm. The mean of measurements is a slightly higher than in the holotype. Unipored conceptacles (120 μm× ×325μm to 145μm×325μm) are typical for this species.

OCCURRENCE: Miocene of Albania, Algeria, Greece, Iraq, Israel, Corsica, Matla, and the Ukraine; Badenian of the Carpathians (Niechobrz).

Lithophyllum corculumis MASLOV, 1962
(Pl. 24, Figs 1—4)

1962. *Lithophyllum corculumis* sp. nov.; V.P. MASLOV, p. 80, Text-fig. 57, Pl. 30, Figs 1—3; Pl. 31, Fig. 1; Pl. 37, Fig. 2.

DESCRIPTION: Hypothallus was not observed. Perithallus thick with numerous conceptacles (84μm×253μm up to 120μm×385μm); perithallial cells rectangular (9—18μm×11—27 μm); structure of the perithallus very regular.

REMARKS: All the above characters are identical with MASLOV's (1962) original diagnosis. As in the holotype the dimensions of the cells vary and are larger near conceptacles. This species is similar to *Lithothamnium* cf. *madagascariense* FOSLIE (*see* JOHNSON 1957, Pl. 53, Fig. 5) but conceptacle size is different as is the growth forms of the two species.

OCCURRENCE: Badenian of the Ukraine.

Lithophyllum cf. *rotundum* (CAPEDER) LEMOINE, 1925
(Pl. 25, Figs 3—4)

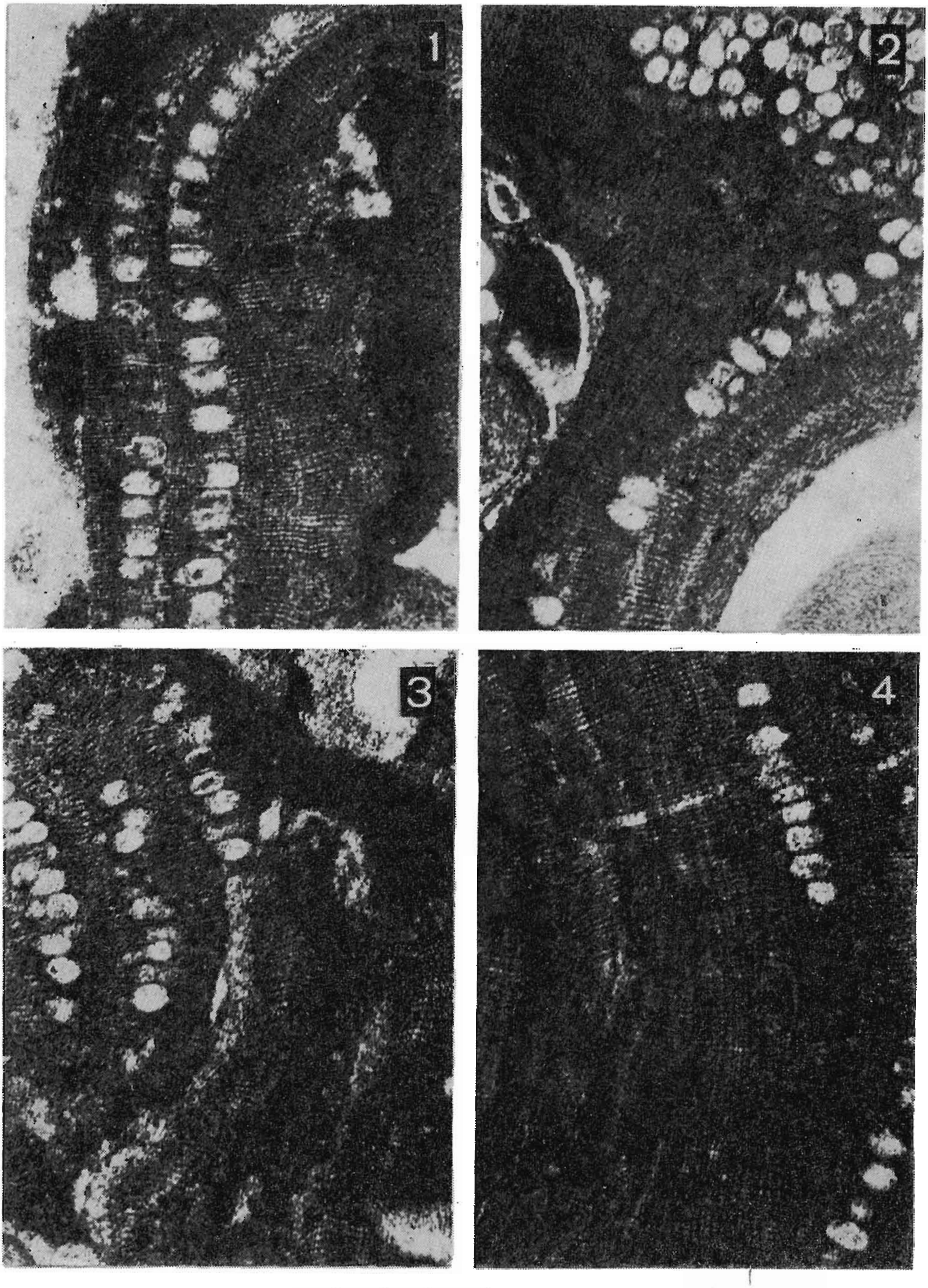
cf. 1956. *Lithophyllum rotundum* (CAP.); V.P.MASLOV, p. 155, Pl. 57, Figs 3—4.
cf. 1962. *Lithophyllum rotundum* (CAP.); V.P. MASLOV, pp. 91—92, Text-fig. 70.

REMARKS: The thickness of coaxial hypothallus is 200—240μm, the thickness of perithallus up to 350μm. No conceptacles were observed. Hypothallial cells rectangular (9—13μm×18—22μm), perithallial cells square to rectangular (11—13μm×11—18μm). The absence, in the investigated material, of conceptacles precludes the exact systematic assignment of our specimens.

OCCURRENCE: Helvetian of Italy; Badenian of the Ukraine.

Lithophyllum prelichenoides LEMOINE, 1917
(Pl. 25, Figs 1—2)

1917. *Lithophyllum prelichenoides* n. sp.; M. LEMOINE, pp. 262, 271, Text-figs 8—9, 19.
1939. *Lithophyllum prelichenoides* LEMOINE; M. LEMOINE, p. 99, Text-figs 65—66.
1956. *Lithophyllum prelichenoides* LEMOINE; V.P. MASLOV, p. 155, Pl. 58, Figs 1—3.
1957. *Lithophyllum prelichenoides* LEMOINE; J.H. JOHNSON, p. 229, Pl. 49, Figs 1—3.
1962. *Lithophyllum prelichenoides* LEMOINE; V.P. MASLOV, p. 80, Text-fig. 67, Pl. 29, Figs 2, 4.
1963. *Lithophyllum prelichenoides* LEMOINE; F.J. SOUAYA, p. 1212, Pl. 161, Figs 2, 6
1975. *Lithophyllum prelichenoides* LEMOINE; H.S.EDGELL & P.W. BASSON, p. 172, Pl. 2, Figs 1—5.
1977. *Lithophyllum prelichenoides* LEMOINE; B. BUCHBINDER, pp. 424, 426, Pl. 5, Figs 4—6.
1983a. *Lithophyllum prelichenoides* LEMOINE; D.W.J. BOSENCE, p. 165, Text-fig. 10, Pl. 18, Fig. 1.



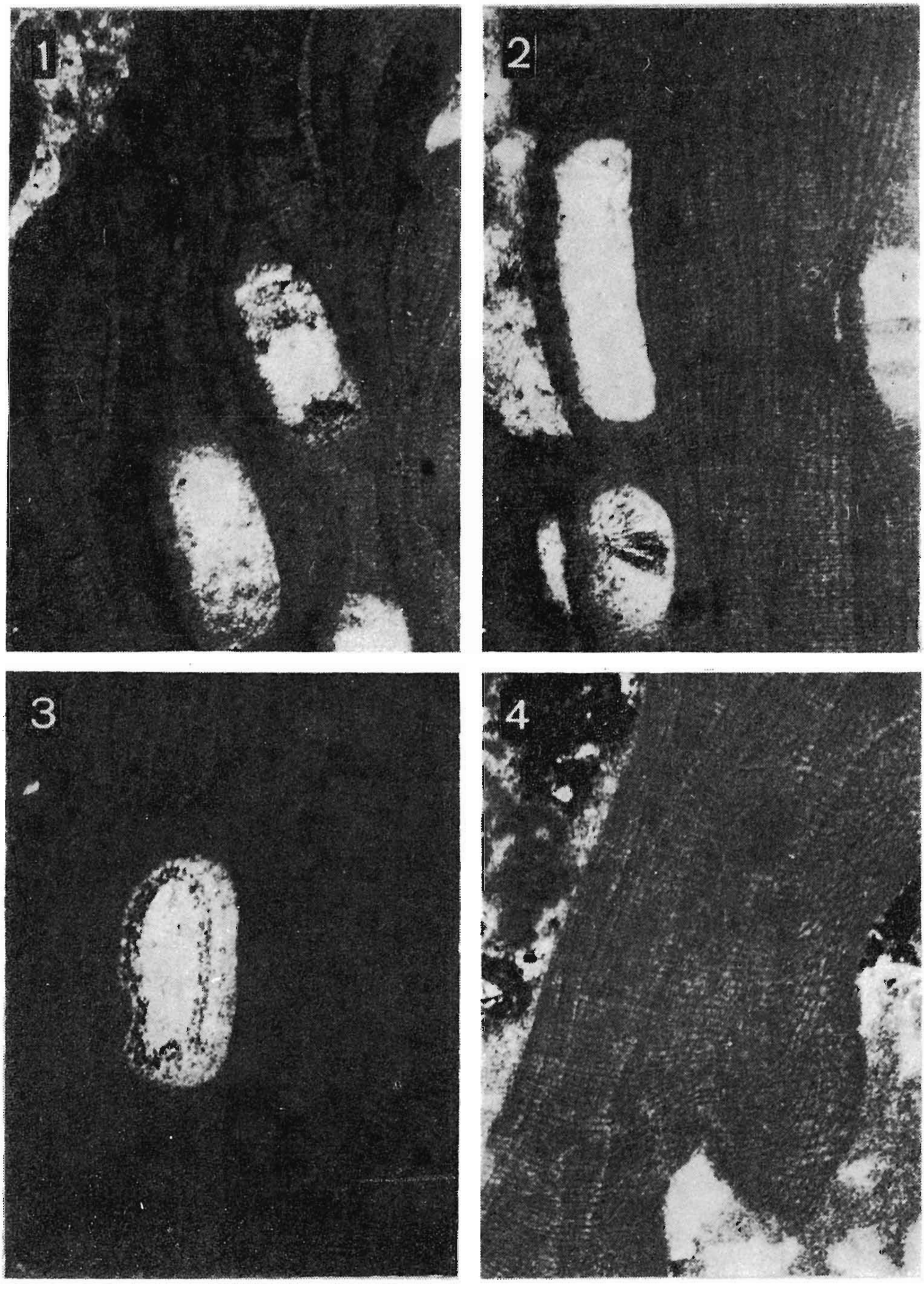
Archaeolithothamnium lvovicum MASLOV; thin sections, ×100

1 — Vertical section of fertile perithallus; Radwanówka

2 — Vertical section showing perithallus with sori and thin hypothallus (*lower part*) and tangential section of the group of sori; Kamienna Hill

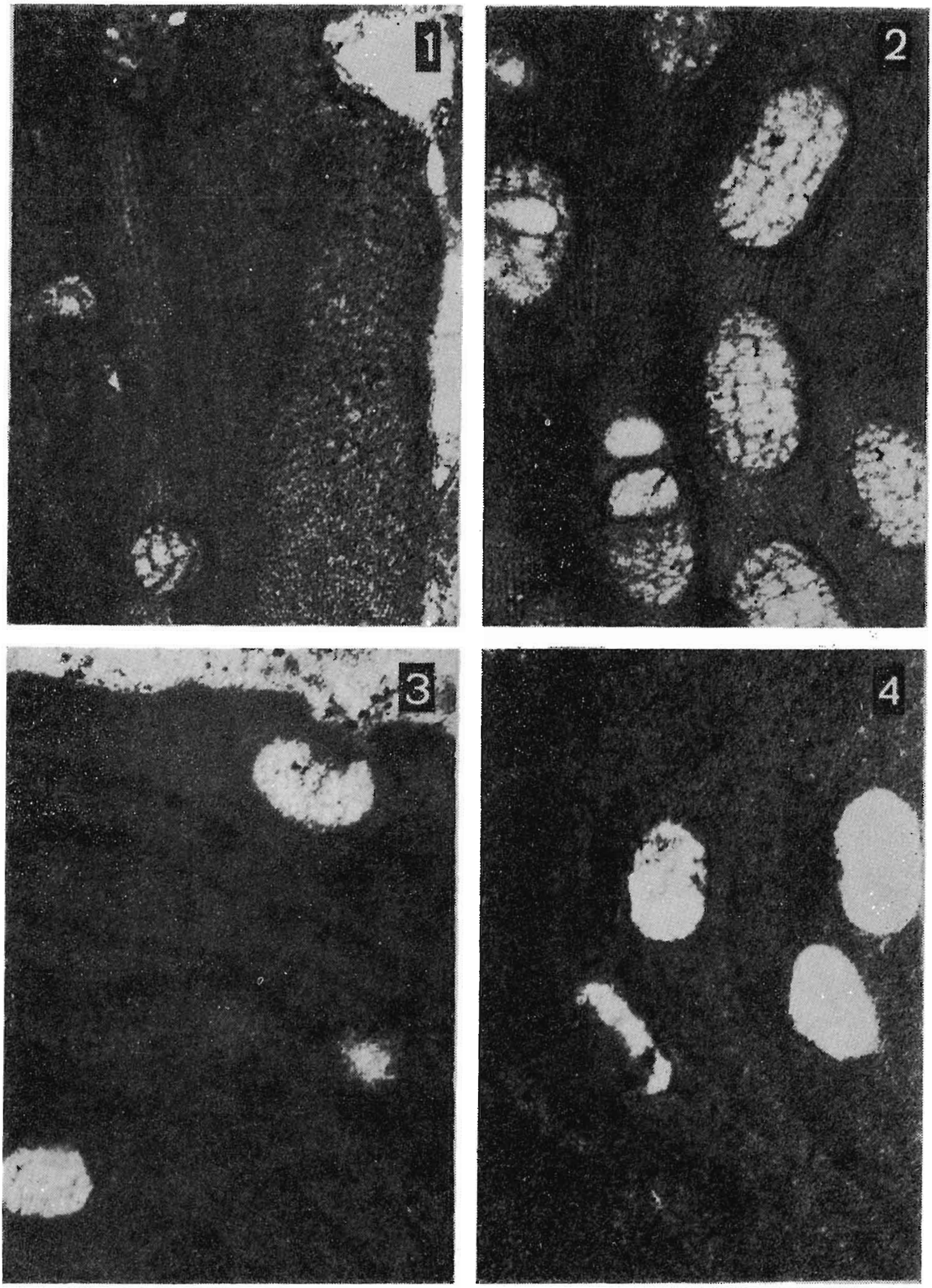
3 — Slightly oblique section of perithallus with sporangia; Węglinek

4 — Vertical section of perithallus (with sporangia) showing regular pattern of cells; Łychów



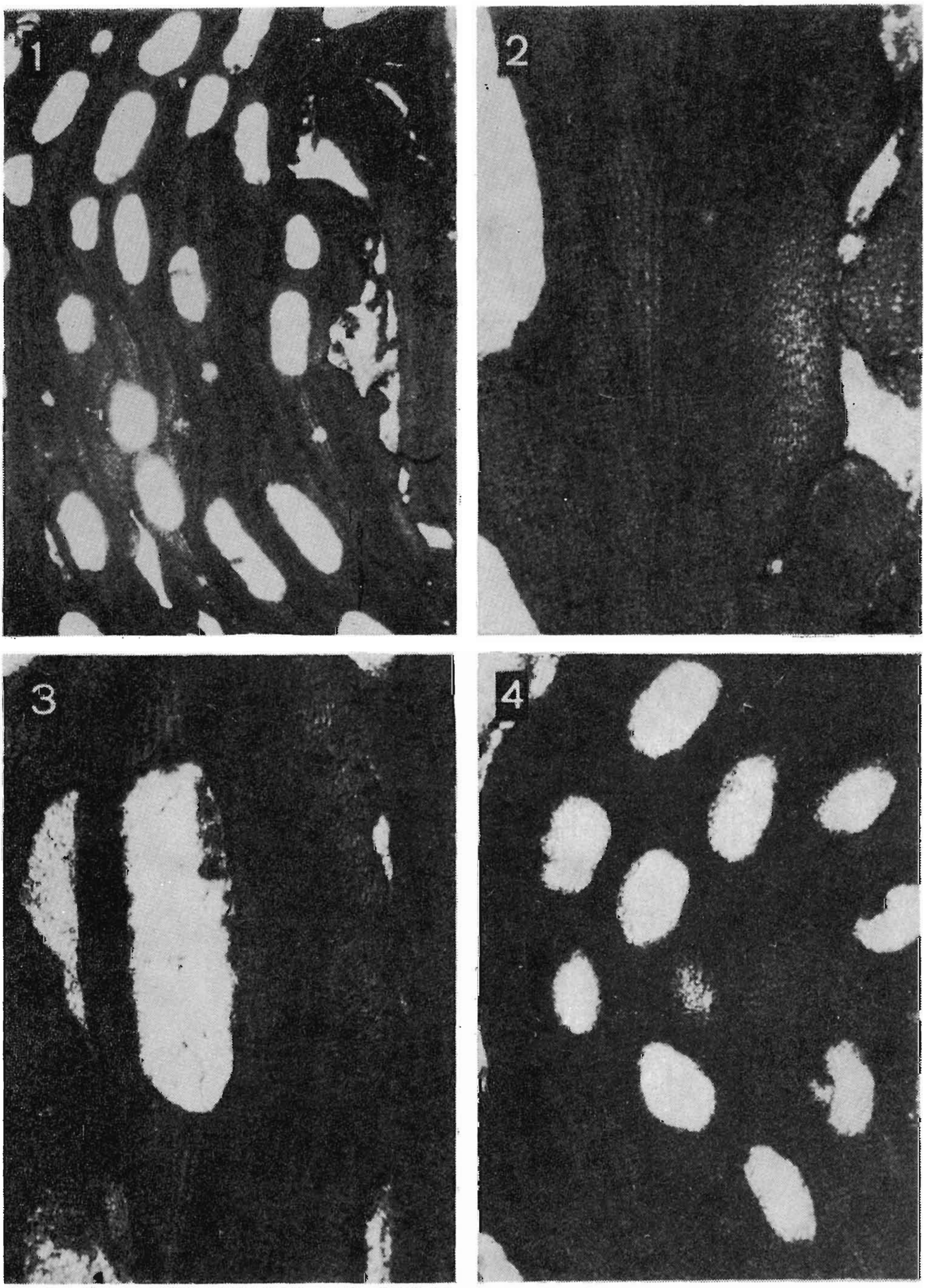
1-2 — *Paleothamnium archaeotypum* CONTI; vertical sections of perithallus showing differentiation of cells arrangements and shape of conceptacles, ×100; Węglinek

3-4 — *Lithothamnium saxorum* CAPEDER: 3 — vertical section of perithallus with conceptacle; 4 — vertical section of hypo- and perithallus; both ×100; Węglinek



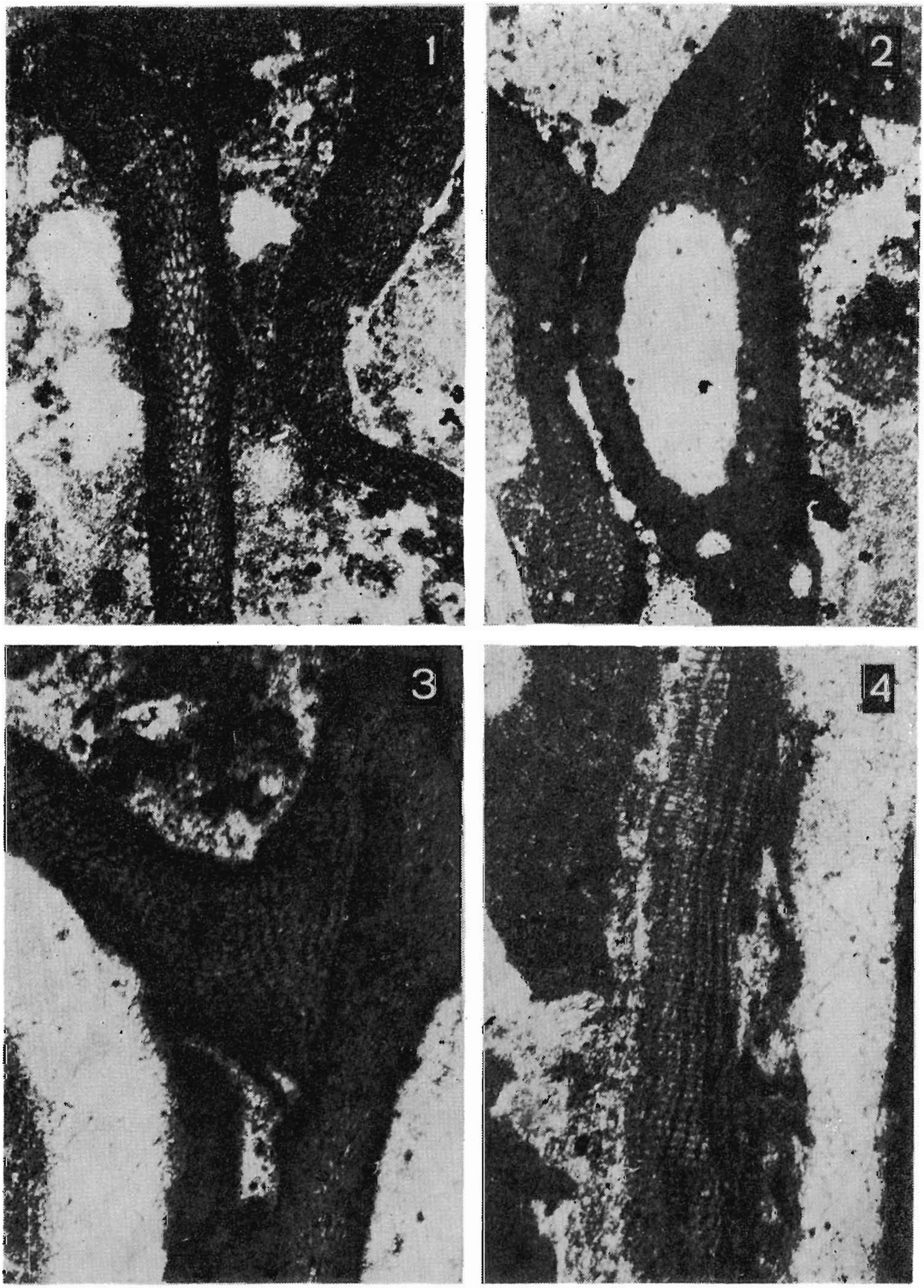
1-2 — *Lithothamnium lacroixi* LEMOINE: 1 — section of hypothallus and perithallus; 2 — section of perithallus with conceptacles (traces of sporangia still visible), ×100; Węglinek

3-4 — *Lithothamnium microphyllum* MASLOV; 3 — oblique section of perithallus with clear zonation pattern; 4 — vertical section of perithallus to show shapes of conceptacles; both ×100; Łychów



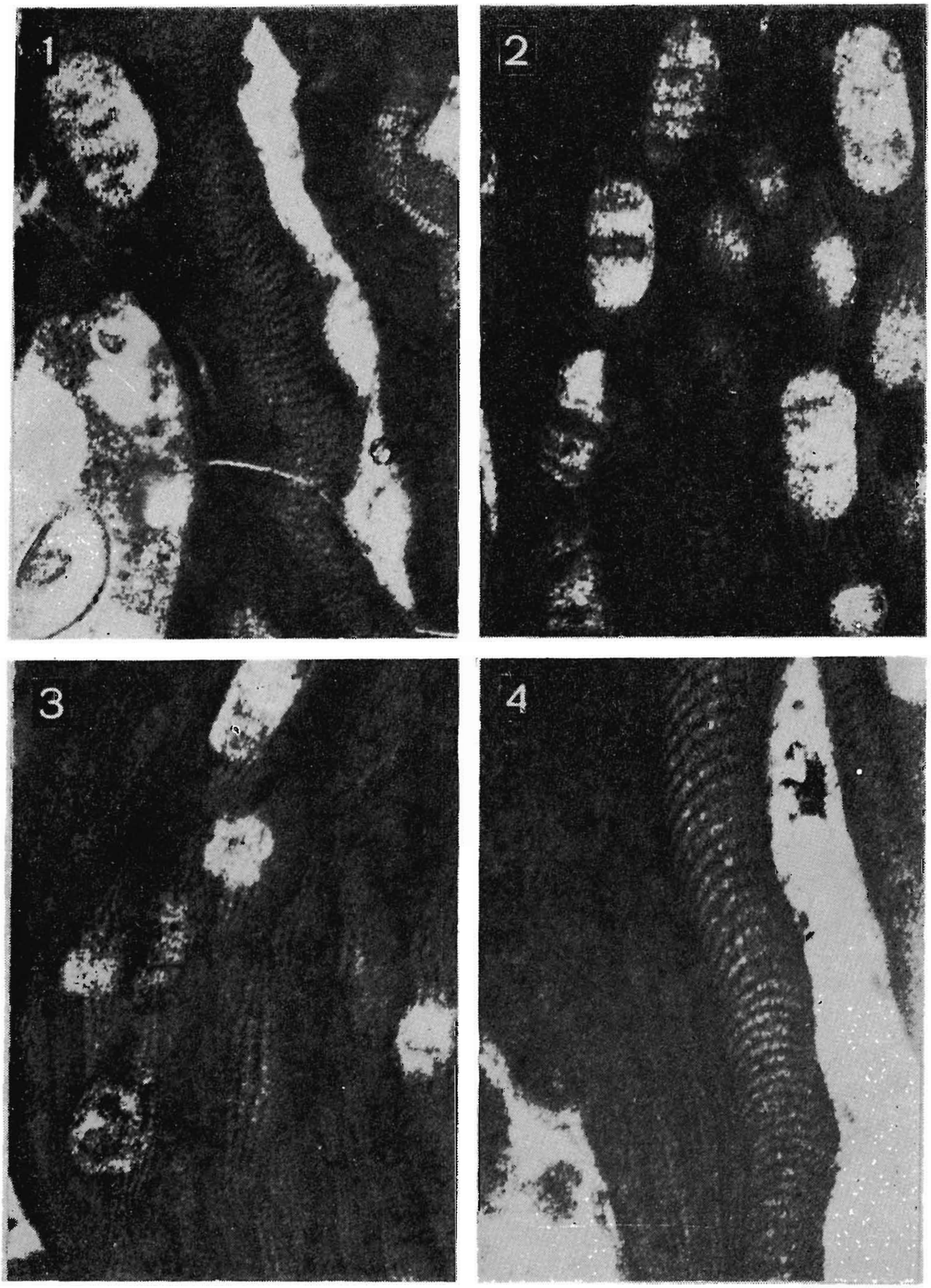
1-3 — *Lithothamnium praefruticulosum* MASLOV: 1 — vertical section of zoned perithallus with abundant conceptacles, ×25; 2 — section of hypothallus and zoned perithallus, ×100; 3 — section of perithallus with single conceptacle, ×100; Radwanówka —

4 — *Lithophyllum* cf. *duplex* MASLOV; slightly oblique section of perithallus with conceptacles, ×100; Łychów



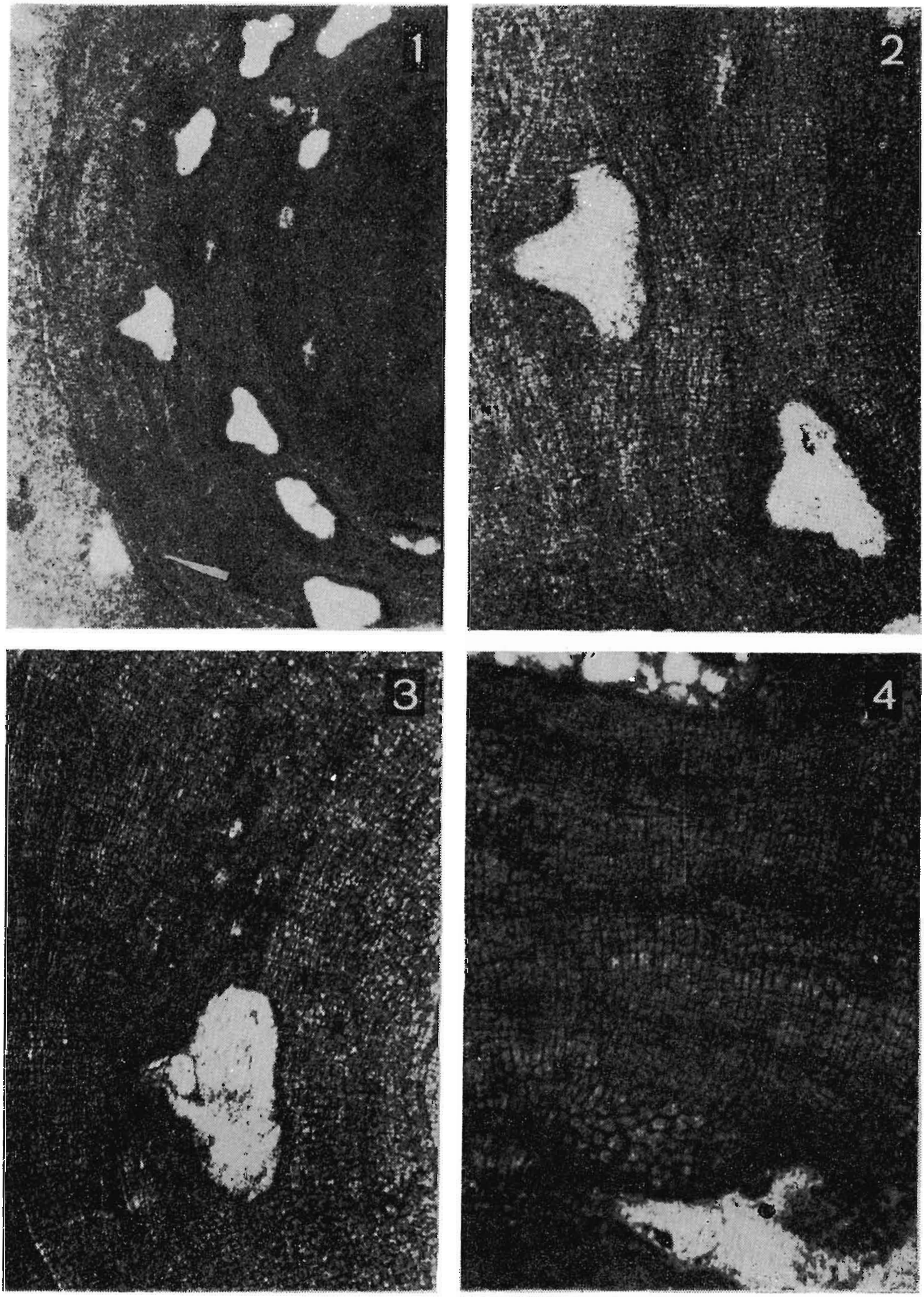
1-3 — *Lithothamnium ishigakiensis* JOHNSON: 1 — oblique section of hypothallus and thin perithallus; 2 — section of thallus with conceptacle; 3 — section of hypothallus with newly formed branch; all ×100; Węglinek

4 — *Dermatolithon natalie* MASLOV; section of perithallus, ×100; Węglinek



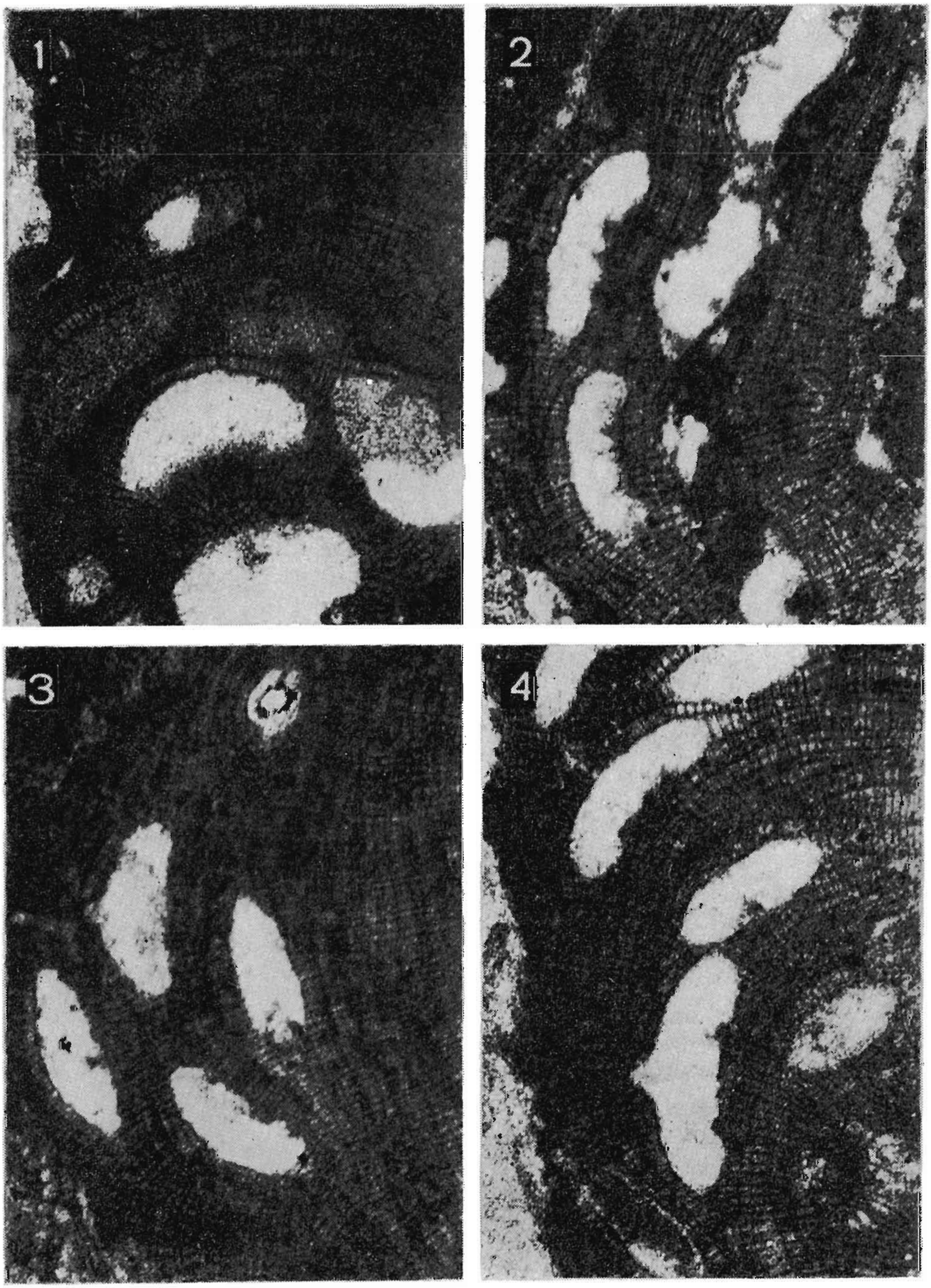
1-3 — *Mesophyllum* cf. *schenki* HOWE: 1 — section of coaxial hypothallus and thin perithallus with a single conceptacle; 2 — section of perithallus with numerous conceptacles, some of them with sporangia; 3 — vertical section of perithallus showing zonation; all ×100; Radwanówka

4 — *Mesophyllum* cf. *roveretoi* CONTI; vertical section showing coaxial hypothallus and zoned perithallus, ×100; Kamienna Hill

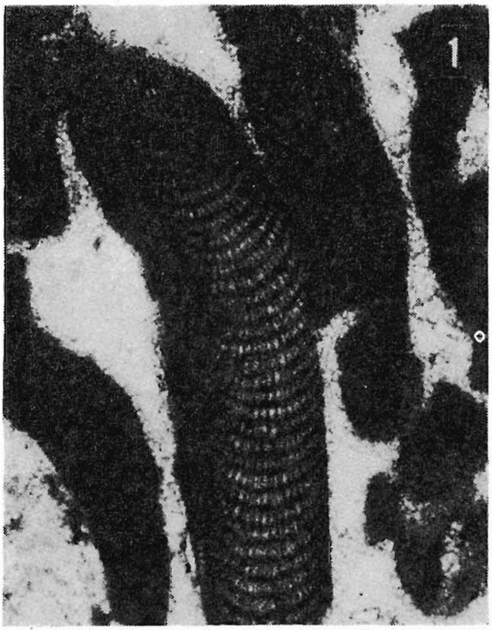


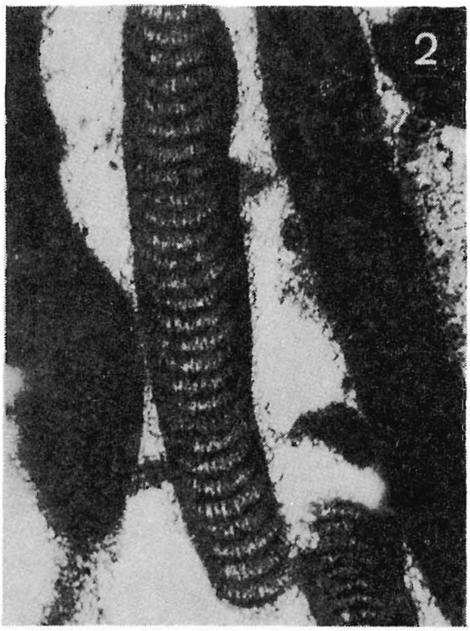
Lithophyllum albanense LEMOINE

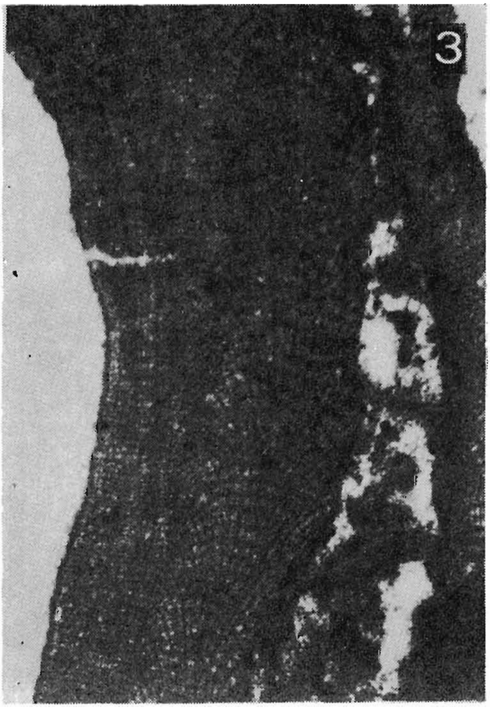
1 — Vertical section of perithallus with numerous conceptacles, ×30; Węglinek
2 — Vertical section of perithallus showing conceptacles with a single opening in the roof, ×100; Łychów
3 — Vertical section of perithallus showing irregular pattern of cells, ×100; Łychów
4 — Oblique section of thin hypothallus and thick perithallus, ×100; Radwanówka

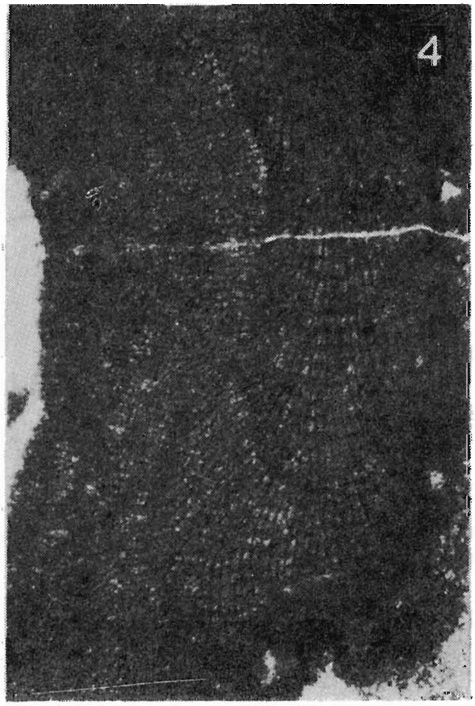


Lithophyllum corculumis MASLOV, to show variability of perithallus (numerous conceptacles visible); all figures ×100, *1* and *3*—*4* from Kamienna Hill, *2* from Radwanówka



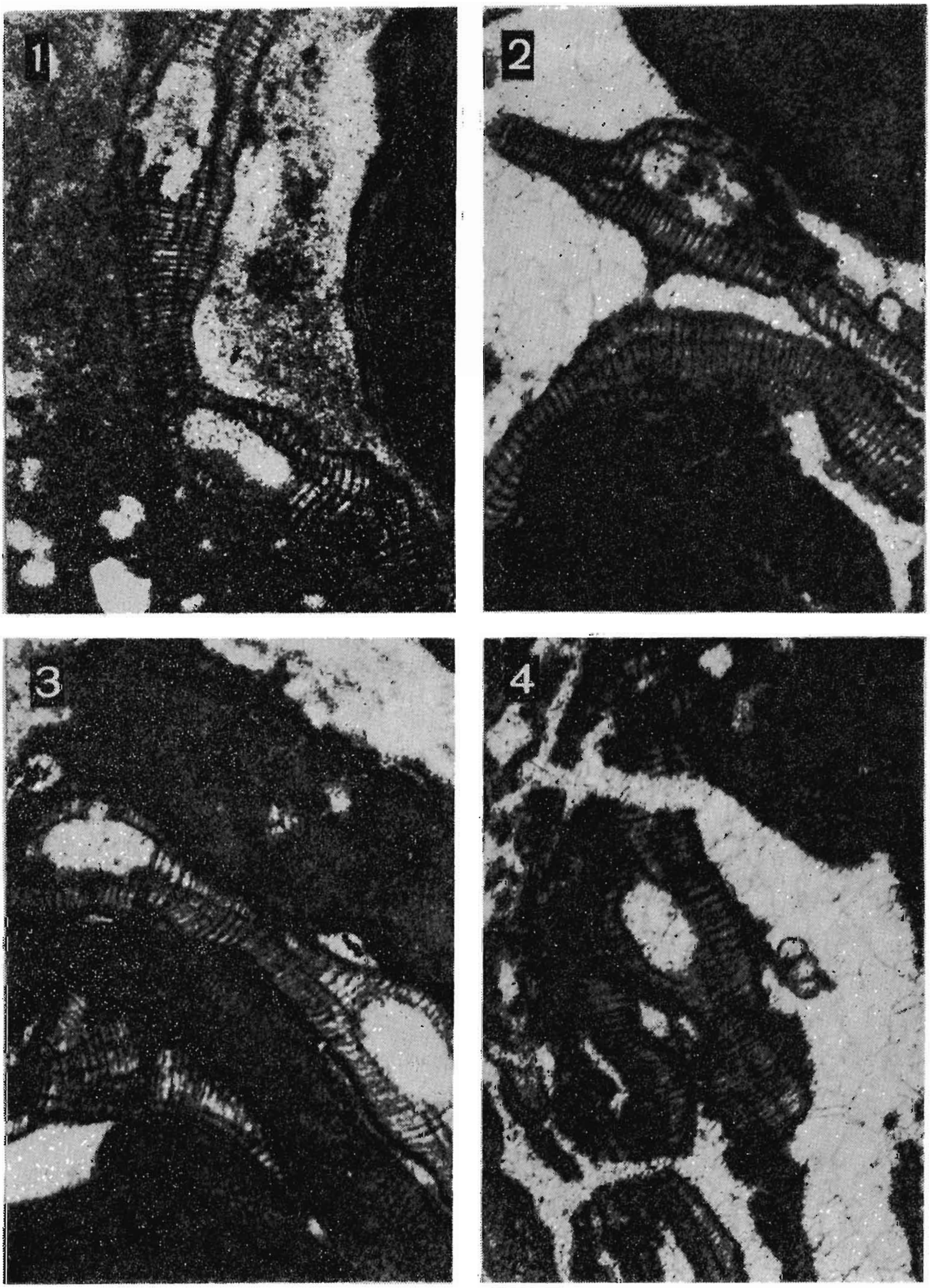




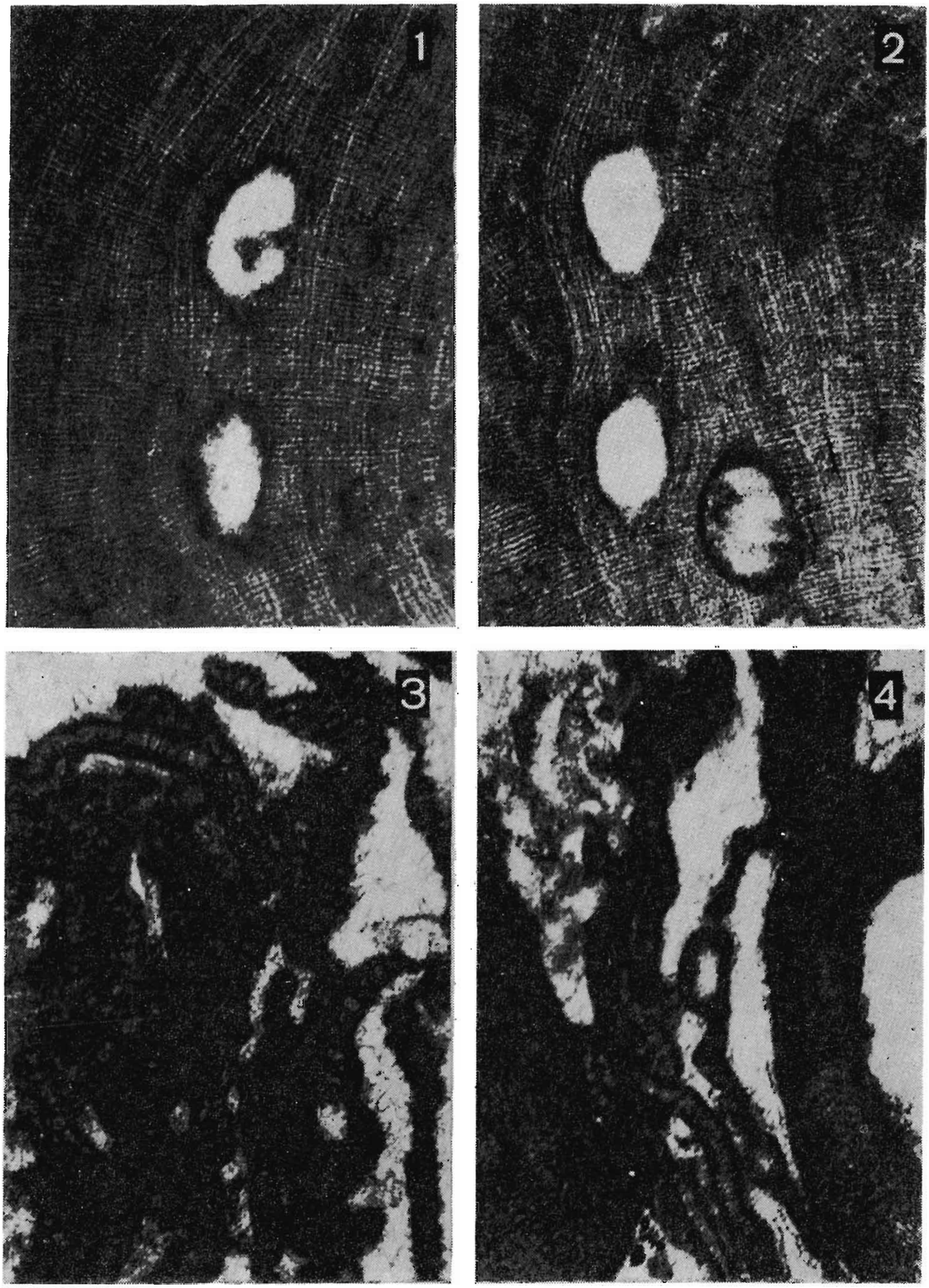


1-2 — *Lithophyllum prelichenoides* LEMOINE: 1 — section of coaxial hypothallus and thin perithallus; 2 — section of coaxial hypothallus; both ×100; Łychów, perireef biocalcarenites

3-4 — *Lithophyllum* cf. *rotundum* CAPEDER: 3 — vertical section of coaxial hypothallus and perithallus; 4 — oblique section of hypo- and perithallus; all ×100; Kamienna Hill

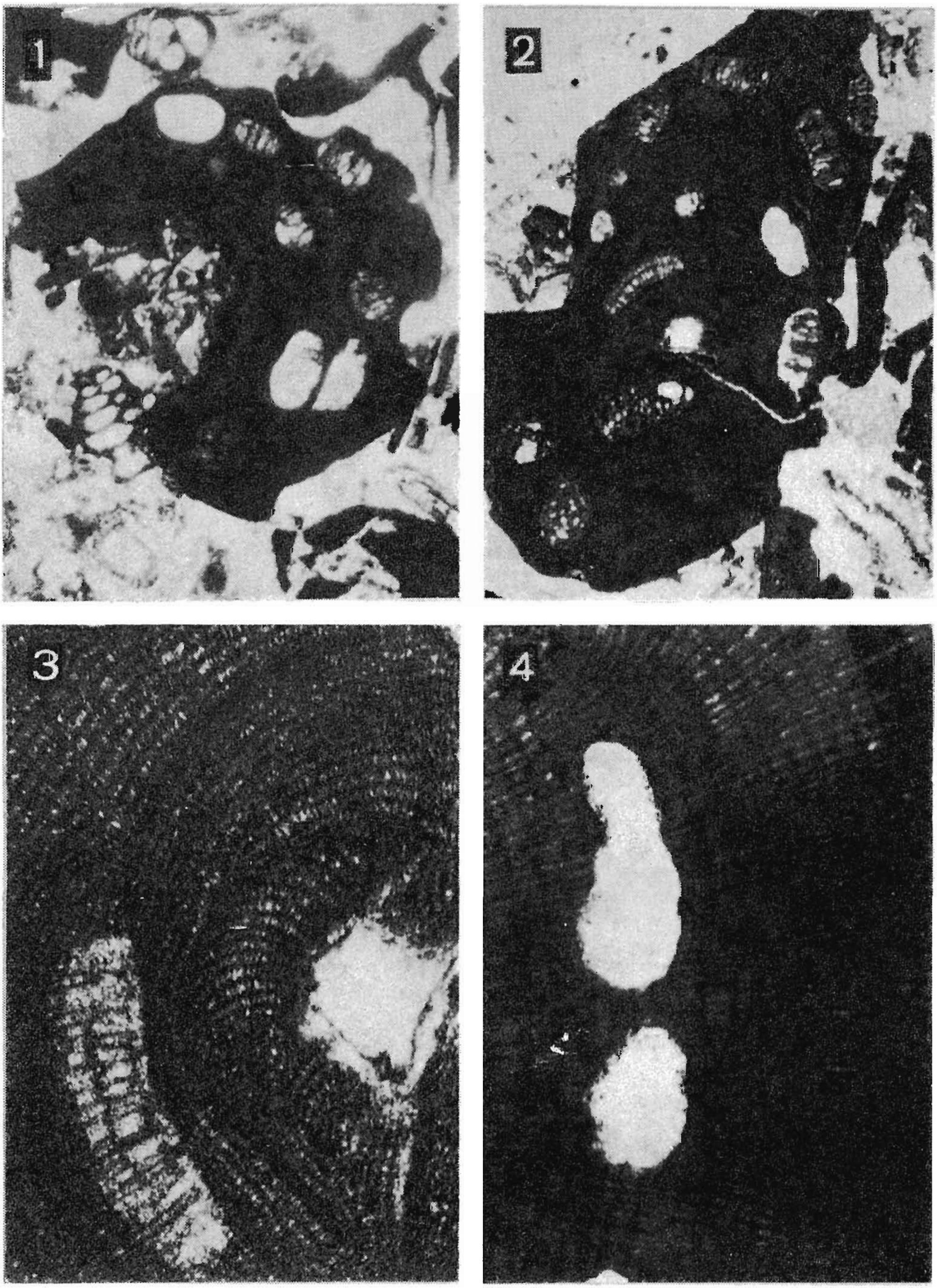


Dermatolithon ucrainicum MASLOV; differently oriented sections of algal thalli, some of which (Figs 1 and 2) show one opening in the conceptacle roof; all figures ×100; *1* from Łychów, *2—4* from Kamienna Hill



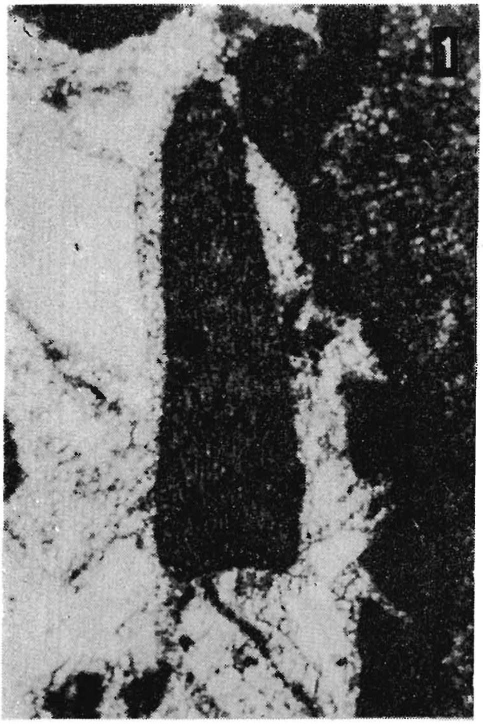
1-2 — *Archaeolithothamnium* sp.: 1 — vertical section of perithallus with reproduction organs; 2 — oblique section of perithallus (showing zonation) with reproduction organs; all ×100; Radwanówka

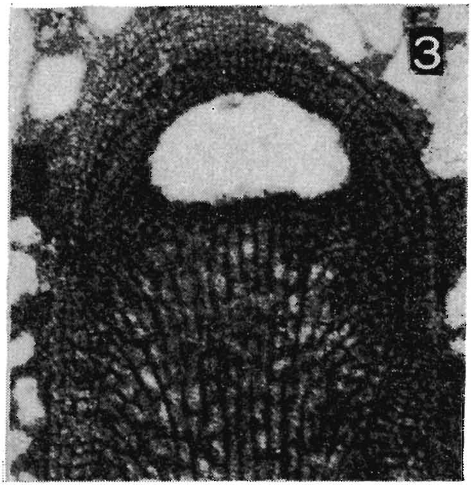
3-4 — *Melobesia badji* MASLOV; sections of several superimposed thalli (in Fig. 4 one conceptacle is visible), ×100; Kamienna Hill



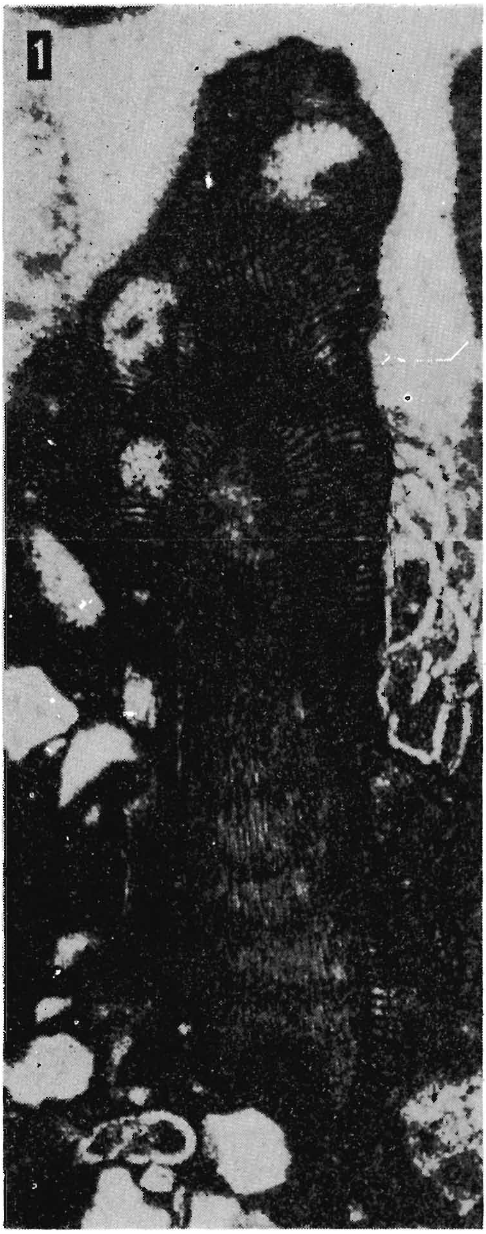
1-3 — *Mesophyllum* sp.: 1-2 — sections of thalli with differently shaped conceptacles, ×25; Radwanówka; 3 — section of coaxial hypothallus and perithallus with a conceptacle; ×100; Radwanówka, perireef biocalcarenites

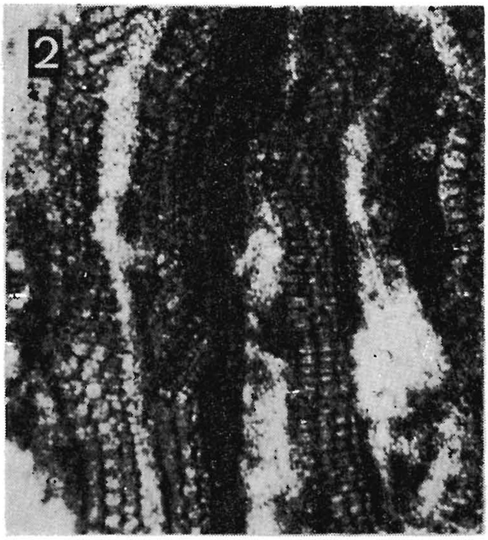
4 — *Lithophyllum* sp.; section of perithallus with conceptacles, ×100; Węglinek

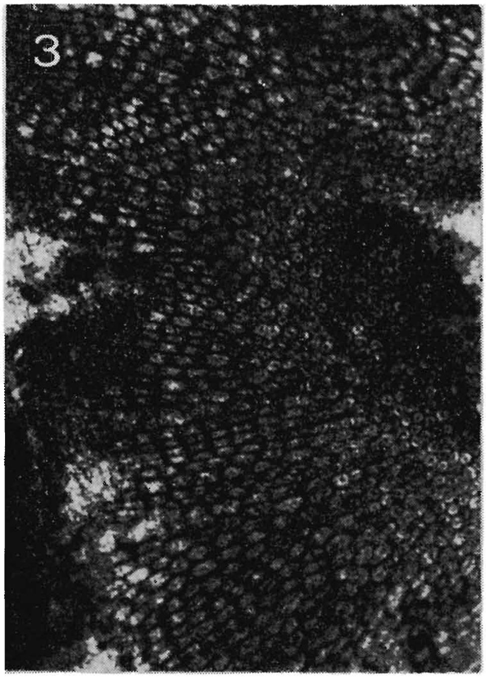




1-2 — *Jania dniestrovica* MASLOV; sections of abraded fragments, ×100; Węglinek
3 — *Jania* sp.; section of terminal segment with reproduction organ, ×250; Węglinek
4a-4b — *Jania ucrainica* MASLOV; section of one segment (Fig. 4a ×100, Fig. 4b ×250); Węglinek







1 — *Jania dniestrovica* MASLOV; section of terminal segment with reproduction organ, ×100; Radwanówka, epireef biocalcarenites

2-3 — *Peyssonnelia antiqua* JOHNSON; 2 — differently oriented thalli; 3 — tangential section of thallus; all ×100; Radwanówka

REMARKS: The investigated specimens agree well with the holotype as well as with subsequent descriptions. Dimensions of rectangular cells of coaxial hypothallus are 9—15µm × 18—36µm; perithallial cells are rectangular to square (7—9µm × 9—11µm).

OCCURRENCE: Miocene of Martinique, Spain, Hungary, Israel, Malta, Algeria, Albania, the Ukraine, and the Pacific Islands; Pliocene of Algeria.

Lithophyllum cf. *duplex* MASLOV, 1962
(Pl. 20, Fig. 4)

cf. 1962. ***Lithophyllum duplex*** sp. nov.; V.P. MASLOV, pp. 82—83. Text-fig. 60, Pl. 21, Figs 2—3.
cf. 1972. ***Lithpohyllum duplex*** MASLOV; F. ORSZAG-SPERBER & A.F. POIGNAT, p. 118.
cf. 1977. ***Lithophyllum duplex*** MASLOV; F. ORSZAG-SPERBER, A.F. POIGNAT & A, POISSON, p. 290, Pl. 4. Fig. 4.

REMARKS: Considering the shape of conceptacles and structure of perithallus the investigated specimen may be classified as *L. duplex* MASLOV. The absence of hypothallus and smaller dimensions of conceptacles (170µm × 97µm) as well as perithallial cells (9—12µm × 14µm) in the investigated specimen do not allow us to be sure about its species assignment.

OCCURRENCE: Badenian of the Ukraine; Miocene of Corsica.

Lithophyllum sp.
(Pl. 22, Fig. 4)

DESCRIPTION: Perithallus built by very regularly disposed rectangular cells (10—25µm × × 25—30µm); conceptacle size is 200µm × 310µm. Hypothallus was not observed.

REMARKS: The absence of hypothallus and the lack of proper section of the conceptacle make the systematic position of this specimen unsure. It is similar to *L. duplex* MASLOV but differs in having more regularly disposed and larger cells.

Genus *Dermatolithon* FOSLIE, 1898
Dermatolithon ucrainicum MASLOV, 1956
(Pl. 26, Figs 1—4)

1956. ***Lithophyllum (Dermatolithon) ucrainicum*** sp. nov.; V.P. MASLOV, pp. 159—160, Text-fig. 80 Pl. 62, Figs. 1—3
1961. ***Lithophyllum (Demartolithon) ucrainicum*** MASLOV; V.P. MASLOV, pp. 75—77, Text-figs 1—2, Pl. 1, Figs 1—2.
1962. ***Lithophyllum (Dermatolithon) ucrainicum*** MASLOV; V.P. MASLOV, p. 95, Text-fig. 79. Pl. 24, Figs 1—2.

DESCRIPTION: Alga occurs in the form of thin crusts among other algal thalli. Hypothallus built by one row of rectangular cells (9—11µm × 13—18µm); perithallus built by 2 or 3 layers of rectangular cells (9—13µm × 18—49µm) — larger cells are disposed near conceptacles. Unipored conceptacles are common and measure 72—120µm × 145—240µm.

REMARKS: The investigated specimens are identical in their structure with specimens previously described by MASLOV; only cell and conceptacle sizes are slightly larger. MASLOV (1956, 1962) attributed this species to the genus *Lithophyllum* but according to the recent investigation of LEMOINE (1970) *Dermatolithon* should be regarded as a generic name, so in the present paper described specimens occur under the name *Dermatolithon ucrainicum* MASLOV.

OCCURRENCE: Badenian of the Ukraine; Sarmatian of Moldavia.

Dermatolithon natalie MASLOV, 1956
(Pl. 21, Fig. 4)

1956. *Lithophyllum (Dermatolithon) natalie* sp. nov.; V.P. MASLOV, p. 160, Text-fig. 81, Pl. 13.
1962. *Lithophyllum (Dermatolithon) natalie* MASLOV; V.P. MASLOV, p. 94, Text-fig. 73, Pl. 23, Figs 1, 3.

REMARKS: Similar to the previously described specimens this alga forms thin crusts up to 200—300μm thick. No hypothallus was observed in the investigated specimens. Perithallial cells are rectangular to square (9—14μm × 11—23μm). Remarks (above) concerning the generic position of *Dermatolithon ucrainicum* MASLOV are valid for this species as well.

OCCURRENCE: Badenian of the Ukraine.

Genus *Melobesia* LAMOUROUX, 1812
Melobesia badji MASLOV, 1956
(Pl. 27, Figs 3—4)

1956. *Melobesia (Lithoporella) badji* sp. nov.; V.P. MASLOV, p. 166, Text-fig. 86, Pl. 54, Figs 1—3.
1961. *Melobesia (Lithoporella) badji* MASLOV; V.P. MASLOV, pp. 77—78, Text-Fig. 3.
1962. *Melobesia (Lithoporella) badji* MASLOV; V.P. MASLOV, pp. 98—99, Text-fig. 77.

REMARKS: General structure of this alga is in accordance with MASLOV's earlier descriptions. Large variability of cell dimensions and very thick cell walls were also observed in the investigated specimens. MASLOV (1962) noted only sterile crusts of this species, however conceptacles were observed in the investigated material from the Roztocze. They measure 60μm × 100μm.

According to recent investigations (LEMOINE 1976) this species should be included in the genus *Melobesia* and excluded from the subgenus *Lithoporella* which is regarded as a genus different from *Melobesia*.

OCCURRENCE: Sarmatian of Podolia and Moldavia, Tschorkak of Georgia.

Subfamily **Corallinoideae** LEMOINE, 1939
Genus *Jania* LAMOUROUX, 1816
Jania dniestrovica MASLOV, 1961
(Pl. 29, Figs 1—2; Pl. 30, Fig. 1)

1961. *Jania dniestrovica* sp. nov.; V.P. MASLOV, pp. 78—79, Text-figs 4—6. Pl. 1, Figs 3—4.
1962. *Jania dniestrovica* MASLOV; V.P. MASLOV, pp. 106—108, Text-fig. 85, Pl. 29, Fig. 1; Pl. 30, F [illegible]—3, 7—8.

REMARKS: The structure and cell sizes of hypothallus of the investigated specimens agree with previously described material. Measurements of perithallial cells were not possible in the investigated material.

OCCURRENCE: Badenian of the Ukraine.

Jania sp.
(Pl. 29, Fig. 3)

DESCRIPTION: Terminal segment of alga with rounded tip. Cell walls of medullary hypothallus placed on different levels, cells rectangular (18—23μm × 36—37μm). Even nearby placed cells may differ considerable in length. Perithallial cells square (13—18μm × 13—18μm); dimensions of conceptacle are 227μm × 133μm.

REMARKS: The investigated specimen is close in its structure to *Jania toltrica* MASLOV but cell measurements are completely different, much larger in our specimen. The highly variable length of hypothallial cells also differentiates the investigated specimen from *J. toltrica*. This marks the discovery of conceptacles in fossil specimens of the genus *Jania* (*see* MASLOV 1962).

Family **Squamariaceae** ZANARDINI, 1841
Genus *Peyssonnelia* DECAISNE, 1841
Peyssonnelia antiqua JOHNSON, 1964
(Pl. 30, Figs 2—3)

1964c. *Peyssonnelia antiqua* n. sp.; J.H. JOHNSON, p. 214, Pl. 1, Fig. 2.
1965. *Peyssonnelia antiqua* JOHNSON; M. DENIZOT & M. MASSIEUX, pp. 96—98, Pl. 1, Figs 1—9; Pl. 2, Figs 10—14
1967b. Squamariaceae; V.I. MASTRORILLI, Pl. 41, Figs 3—5.
1977. *Peyssonnelia antiqua* JOHNSON; M. LEMOINE, pp. 33—34.
1978. *Peyssonnelia antiqua* JOHNSON; S. LESZCZYŃSKI, Pl. 1, Fig. 1.

REMARKS: Structure of the thalli of the investigated specimens does not differ from those previously described. Hypothallial cell dimensions are 25µm×40µm; lower perithallial cells measure 12µm×25µm, in the upper part 13µm×13µm. These measurements agree well with those given in the literature. The thickness of thalli is 120µm to 300µm.

OCCURRENCE: Paleocene of Iraq and Guatemala; Eocene of France, Italy, and Poland; Oligocene of Italy and Tunisia; Miocene of the Carpathians in Poland; Oligocene (?) of Yugoslavia.

FORAMINIFERS

Arenaceous foraminifers, elphidids and miliolids were commonly observed in thin sections. Also very common are encrusting forms such as *Nubecularia* sp. (Pl. 32, Fig. 4), *Miniacina miniacea* (PALLAS) (Pl. 31, Figs 1-4), *Cibicides* sp. (Pl. 32, Fig. 3), and presumably also planorbulinids. All these forms are typical of very shallow sea and occur even in the littoral zone (BOLTOVSKOY & WRIGHT 1976). The most characteristic species is *Miniacina miniacea* (PALLAS), hitherto unknown from Poland. This sessile species is common today in shallow zones of warm and tropical seas (HAGEMAN 1976, HASEGAWA & TAKAYANAGI 1981) and occurs also in the Mediterranean (PÉRÈS & PICARD 1964, MURRAY 1973) where it is a typical element in cryptic habitats (PÉRÈS & PICARD 1964, BLANC-VERNET 1969). Closely related and similar morphologically *Homotrema rubrum* (LAMARCK) is a common encruster in cryptic environments of the Recent coral and algal-vermetid reefs (MURRAY 1973, GINSBURG & SCHROEDER 1973).

Additionally, the most common foraminifers (identified by Docent J. SZCZECHURA) from washed samples are as follows: *Elphidium* div. sp., *Cibicides lobatulus* (WALKER & JACOB), *Cibicides pseudoungerianus* (CUSHMAN), *Rosalina globularis* D'ORBIGNY, *Planulina* sp., *Reussella spinulosa* (REUSS), polymorphinids, miliolids, *Asterigerina palnorbis* D'ORBIGNY, *Protoelphidium subgranosum* (EGGER), *Cassidulina* sp., *Fursenkoina schreibersiana* (CZJZEK), *Ammonia beccari* (LINNAEUS), *Hanzawaia boueana* (D'ORBIGNY), *Glabratella imperatoria* (D'ORBIGNY), *Bolivina* div. sp., *Cymbalopora* sp., *Textularia* sp., *Glabratella* sp., *Discorbis discoides* (D'ORBIGNY), *Eponides repandus* (FICHTELL & MOLL), *Neoconorbina* cf. *miocenica* KRASHENNIKOV, *Cancris auriculatus* (FICHTELL & MOLL).

Such a species composition indicates shallow water environments (MURRAY 1973, BOLTOVSKOY & WRIGHT 1976) and the presence of such genera as *Asterigerina*, *Discorbis*, *Elphidium*, *Nubecularia* and other miliolids clearly points to the existence of submarine flora (PHLEGER 1960, MURRAY 1973, BRASIER 1975, BUZAS & *al.* 1977). Interesting is the close similarity of the studied foraminiferal assemblage to that from coral reefs (*see* WEISS & STEINKER 1977, STEINKER & *al.* 1977) and a small resemblance with the foraminiferal assemblage found in the algal cup reefs (*see* GINSBURG & SCHROEDER 1973). Planktic foraminifers do not occur in the investigated rocks, this indicates a proximal shoreline and very shallow water conditions.

SPONGES

In addition to the boring sponges *Cliona*, other forms also probably occurred what may be indicated by the presence of such usually sponge associated gastropods as *Cerithiopsis* and *Emarginula*.

CORALS

Corals are very rare in the samples, and only few small solitary specimens were obtained.

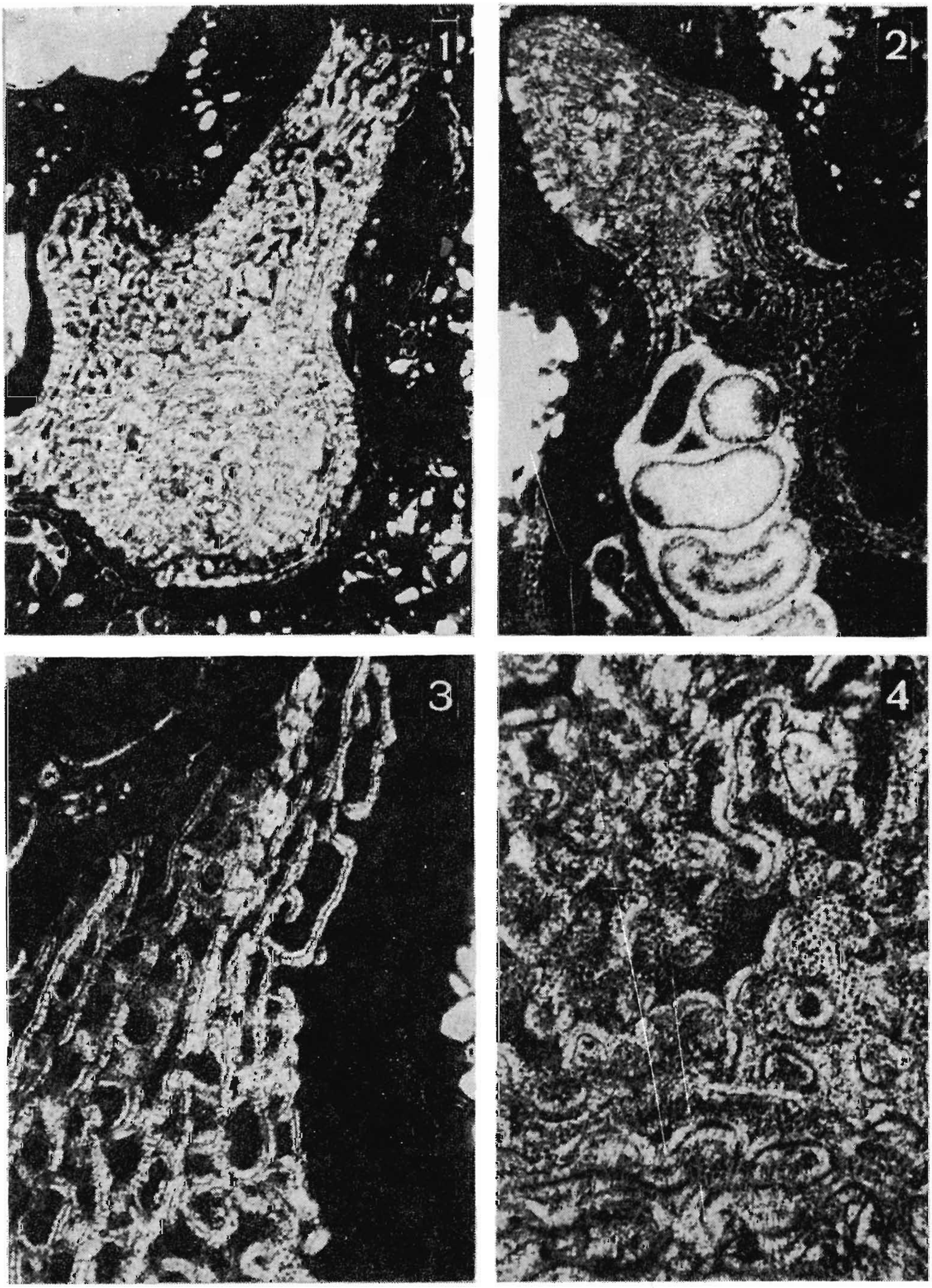
SERPULIDS

Serpulid tubes are one of the most important encrusters of the reef frame and are also very common in the detrital internal sediments. The following genera were recognized: *Serpula*, *Pomatoceras*, *Protula*, *Vermilliopsis*, *Vermilia*, and *Spirorbis*.

BRYOZOANS

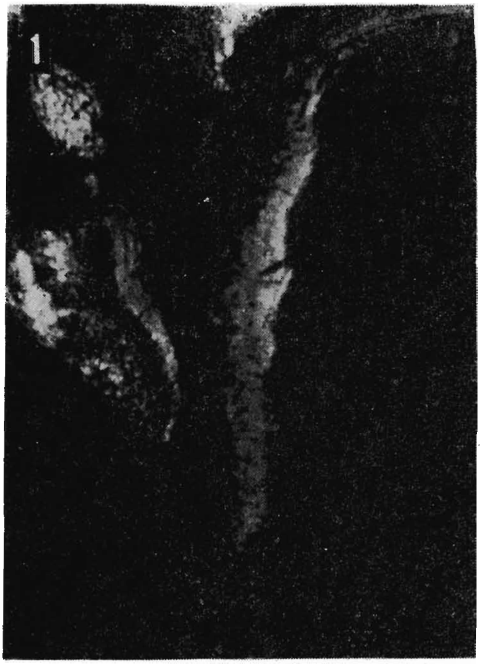
Bryozoans are present both in the internal sediments and incorporated into the reef frame as common encruster. In some samples they are volumetrically equal to/or dominate molluscs. The most common is *Schizoporella* sp. which occurs as multilamellar encrustations of cavity walls or hemispherical masses attached to the algal frame. It is present, however, also in the internal sediments. This suggests that the bryozoan was encrusting some unpreserved substrate, presumably submarine flora. The bryozoans of the genus *Schizoporella* are known today as a reef encruster and sometimes are even able to build small bryozoan bioherms (HOFFMEISTER & *al.* 1967, CUFFEY & *al.* 1977).

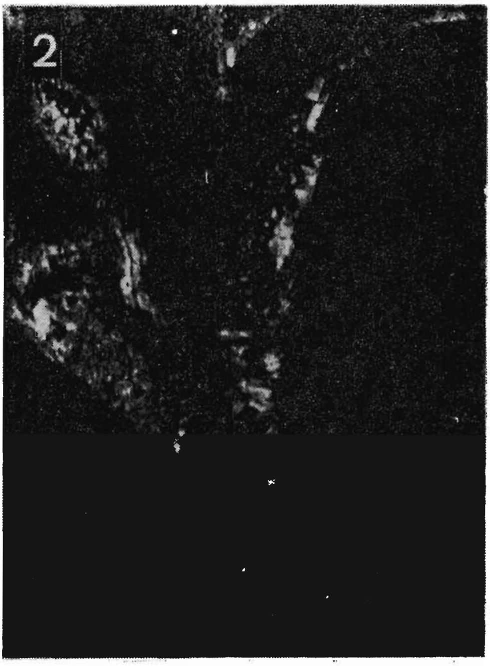
Two morphological forms of bryozoans, celleporiform and reteporiform dominate in the internal sediments (for this classification *see* STACH 1936, LAGAAIJ & GAUTIER 1965, SCHOPF 1969, POUYET 1973). Less common elements are membraniform and cellariform specimens. Numerous bryozoans lack calcified lower walls demonstrating that they were encrusting some unpreserved objects, most probably submarine flora. Such a supposition is supported by the shape of some

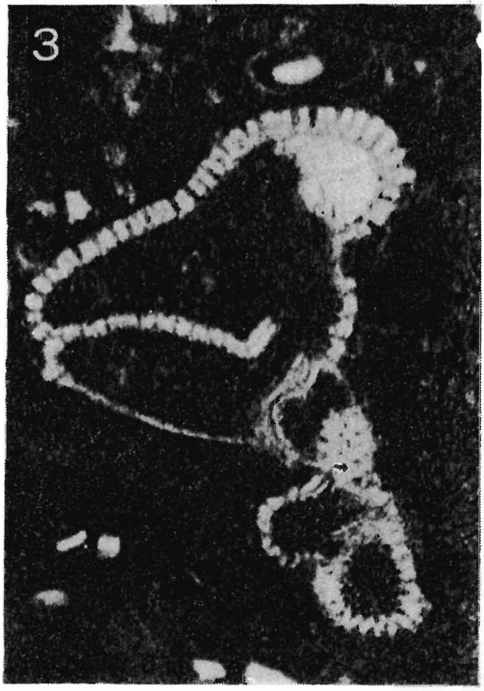


Miniacina miniacea (PALLAS) from Węglinek

1 — Vertical section, ×30; **2** — Foraminifer overgrowing vermetid shell; vertical section, ×25; **3** — Details of structure, vertical section, ×100; **4** — Details of structure, tangential section, ×100







1-2 — Inorganic encrustations (?phosphates) of algal thalli; thin section (*1* uncrossed nicols; *2* crossed nicols), ×100; Węglinek

3 — Sessile foraminifer (?*Cibicides*) overgrowing algal thallus; thin section, ×100; Węglinek

4 — Sessile foraminifer *Nubecularia* sp. overgrowing algal thallus; thin section, ×100; Węglinek colonies which show a round hole left by an unpreserved cylindrical object which they encrusted or a U-shaped cleft between laminae of colony.

The celleporiform colonies are characteristic of littoral and sublittoral zones in areas where the sedimentation rate is low and resedimentation unimportant, features commonly associated with medium energy hydrodynamic conditions (LAGAAIJ & GAUTIER 1965, SCHOPF 1969).

Reteporiform colonies occur both in littoral and sublittoral zone habitats and are associated with hard substrates in areas of low sedimentation and rather high hydrodynamic energy (STACH 1936, LAGAAIJ & GAUTIER 1965, SCHOPF 1969). Cellariform growth-forms are also typical littoral and shallow sublittoral zones characterized by high hydrodynamic energy (SCHOPF 1969).

Such growth-form composition as presented above indicates low detrital sedimentation and high hydrodynamic energy (but of course microenvironments with very low energy were also present inside cavities which existed in the reef body) in the shallow sublittoral zone. Similar growth-form composition of bryozoans was found by PEDLEY (1976) in a coralline algal bioherm from the Miocene of Malta, but inferred a depth of 20 to 50 m — much more than that postulated here for the algal-vermetid reefs from Roztocze.

As is shown, bryozoans played important and dual role in the algal-vermetid reefs. They were contributors to the reef frame as well as to the detrital internal sediments. Similar to their role in Recent reefs (JACKSON & *al.* 1971; CUFFEY 1972, 1977; SCOFFIN & GARRETT 1974; ZIEGLER & *al.* 1974; VASSEUR 1977) they most probably were part of cryptic associations.

BRACHIOPODS

Small brachiopods are common in the internal sediments of the reefs. They are represented by several species of the genera *Megathiris, Argyrotheca* and *Megerlia* (determined by M. A. BITNER). Specimens of *Crania* are rare. This association resembles Recent shallow water brachiopod assemblage from the Mediterranean (CAULET 1967, LOGAN 1979). The brachiopods from the Badenian algal-vermetid reefs were also part of cryptic fauna, similar to the congeneric brachiopods in Recent reefs and the biohermal deposits (LOGAN 1975, 1977).

CIRRIPEDES

Cirripedes are represented by ubiquitous plates of *Verruca* sp. and rare valves of *Lepas miocaenicus* (REUSS). Only rarely were whole shells of *Verruca* sp., growing on cavity walls observed, and they should be also regarded as cryptic element. This is suggested by the life habit of the morphologically similar Recent species *Verruca stroemia* (O. F. MÜLLER) from the Mediterranean — a species which occurs under rocks of the littoral zone (*see* RIEDL 1963).

Both *Verruca* and *Lepas* were previously noted in the deposits of Miocene age in Poland, the first genus being very common (*see* BAŁUK & RADWAŃSKI 1968, 1977; BAŁUK 1975; RADWAŃSKI 1977a; JAKUBOWSKI & MUSIAŁ 1977, 1979a, b).

OSTRACODES

Among ostracodes the most common forms are (determined by Docent J. SZCZECHURA) as follow: *Cnestocythere* sp., *Loxoconcha* sp., *Pseudocythere* sp., *Aurilia* sp., *Xestoleberis* sp., *Sclerochilus* sp., *Triebelina raripila* (G. W. MÜLLER), *Hemicytherura* sp., *Bairdia* sp., *Paracytherida triquetra* (REUSS), *Hermanites haidingeri* (REUSS), *Flexus triebeli* (RUGGIERI), *Phlyctenophora* sp., *Ponthocythere* sp., *Quadracythere* sp. They represent a shallow water association with clearly phytophile elements (J. SZCZECHURA, *personal communication*).

MOLLUSCS

Characteristic of the most common molluscs (*see* Table 1—3) are given below without paleontological description which are presented by KRACH (1981).

HALIOTIDS

Although rare in the other Miocene deposits of Poland these gastropods are numerous and form very characteristic element of the macrofauna in the Roztocze algal-vermetid reefs. In older papers those reefs are even called the haliotid reefs (*see* KRACH 1962b, BIELECKA 1967). According to KRACH (1981) two subspecies *Haliotis tuberculata tauroplana* SACCO and *Haliotis tuberculata volhynica* (EICHWALD) are present. Considering the variability of the Recent haliotids (*see* COX 1962), differences observed in the collected material suggest that two distinct species, also different from the Recent forms, occur in the algal-vermetid reefs. Coexistence of many closely related species of haliotids in the same area is known among Recent species (SHEPARD 1973).

Recent haliotid gastropods occur along the rocky shores of all the oceans but only one species is known from the Mediterranean, viz. *Haliotis lamellosa* which lives on the rocky bottom, commonly under blocks of rock (STARMÜHLNER 1963). The closely related Atlantic species *Haliotis tuberculata*, lives in waters up to 12—13 m of depth and in fissures of rocks and under large blocks, seldom on their surface (FRETTER & GRAHAM 1976). These habitats are typical for haliotids in other geographic areas (COX 1962, SHEPARD 1973, MORTON & MILLER 1973).

All haliotid gastropods are herbivorous and feed on red algae (but other than coralline algae) but are also able to utilize organic detritus as food (FRETTER & GRAHAM 1976, SHEPARD 1973). Haliotids, although moving freely, are restricted to their teritory through their whole life, moving in a very limited area, so they practically may be regarded as sessile organisms (POORE 1972, SHEPARD 1973).

ASTRAEA MAMMILLARIS (EICHWALD)

This gastropod is the second characteristic reef dwelling mollusc in the Roztocze reefs. Hitherto included in the genus *Turbo*, it is placed by the author into the genus *Astraea* on the basis of the morphology of the shell. The sculpture of *Astraea mammillaris* (EICHWALD) is very variable and expresses itself in the degree of rib development and separation of coils. This species has a thick, calcareous operculum accumulations of which are sometimes observed in the reef caverns (Pl. 5, Fig. 2).

Recent turbinids are herbivorous and occur commonly on hard substrates, especially in coral reefs (FISHER & SALVAT 1971, TAYLOR 1971, FELL 1975). *Astraea rugosa* (LINNAEUS) a species very close morphologically to the collected specimens, occurs today in the Mediterranean (STARMÜHLNER 1963). Turbinids are also very common and are a characteristic element of Recent algal ridge fauna (TAYLOR 1968, FISHER & SALVAT 1971).

TROCHIDS

Trochids are represented in the Roztocze reefs by numerous individuals which belong to at least 10 species of the genera *Clanculus*, *Jujubinus*, *Gibbula*, and *Calliostoma*. These small epibenthic gastropods live today on various substrates, but commonly on rocks with algal cover (DAVITASHVILI & MERKLIN 1968, FRETTER & GRAHAM 1977). They feed on microscopic algae and organic detritus, some calliostomids may be also predators feeding on sponges, hydroids and sea anemones (FRETTER & GRAHAM 1977). Trochids occur in all climatic zones (DAVITASHVILI & MERKLIN 1968), representatives of the genus *Clanculus* are very common in tropical regions (FELL 1975) but also live in the Mediterranean (STARMÜHLNER 1963). Trochids are also typical of the algal ridge zone of the Recent coral reefs (TAYLOR 1968, FISHER & SALVAT 1971).

Table 1

Frequency (in %) and ecological classification of bivalves of the reef assemblage
SF — suspension feeders, **H** — herbivores, **EP** — ectoparasites, **PR** — predators, **EPI** — epifauna, **INF** — infauna

Pycnodonte navicularis (BROCCHI)	10.65	SF	EPI
Musculus biformis (REUSS)	9.65	SF	EPI
Striarca lactea (LINNAEUS)	2.99	SF	EPI
Chlamys multistriata (POLI)	2.47	SF	EPI
Hiatella arctica (LINNAEUS)	2.32	SF	EPI
Barbatia barbata (LINNAEUS)	1.61	SF	EPI
Coralliophaga lithophagella (LAMARCK)	1.53	SF	EPI
Barbatia praenominata (COSSMANN & PEYROT)	1.47	SF	EPI
Venus cincta EICHWALD	0.99	SF	INF
Gregariella coralliophaga (GMELIN)	0.96	SF	INF
Chama gryphoides LINNAEUS	0.80	SF	EPI
Gastrochaena dubia PENNANT	0.73	SF	INF
Lima lima (LINNAEUS)	0.71	SF	EPI
Barbatia clathrata (DEFRANCE)	0.70	SF	EPI
Timoclea sobieskii (HILBER)	0.65	SF	INF
Limopsis anomala (EICHWALD)	0.62	SF	INF
Cardita rudista (LAMARCK)	0.46	SF	EPI
Plicatula ruperella DUJARDIN	0.46	SF	EPI
Modiolus hoernesi (REUSS)	0.45	SF	EPI
Lithophaga lithophaga (LINNAEUS)	0.25	SF	INF
Coralliophaga transylvanica (HÖRNES)	0.15	SF	EPI
Cardium sp.	0.14	SF	INF
Lutetia nitida (REUSS)	0.14	SF	INF
Ervilia pusilla (PHILIPPI)	0.13	SF	INF
Limatula subauriculata (MONTAGU)	0.07	SF	EPI
Glycymeris deshayesi (MAYER)	0.07	SF	INF
Crenella sp.	0.07	SF	EPI
Spondylus sp.	0.05	SF	EPI
Cuspidaria costellata DESHAYEUX	0.04	SC	INF
Chlamys cf. *lilli* (PUSCH)	0.04	SF	EPI
Parvilucina dentata (DEFRANCE)	0.04	SF	INF
Sphenia sp.	0.04	SF	EPI
Circe minima MONTAGU	0.04	SF	INF
Isognomon sp.	0.02	SF	EPI
Musculus sp.	0.02	SF	EPI
Ctena decussata (DA COSTA)	0.01	SF	INF
Chlamys sp.	0.01	SF	EPI
Pecten sp.	0.01	SF	EPI
Cardium papillosum POLI	0.01	SF	INF

BITTIUM RETICULATUM (DA COSTA)

These small cerithids are ubiquitous in both recognized assemblages. Recent species feed on microscopic algae-epiphytes on marine flora (PARKER 1959, DAVITASHVILI & MERKLIN 1968) and occur in large populations associated with green (DUFFUS 1969) and/or brown algae

Table 2

Frequency (in %) and ecological classification of gastropods of the reef assemblage; explanation the same as in Table 1

Petaloconchus intortus (LAMARCK)	29.98	SF	EPI
Bittium reticulatum (DA COSTA)	11.76	H	EPI
Jujubinus turricula (EICHWALD)	2.78	H	EPI
Turboella sp.	2.68	H	EPI
Gibbula renatae BOETTGER	2.30	H	EPI
Calliostoma planatum FRIEDBERG	1.92	H/SC	EPI
Clanculus araonis (BASTEROT)	1.27	H	EPI
Emarginula chemnitzi MICHELOTTI	0.81	SC	EPI
Astraea mammillaris (EICHWALD)	0.69	H	EPI
Calliostoma zukowcense (ANDRZEJOWSKI)	0.59	H	EPI
Skenea sp.	0.44	H	EPI
Diodora graeca (LINNAEUS)	0.40	SC	EPI
Odostomia sp.	0.25	EP	EPI
Acmaea laevigata (EICHWALD)	0.23	H	EPI
Alvania montagui ampulla (EICHWALD)	0.23	H	EPI
Hydrobia sp.	0.22	H	EPI
Haliotis sp.	0.19	H	EPI
Scissurella subaspera BOETTGER	0.19	H	EPI
Patella neglecta MICHELOTTI	0.15	H	EPI
Clanculus sp.	0.11	H	EPI
Cerithiopsis tubercularis (MONTAGU)	0.11	EP	EPI
Cerithium sp.	0.11	H	EPI
Bittium sp.	0.11	H	EPI
Gibbula sp.	0.10	H	EPI
Odostomia deubeli (BOETTGER)	0.07	EP	EPI
Rissoina extranea (EICHWALD)	0.06	H	EPI
Seila trilineata (PHILIPPI)	0.05	H	EPI
Ringicula auriculata (MENBUCCINERE)	0.04	PR	ENF
Triphora sp.	0.04	H	EPI
Fossarus costatus (BROCCHI)	0.04	H	EPI
Cerithiopsis pussilla BOETTGER	0.03	EP	EPI
Rissoina sp.	0.03	H	EPI
Cerithiopsis bilineata (HÖRNES)	0.02	EP	EPI
Acmaea compressiuscula (EICHWALD)	0.02	H	EPI
Cerithiopsis metaxae (DELLA CHIAJE)	0.02	EP	EPI
Turbonilla scala (EICHWALD)	0.02	EP	EPI
Vanikoro sp.	0.01	?	?
Conus sp.	0.01	PR	EPI
Gibbula novemcincta (DE BUCH)	0.01	H	EPI
Solarium sp.	0.01	H	EPI
Alvania oceani (D'ORBIGNY)	0.01	H	EPI
Bittium turritella (EICHWALD)	0.01	H	EPI
Turbonilla sp.	0.01	EP	EPI
Leucorhynchia rotellaeformis (GRATELOUP)	0.01	H	EPI
Scala sp.	0.01	?	?
Scissurella transylvanica REUSS	0.01	H	EPI
Alvania perregularis (SACCO)	0.01	H	EPI
Vermetus sp.	0.01	H	EPI
Fossarus sp.	0.01	H	EPI
Triphora perversa (LINNAEUS)	0.01	H	EPI
Diloma orientalis (COSSMANN & PEYROT)	0.01	H	EPI
Scaphander sp.	0.01	PR	INF
Scala cf. *spinosa* BONELLI	0.01	?	?
Eulimella subumbilicatoides SACCO	0.01	EP	EPI
Couthouyia sp.	0.01	?	?
Turritella sp.	0.01	SF	INF
Microliotia sp.	0.01	H	EPI

(RADWAŃSKI 1977a; HOFFMAN, PISERA & STUDENCKI 1978) which may indicate the presence of such flora in Badenian communities. These gastropods are shallow water eurybiotic forms which also live in the Mediterranean (STARMÜLHNER 1963).

RISSOIDS

Rissoids are represented in the Roztocze reef deposits by diverse species on the genera *Turboella, Alvania, Manzonia, Rissoina*. Single specimens of the genera *Setia* and *Microlotia* were also noted. Rissoids are epibenthic gastropods that live today on submarine flora and feed on microscopic

Table 3

Frequency (in %) and ecological classification of molluscs of the epi-reef assemblage; explanation the same as in Table 1

BIVALVES

Pycnodonte navicularis (BROCCHI)	6.31	SF	EPI
Musculus biformis (REUSS)	4.80	SF	EPI
Chlamys multistriata (POLI)	3.98	SF	EPI
Septifer oblitus (MICHELOTTI)	3.24	SF	EPI
Chama gryphoides LINNAEUS	1.27	SF	EPI
Barbatia barbata (LINNAEUS)	0.85	SF	EPI
Ctena decussata (DA COSTA)	0.81	SF	INF
Plicatula ruperella DUJARDIN	0.73	SF	EPI
Modiolus hoernesi (REUSS)	0.44	SF	EPI
Lima lima (LINNAEUS)	0.42	SF	EPI
Cardium sp.	0.28	SF	INF
Ervilia sp.	0.26	SF	INF
Phacoides sp.	0.08	SF	INF
Hiatella arctica (LINNAEUS)	0.04	SF	INF

GASTROPODS

Rissoids	23.69	H	EPI
Calliostoma zukowcense (ANDRZEJOWSKI)	18.37	H/SC	EPI
Bittum reticulatum (DA COSTA)	9.73	H	EPI
Gibbula renatae BOETTGER	8.46	H	EPI
Rissoina sp.	3.04	H	EPI
Calliostoma planatum FRIEDBERG	2.62	H/SC	EPI
Clanculus sp.	1.78	H	EPI
Gibbula cremenensis (ANDRZEJOWSKI)	1.33	H	EPI
Clanculus araonis (BASTEROT)	1.28	H	EPI
Haliotis sp.	1.27	H	EPI
Petaloconchus intortus (LAMARCK)	1.15	SF	EPI
Patella neglecta MICHELOTTI	1.13	H	EPI
Conus sp.	0.55	PR	EPI
Rissoina decussata (MONTAGU)	0.23	H	EPI
Tornatina truncatula (BRUGUIÈRE)	0.23	PR	INF
Emarginula chemnitzi MICHELOTTI	0.21	SC	EPI
Cerithium sp.	0.17	H	EPI
Vexillum sp.	0.17	PR	EPI
Hydrobia sp.	0.17	H	EPI
Diodora graeca (LINNAEUS)	0.14	SC	EPI
Alvania ellae BOETTGER	0.11	H	EPI
Gibbula sp.	0.06	H	EPI
Diloma orientalis (COSSMANN & PEYROT)	0.06	H	EPI
Rissoina zboroviensis FRIEDBERG	0.06	H	EPI
Bulla cf. *hydatis* (LINNAEUS)	0.06	PR	? INF
Tornatina sp.	0.06	PR	INF
Nassa serraticosta (BRONN)	0.06	PR	INF
Turbonilla sp.	0.06	EP	EPI
Manzonia sp.	0.06	H	EPI
Scissurella subaspera BOETTGER	0.04	H	EPI

algae (mostly diatoms) that cover macroflora (FRETTER & GRAHAM 1962, DAVITASHVILI & MERKLIN 1968, DUFFUS 1969). Large populations of rissoids are common today at depths up to 20 m in the near shore zone.

PETALOCONCHUS INTORTUS (LAMARCK)

This small vermetid species is common in Polish Middle Miocene deposits (*see* FRIEDBERG 1914, BAŁUK 1975, RADWAŃSKI 1977b), but only in the Roztocze it occurs as a rock forming element.

Recent vermetids are characteristic of intertidal and shallow subtidal zones in tropical and warm climates (SAFRIEL 1975; LABOREL 1979, 1980). They are typical encrusters in Recent coral reefs (TAYLOR 1968, ADEY 1975, BURCHETTE & RIDING 1977), but, together with coralline algae, they dominate in the various reef-like structures formed in the intertidal and shallow subtidal zones (KEEN 1960; SAFRIEL 1966, 1974, 1975; KEMPF & LABOREL 1968; PÉRÈS & PICARD 1964; GLYNN 1973; GINSBURG & SCHROEDER 1973; LABOREL 1977, 1979, 1980; FOCKE 1977, 1978a,b; GEISTER 1975, 1977, 1980, 1983). In places, vermetids alone are able to build biohermal structures (SHIER 1969).

The development of algal-vermetid reefs depends on high hydrodynamic regime (LABOREL 1980), but the genus *Petaloconchus* characterizes conditions calmer than *Dendropoma* which lives in areas of very high hydrodynamic energy (KEEN 1960, LEWIS 1960, LABOREL 1977).

PYCNODONTE NAVICULARIS (BROCCHI)

This bivalve is a dominant faunal element in the reefs. It is a cemented form and occurs in small clusters. The Recent forms of the genus *Pycnodonte* are stenohaline and inhabits all oceans (STENZEL 1971). A close relative of *Pycnodonte navicularis*, *Pycnodonte cochlear* lives today in temperate seas at depths from 30 to 1500 m (FRENEIX 1975).

ARCIDS

These bivalves are represented in the Roztocze reefs by 5 species from the genera *Barbatia*, *Striarca*, and *Arca*. All are typical epibenthic, byssally attached animals (STANLEY 1970, 1972). Various species belonging to the genera *Arca* and *Barbatia* are typical reef-dwellers from coral reefs where they live attached (*see also* subchapter on squating bivalves) among branched coral colonies (STANLEY 1970, TAYLOR 1971, THOMAS 1978). The present-day species, *Barbatia barbata* (LINNAEUS), *Striarca lactea* (LINNAEUS), and *Arca noae* LINNAEUS, live in the Mediterranean on rocky substrates, at depths from 1 to 30 m (STARMÜHLNER 1963, PÉRÈS & PICARD 1964, DAVITASHVILI & MERKLIN 1968).

CHLAMYS MULTISTRIATA POLI

The morphology of this species indicates that it was byssally attached (*see* STANLEY 1969, 1972). Other representatives of the genus *Chlamys* inhabit various substrates but commonly occur under rocks or among coral branches in Recent reefs (TAYLOR 1968, 1978).

CHAMA GRYPHOIDES (LINNAEUS)

This bivalve is not very numerous but it is important volumetrically. It is a cemented form which today typically inhabits warm seas. The species *Chama gryphoides* (LINNAEUS) lives in the Mediterranean and along the Atlantic shores of Africa in waters up to 30 m in depth. It cements to rocky substrates in zone of high hydrodynamic energy (DAVITASHVILI & MERKLIN 1966). Other species of the genus *Chama* are also common within the coral reefs (FISHER & SALVAT 1971).

ECHINOIDS

Echinoids occur sporadically in the study material. They are represented mostly by spines (cidaroid, ?spatangoid) and single fragments of tests of *Echinocyamus* sp. Such low frequency of echinoids is surprising because they are very common in several Recent algal-vermetid reefs and are even able to control growth by their erosional activities (ADEY & VASSAR 1975).

CRABS

Chelae and numerous fragments of carapaces occur in our material. They belong to at least 3—4 species, but the detailed paleontological investigation of this group is beyond the scope of the present paper.

FISHES

Remains of fishes are extremely rare in the investigated rocks and represented only by few otoliths. Probably the absence of large cavities in the reefs made the studied environments not favourable for proliferation of any fishes.

SOME SELECTED ECOLOGICAL GROUPS

ROCK-BORING ORGANISMS

Rock-boring organisms and/or traces of their activity are common in the Roztocze fossil assemblages. Borings were found in the shells of molluscs, mainly thick shells of *Astraea mammillaris* (EICHWALD) and *Pycnodonte navicularis* (BROCCHI), as well as in the frame of the reef. The most common boring organisms are the bivalves *Lithophaga lithophaga* (LINNAEUS) and *Gastrochaena dubia* (PENNANT). Borings of those bivalves are distinctive for the particular genus and permit their identification even without the preservation of the shell (RADWAŃSKI 1964, 1965, 1967, 1968, 1969, 1977a). They are common in the limestone substrate of the Badenian littoral zone of southern Poland. All *Lithophaga* shells found were preserved inside their borings, but gastrochaenid shells were also common in the internal sediment. The bioerosion of the reef, penecontemporaneous with its growth, may have caused the enlargement of the openings of the boring and led to the dropping out of the empty shells.

The boring bivalve *Gregariella coralliophaga* (GMELIN) new for the Polish Miocene has been found in the algal-vermetid reefs. It occurs mainly outside borings. Recent members of the species bore in corals (ABBOTT 1974, MACGEACHY &

STEARN 1976, BROMLEY 1978). The borings are shallow cavities with the shape following the shape of the shell and are caused by nonrotating mode of boring. The shallow depth of the boring facilitates the natural removal the shell from its boring.

Comparable Recent boring bivalve associations thrive in the coral reefs (SOLIMAN 1969; WARME 1975, 1977; MACGEACHY & STEARN 1976; BROMLEY 1978; CARTER 1978), but they are also known from other hard substrates (KÜHNELT 1933, STARMÜHLNER 1963, YONGE 1963, RAYNAUD 1969), for example from algal-cup reefs (GINSBURG & SCHROEDER 1973).

After bivalves, the most common boring organisms are sponges of the genus *Cliona*. Their borings are nearly entirely limited to molluscan shells, rarely are they observed in the reef frame (Pl. 11, Fig. 2). Usually clionid borings are very common in oyster shells.

Some borings observed in molluscan shells seem to be polychetous borings, other of μm dimensions are most likely algal (Pl. 44, Figs 1—2) and marine fungi borings.

SQUATTING BIVALVES

Such bivalves as *Musculus biformis* (REUSS), *Hiatella arctica* (LINNAEUS), *Barbatia barbata* (LINNAEUS), *Striarca lactea* (LINNAEUS), and *Coralliophaga coralliophaga* (LAMARCK) are among squatters. The species *Musculus biformis* (REUSS) and *Hiatella arctica* (LINNAEUS) are typical secondary inhabitants of gastrochaenid borings in the Roztocze reefs, but in Recent conditions they are also able to live outside borings, and they attach to rocks or submarine flora or inhabit fissures in a rocky substrate (HUNTER 1949, YONGE 1963, KELLY 1980). The shape of the specimens of both species is very variable and depends on the shape of the boring or on the character of other cavity it lives in. An adaptation of this type of *Sphenia anatina* (BASTEROT) from the Polish Miocene is also known (BAŁUK & RADWAŃSKI 1979).

Recent forms of arcid bivalves are able to modify the substrate where they are attached byssally. Commonly however, they inhabit various cavities and fissures as well as the borings of other bivalves (KÜHNELT 1933, STARMÜHLNER 1963, STANLEY 1972, THOMAS 1978, BAŁUK & RADWAŃSKI 1979). One presumes that in the Badenian algal-vermetid reefs they inhabited similar microhabitats.

PREDATORY ORGANISMS

Numerous traces of the predatory activity of gastropods mainly borings in the shells of molluscs and cirripedes (*see* Table 4), were noted. Based on the morphology of the borings naticid and muricid gastropods were the likely predators (despite the absence of their shells in the samples) (*cf.* CARRIKER & YOCHELSON 1968; TAYLOR 1970; HOFFMAN, PISERA & RYSZKIEWICZ 1974).

Predation by muricid and naticid gastropods was important ecological factor in other localities of the Polish Miocene (HOFFMAN, PISERA & RYSZKIEWICZ 1974). In the Roztocze deposits, however, the frequency of borings indicates that it was of no importance. One exception may be *Plicatula* but its low frequency in the samples precludes any far reaching conclusions. Infrequent predation among molluscs is consistent with the lack of muricid and naticid gastropods in the samples. The absence of naticids is understandable in light of infaunal habit and the lack unconsolidated sediment in the reef. The absence of muricids is surprising as these castropods are important element of rocky substrates faunas today, especially in goral reefs (TAYLOR 1968, 1971, 1978; FISHER & SALVAT 1971).

Table 4

Predation by muricid and naticid gastropods in the studied assemblages

Species	N	% of attacked and 95% conf. lev.
Musculus biformis (REUSS)	851	0.82 ± 0.06
Plicatula ruperella DUJARDIN	19	10.53 ± 0.14
Limopsis anomala (EICHWALD)	72	4.17 ± 0.05
Pycnodonte navicularis (BROCCHI)	742	0.94 ± 0.007
Hiatella arctica (LINNAEUS)	323	0.93 ± 0.01
Venus cincta EICHWALD	65	4.61 ± 0.05
Bittium reticulatum (DA COSTA)	1908	1.00 ± 0.004
Jujubinus turricula (EICHWALD)	340	1.18 ± 0.01
Calliostoma planatum FRIEDBERG	263	0.76 ± 0.01
Gibbula renatae BOETTGER	273	0.73 ± 0.01
Verruca sp.	2418	1.45 ± 0.005

Also very characteristic is the fact that most of the drilled gastropod specimens are juvenile individuals. This is especially well seen in the case of *Bittium reticulatum* (DA COSTA). A preference for juveniles as prey for drilling gastropods also exist today (*cf.* BOUCOT 1981).

Drilling predatory gastropods were not the only predatory gastropods in the assemblages, specimens of *Conus* have also been found but its activity leaves no traces of predation on the shell. One should keep in mind that in reality predation was more important that it seems from the table shown here because it concerns only naticid and muricid predation.

QUANTITATIVE ANALYSIS OF THE MACROFAUNA

The material studied represents two fossil assemblages that differ in their structure and relation to the reef body. The reef assemblage comprises organisms inhabiting the reef during its active growth and occurs throughout the whole reef section. The epi-reef assemblage is always associated with the boundary between the reef body and the covering detrital sediment and inhabited the reef surface after termination of the reef growth.

One of the means of the function and structure investigations of fossil assemblage is trophic analysis (RHODES & *al.* 1972; WALKER 1972; SCOTT 1974, 1976, 1978; HOFFMAN 1977; HOFFMAN, PISERA & STUDENCKI 1978; STANTON & NELSON 1980; STANTON & DODD 1976; DODD & STANTON 1981). Especially suitable for such an analysis are hard bottom assemblages which as a rule contain relatively small proportion of infaunal soft-bodied polychaetes and are characterized by higher and more equal fossilization potential of their members (*see* STANTON 1976, SCOTT 1978, BOSENCE 1979).

Trophic analysis of the general character of the fauna allows to reconstruct the paleoenvironment and to identify important factors controlling the structure of the assemblage. It also permits inferences about the likely presence of nonpreserved taxa and thus permits more complete reconstruction of fossil assemblage (KAUFFMAN & SCOTT 1976, SCOTT 1978, HOFFMAN 1979, STANTON & NELSON 1980, DODD & STANTON 1981).

In the Roztocze assemblages the occurrence of exotic species is very low because of the role of the reef as a positive morphological element on the bottom.

In the analysis presented below the trophic structure scheme of HOFFMAN, PISERA & STUDENCKI (1978) is adopted.

REEF ASSEMBLAGE

This assemblage is represented by 23 samples comprising about 13 000 specimens of bivalves and gastropods and about 12 000 specimens of other macrofauna. Bivalves are represented by 41 species and gastropods by about 64 species.

The molluscan assemblage (Text-fig. 9) is dominated by the gastropods *Petaloconchus intortus* (LAMARCK) and *Bittium reticulatum* (DA COSTA) and by the bivalves *Pycnodonte navicularis* (BROCCHI) and *Musculus biformis* (REUSS). Other common taxa are the trochids, the rissoids, the arcids, *Chlamys multistriata* POLI and *Hiatella arctica* (LINNAEUS).

The relative abundance of molluscs differs somewhat when ranked according to biomass (Text-fig. 9; based on weight of empty shell). The clear dominance (58.13%) of *Pycnodonte navicularis* (BROCCHI) is noted, second in biomass (17.41%) is *Astraea mammillaris* (EICHWALD) and the third (4.91%) is *Petaloconchus intortus* (LAMARCK). Such a rank order is also characteristic for collections made directly in the outcrops. Because reconstruction of community structure based on the biomass of particular taxa (which in a fossil assemblage is a function of biological productivity; *see* DZIK 1979) has been strongly criticized (STANTON & NELSON 1980), the presented one here was based on numerical dominance. After the molluscs very common are in most samples bryozoans, cirripedes (*Verruca*) and serpulids. In some samples the biomass of bryozoans is comparable to the biomass of molluscs.

The dominant life habit of the molluscan fauna (and practically all nonmolluscan fauna) is the epibenthic one (Text-fig. 10) and 41.76% represent forms cementing to the substrate (*Pycnodonte*, *Petaloconchus*, *Chama*, *Plicatula*, *Spondylus*). Epifaunal bivalves that are byssally attached (the arcids, *Chlamys*, *Musculus*, *Hiatella*, *Lima*, *Cardita*, *Coralliophaga*) amount to 24.45% of the molluscan fauna. Epifaunal gastropods (*Bittium*, the trochids, the rissoids, *Haliotis*, *Astraea*) account for 28.35%

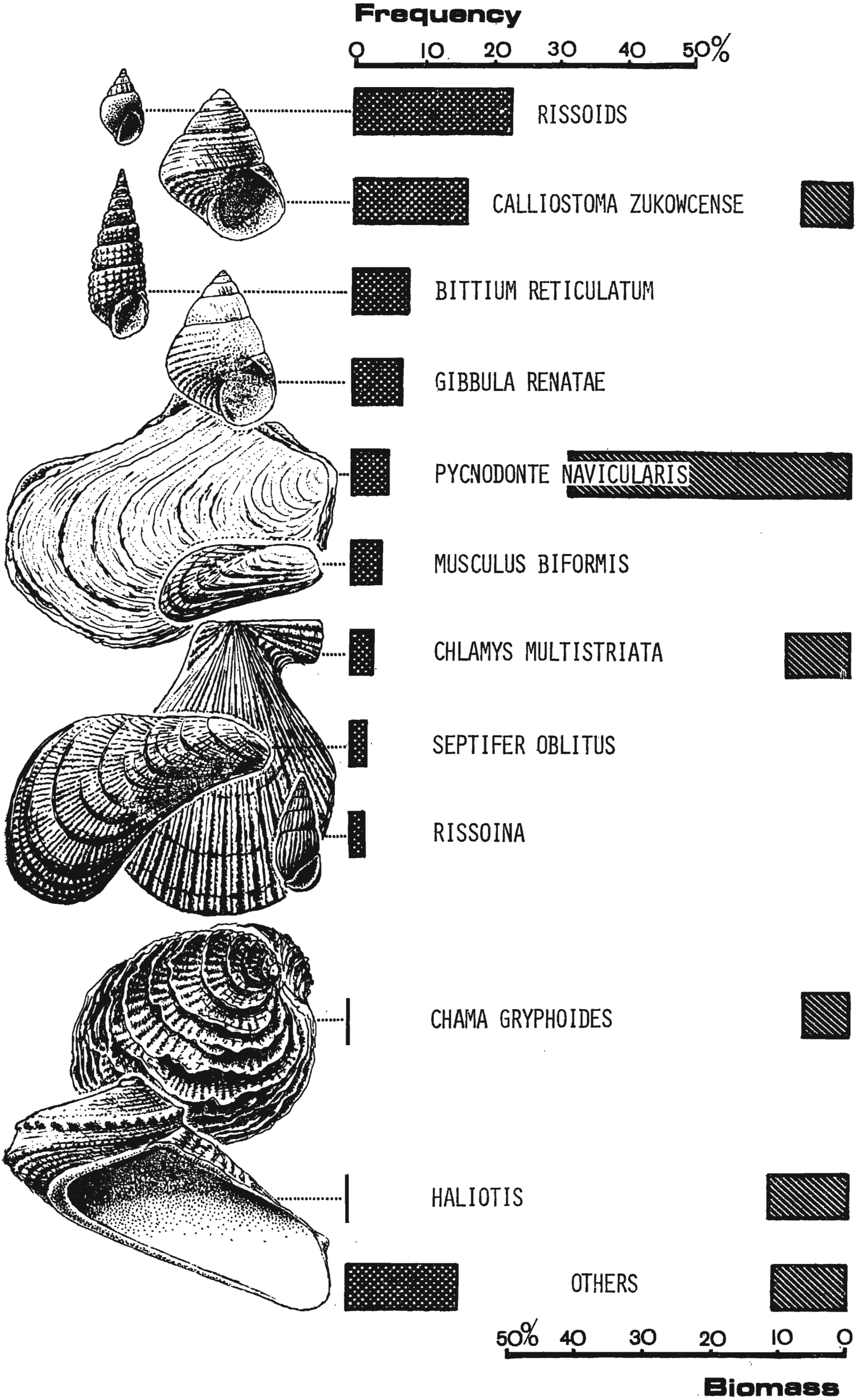


Fig. 9. Molluscan taxa dominating the reef assemblage

of the molluscan assemblage. Infaunal molluscs amount to only 5.5% (of which boring bivalves *Gastrochaena*, *Lithophaga*, *Gregariella* amount to about 2.33%) and about 3.0% are shallow burrowing bivalves (*Venus*, *Timoclea*, *Limopsis*, *Cardium*). Infaunal gastropods (*Turritella*, *Ringicula*, *Scaphander*) are very rare and amount to about 0.17%. Most molluscs are nestling and/or cryptic forms.

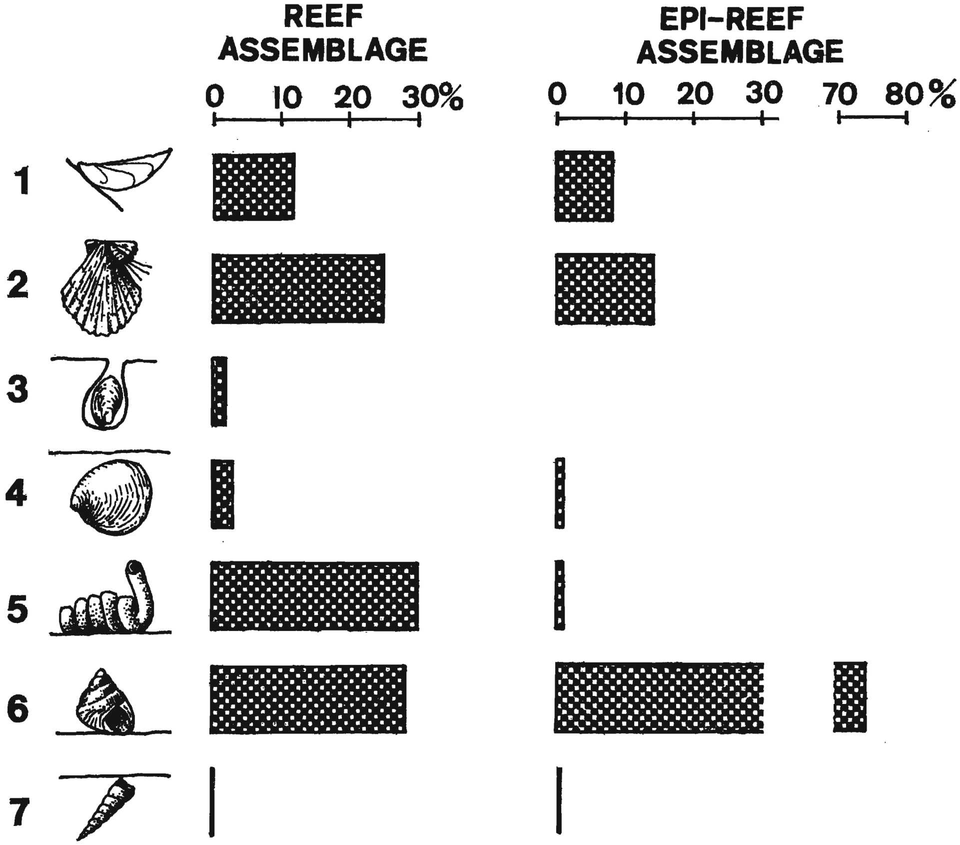


Fig. 10. Ecological groups of molluscs of the recognized assemblages
1 — epifaunal cemented bivalves, 2 — byssally attached bivalves, 3 — boring bivalves, 4 — burrowing bivalves, 5 — epifaunal cemented gastropods, 6 — epifaunal free-living gastropods, 7 — infaunal gastropods

The trophic structure of the reef assemblage is relatively simple (Text-fig. 11), lower trophic levels are of course not preserved but they may be easily inferred. Two nearly independent trophic chains existed at the higher level. One consists of herbivorous species and detritus eating species, the second of filter feeding species. Both of course depend on primary production (phytoplankton and submarine flora). Filter-feeding molluscs (over 70%) dominate. The absence of sufficient amount of unconsolidated sediment excluded nearly all burrowers.

No deposit feeding organisms occur in this assemblage and infaunal filter feeders are represented predominantly by borers. This suggests that food resources were not the limiting factor but only the accessibility of hard substrate (or loose sediment) suitable for colonization played the main role, as is the situation in Recent hard-bottom assemblages (JACKSON & BUSS 1975, JACKSON 1977). The presence of numerous herbivores and detritus feeding organisms as well as the morphological forms of some bryozoans indicates that a submarine flora was present, in the living assemblage. Of little importance were scavengers (*Emarginula*, *Diodora* and crabs, as well as maybe some the calliostomids), but crabs, because of their relatively low fossilization potential (*cf.* BOSENCE 1979), were probably more numerous in the life assemblage. The assemblage is dominated by the second level of a trophic pyramid, higher levels are poorly represented. As similar situation was noted in some Recent reefs where biological productivity of higher level (especially predators) is low because of the retention in the porous reef structure of lower trophic level production (*see* PÉRÈS & PICARD 1969). Theoretically it is possible that most predatory organisms were without important skeletal parts and left no traces as fossils. However this seems improbable when considering the ecology of Recent reefs and other hard-substrate assemblages.

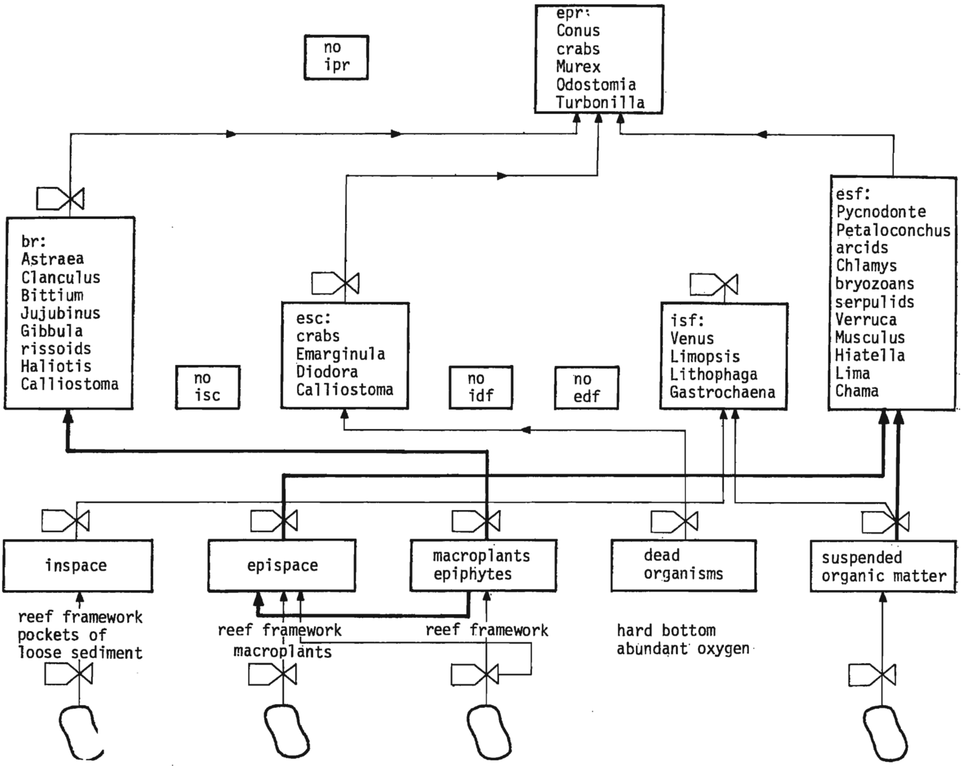


Fig. 11. Trophic structure of the reef assemblage (*clouds* — system independent states, *rectangles* — levels, *arrows* — rates or flows, *faucets* — rate controls)

The predator level is represented by only 0.46% of collected molluscs; some crabs probably belong here as well. The only predatory gastropods which have

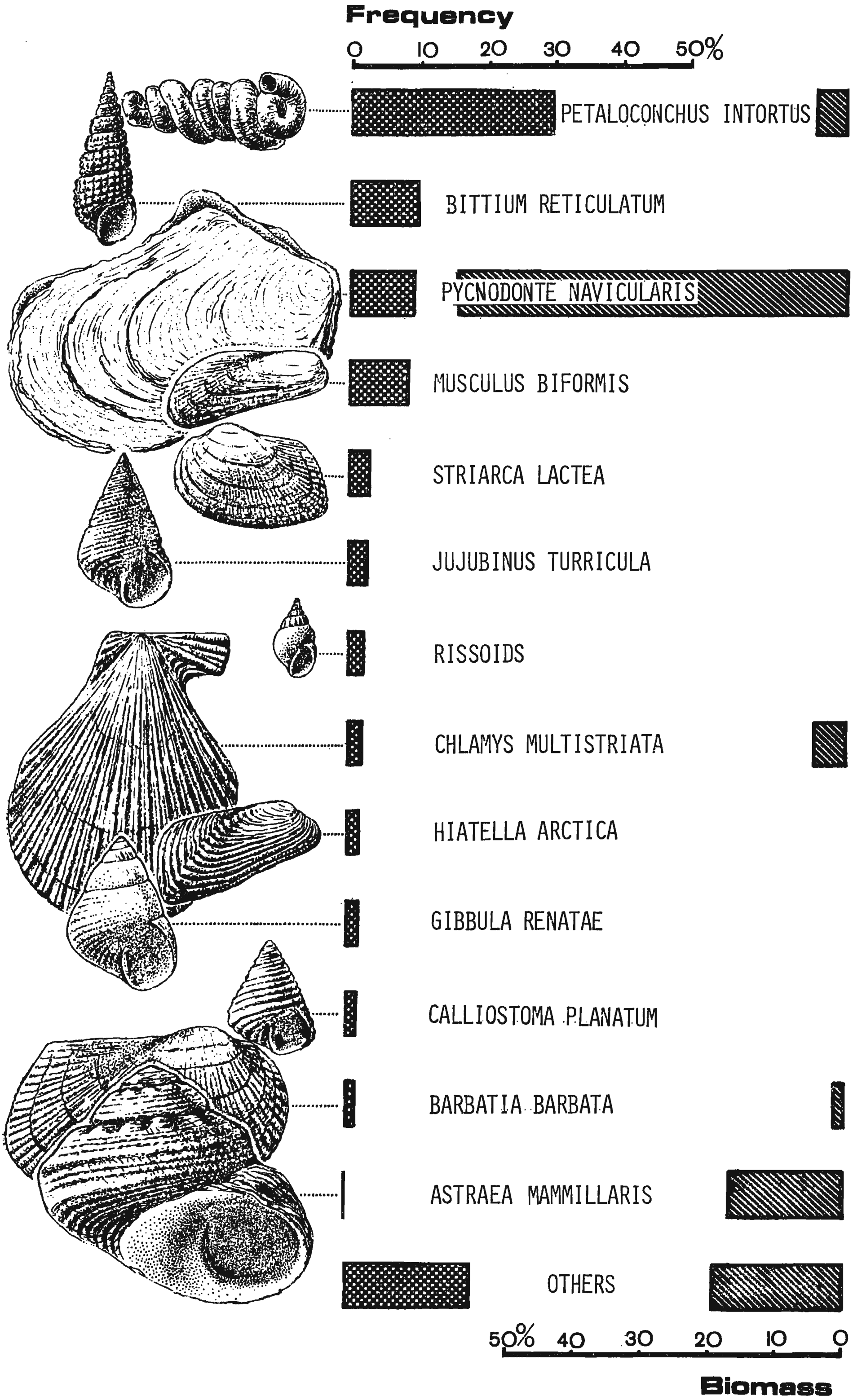


Fig. 12. Molluscan taxa dominating the epi-reef assemblage

been found in the samples are *Conus* and *Ringicula*. However, judging from the presence of bored shells muricid and naticid predatory gastropods were also present. Ectoparsites (*Cerithiopsis*, *Turbonilla*, and *Odostomia*) are quite common and are classified in the same category as predators.

The reef assemblage shows great taxic diversity — comparable to that of the richest assemblages from other Badenian localities from Poland.

EPI-REEF ASSEMBLAGE

This assemblage is represented by only 4 samples which comprise 1100 specimens of bivalves and gastropods and about 500 specimens of non-mollusc fauna. Bivalves are represented by 14 species, gastropods by about 30 species. The molluscan assemblage (Text-fig. 12) is dominated by the rissoids and the trochids, such as *Turboella*, *Alvania*, *Rissoina*, *Calliostoma zukowcense* (ANDRZEJOWSKI), *Gibbula renatae* (BOETTGER). Important also are *Bittium reticulatum* (DA COSTA), *Pycnodonte navicularis* (BROCCHI), *Musculus biformis* (REUSS), *Chlamys multistriata* POLI, *Septifer oblitus* (MICHELOTTI). With respect to biomass *Pycnodonte navicularis* (BROCCHI) dominates (47%), and other important forms are *Haliotis* (about 14%), *Chlamys multistriata* POLI (about 10%) and *Chama gryphoides* LINNAEUS (about 8%). Bryozoans and cirripedes (*Verruca*) are also ubiqui-

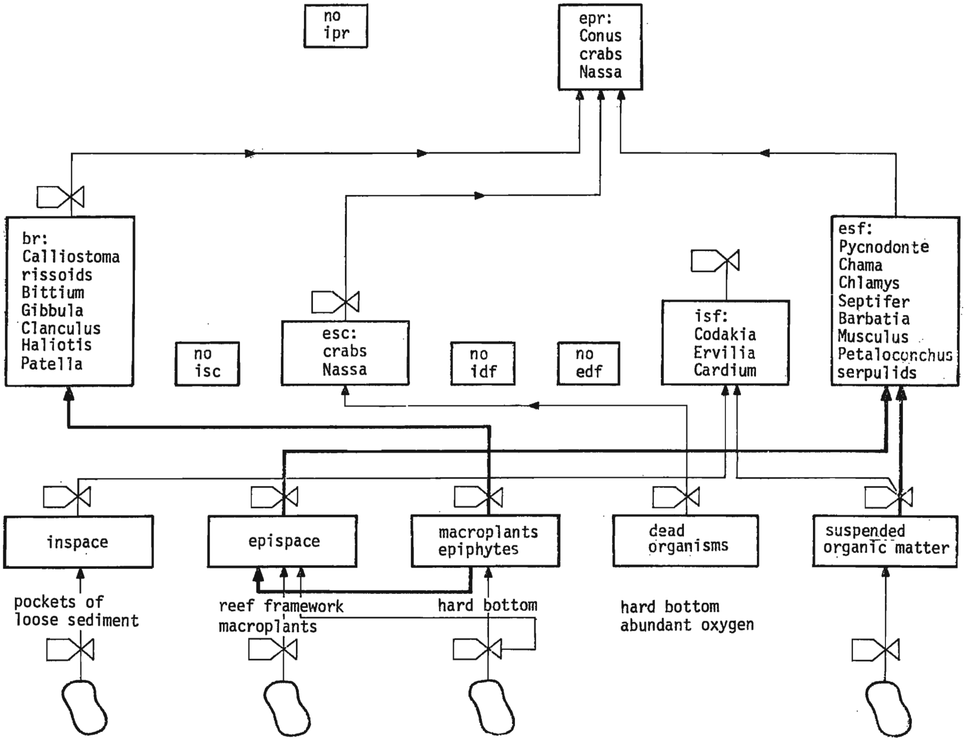


Fig. 13. Trophic structure of the epi-reef assemblage; explanations the same as in Text-fig. 11

tous. Most molluscs (about 98%) are epifaunal (Text-fig. 10), and practically all the nonmolluscan macrofauna belong to this group. Among molluscs over 9% of specimens are cementing forms (*Pycnodonte*, *Chama*, *Plicatula*, *Petaloconchus*). Byssally attached bivalves (*Musculus*, *Chlamys*, *Septifer*, *Barbatia*) amount to about 14% of molluscs. Burrowing bivalves are rare and account for 1.43% of the molluscan assemblage, among them are *Ctena*, *Cardium*, and *Ervilia*. Epifaunal gastropods (the rissoids, the trochids, *Bittium*, *Haliotis*, *Patella*) dominate and amount for 76% of the molluscan assemblage. Practically no infaunal gastropods were noted.

The trophic structure (Text-fig. 13) indicates that, similary to the reef assemblage, two nearly independent food chains existed i.e. filter feeding and herbivorous-detritus eating organisms. In contrast to the reef assemblage, however, herbivorous forms (74% of specimens) dominate over filter feeders (24.76% of specimens) in the epi-reef assemblage. This clearly indicates that the submarine flora was an important factor that structured this assemblage. Scavengers are relatively common and are represented by crabs and the gastropods *Emarginula* and *Diodora* (probably also some calliostomids belong to this group). Predators are rare and represented by the gastropods *Conus* and *Nassa* and probably, some crabs.

The most similar Recent assemblage was described by STARMÜHLNER (1969) from the Adriatic: it is dominated by rissoids and trochids together with *Bittium reticulatum* (DA COSTA) as well as mytilids; the haliotids and *Conus* were also noted. This Recent assemblage is associated with algal meadows of *Cystoseira* growing on a rocky substrate with small quantities of unconsolidated sediment. Based on the taxonomic composition of the Recent and Badenian assemblages one may claim that the fossil one dwelt in similar environment i.e. algal meadows growing on the rocky substrate of the already dead algal-vermetid reef in a shallow sublittoral zone with normal marine salinity.

GENERAL MINERALOGY OF THE REEF LIMESTONES

The investigated reef limestones from the Roztocze Hills are composed, as revealed by the staining method, of low-Mg calcite associated with aragonite. The latter is biogenic in its nature and, partly, also makes an inorganic cement. The *X*-ray analysis confirms the presence of calcite, and the aragonitic composition of vermetid shells; in some samples it also indicates traces of dolomite (*see* Text-fig. 14). As no dolomite was noted in thin section it is probably dispered as micrite. Based on the shift of the main calcite peak (GOLDSMITH 1955; IWASIŃSKA, NARKIEWICZ & PISERA 1981) it was estimated that the calcite constains about 2 mole % of $MgCO_3$. It is apparent that, despite the large primary amount of Mg-calcite in the rock (coralline algae, part of micrite) Mg-calcite has been totally stabilized. The stabilization results from the low stability of this calcite polymorph in a meteoric environment as Mg-calcite is even more unstable than aragonite (STEHLI & HOWER 1961, GAVISH & FRIEDMAN 1969, LIPMANN 1973). In this light the absence of dolomitization seems interesting. Apparently most of the Mg-ions which were removed from Mg-calcite during its inversion to low-Mg calcite, were flushed out of the diagenetic system as no dolomitization was observed. Such an open diagenetic system resulted from the large primary porosity of the reef and peri-reef deposits.

The micritic matrix of the internal sediments also contains only low-Mg calcite but Recent counterparts show important quantities of argonite as well (GINSBURG & SCHROEDER 1973, DEAN & EGGLESTONE 1975). So, only aragonite of biogenic origin and large crystals of this

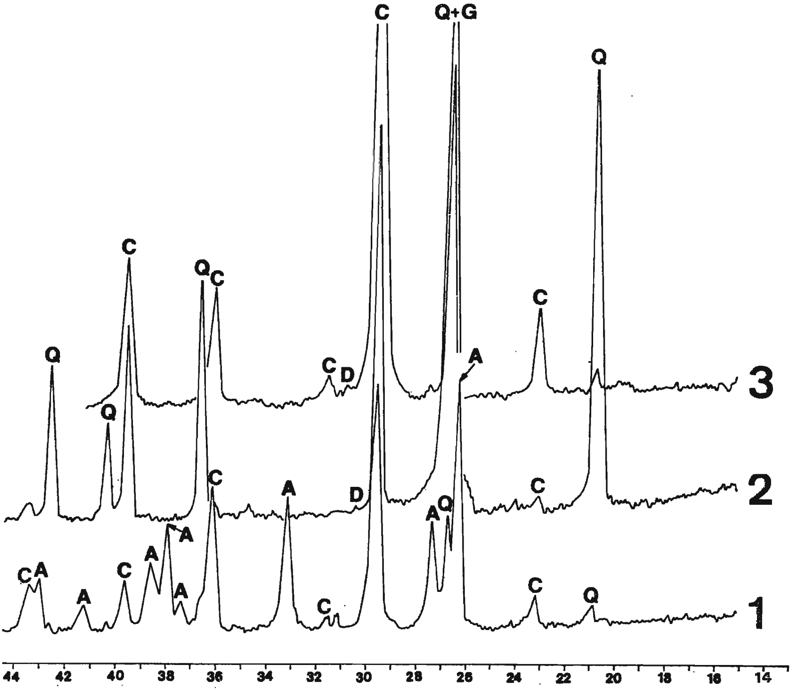


Fig. 14. *X*-ray diffraction diagrams of typical samples from the algal-vermetid reef rocks
1 — vermetid shell with sediment inside, 2 — residuum after dissolving bulk sample in acetic acid,
3 — bulk sample containing algal thalli and sediment
A aragonite, *C* calcite, *D* dolomite, *G* glauconite, *Q* quartz

calcium polymorph in cement are preserved. This may be explained by the higher reactivity of smaller crystals and in effect their lower stability (FOLK 1965, BATHURST 1975) as well as by the protective function of organic matrices present in the biogenic aragonite. Some effect may be also caused by differences in the distribution of centers of recrystalization which are more common in micrite (*cf.* MATTHEWS 1968).

The preservation of aragonite in some of the investigated sections needed also special conditions during diagenesis. One of the decisive factors was its probable isolation from proper quantities of fresh water which would cause the stabilization or dissolution of aragonite (FYFE & BISCHOFF 1965, LIPMANN 1973). As no isolating clay deposits were observed over the reef, other explanation may be that this particular section was in a vadose meteoric environment with very brief period of fresh water phreatic influences shortly after deposition. In the early stages of this process the inhibiting effects of Mg-ions released from Mg-calcite (*see* LAND 1967, LIPMANN 1973, BATHURST 1975) may have been of some importance.

Other authors associated the long preservation of aragonite in their sections with inhibiting effect of marine water (SCHLANGER 1963) or the isolation of sediments from the influence of fresh water by marly deposits (SCHERER 1977).

Authigenic glauconite, which may be differentiated from detrital by fresh green colour, was observed in some thin sections. It infills intraskeletal pores of foraminifers and algal borings in the calcitic molluscan shells (Pl. 44, Fig. 1).

Brown colloidal incrustations and impregnations of algal thalli (Pl. 32, Figs 1—2) are also common. Sometimes this substance infills small pores between algal thalli. With crossed nicols it shows very low birefringence and zebra-like light extinction. Its composition is unknown to the author, but the authigenic character is indicated by the fact that it is covered commonly by internal sediments.

PETROLOGY OF THE REEF LIMESTONES

INTERNAL SEDIMENTS

In the Roztocze reefs, as in the Recent ones, detrital internal secdiments are an important component. They often occur in geopetal form and fill synsedimentary pores and cavities which originated as result of the reef growth, or as intreskeletal pores of serpulids, molluscs and borings of *Cliona*. Internal sediments represent the whole spectrum from calcareous sandstones (Pl. 10, Fig. 1), through biomicrites with quartz (Pl. 11, Fig. 1) and biocalcarenites to micrites and pelmicrites (Pl. 16, Fig. 1). One infilling even has different generations of sediment that are of different character (Pl. 4; Pl. 10, Fig. 2; Pl. 37, Fig. 1). Such a differentiation of internal sediments is also a common feature in the Holocene coral reefs from Belize (JAMES & GINSBURG 1979) as well as in the Holocene algal-vermetid reefs from Bermuda (GINSBURG & SCHROEDER 1973).

The type of internal sediment depends on the size and position of the cavity in the profile. In one cavity a typical sequence is biomicrite with quartz garding into biomicrite and pelmicrite (Pl. 37, Fig. 1). This sequence was caused by the gradual closing of the cavity opening during reef growth and the progressive limiting of detrital material supply, as well as by the partial retention in the overlying part of the reef of coarser material. In small pores eg. intraparticle pores, only fine-grained material is present. In larger pores, with size of centimeters and more, accumulations of mollusc shells in a micrite matrix are common (Pl. 4; Pl. 5, Fig. 2). The absence of sorting or roundning in this material indicates autochtonic character. Only quartz grains were supplied. Some larger sized cavities contain well sorted biocalcarenites (Pl. 16, Fig. 2) but any significant transport distances are unlikely because they are composed of biogenic material derived from the reef organisms. Matrix, when present, is composed of micrite, which is commonly neomorphosed. There is no doubt that in most cases the micrite in the internal sediment is of detrital origin as indicated by unsupported grains, stratification and the geopetal character of infilling.

In some cases, the first generation of internal sediment containing bioclasts and abundant quartz, underlies a second generation of light micrite, without bioclasts and only rare quartz grains (Pl. 37, Figs 2—3). Commonly, towards the top it passes into a pelmicrite with pellids about 30—40 µm in size. The boundary between these two generations is of erosional character; sharp and very irregular (Pl. 21, Fig. 2). Pelmicrites are postdated by drusy calcite cement. Such sediments may be regarded as crystal silt and/or pelletal silt, which are characteristic of a vadose zone in early diagenetic stages (DUNHAM 1969, FLÜGEL 1982).

Quartz grains are the most common detrital grains sometimes accounting for 60% of sediment (Pl. 10, Fig. 1). Usually they are poorly sorted and angular, with a size range from 0.001 to 0.6 mm (mean 0.1 mm) (Pl. 37, Fig. 1; Pl. 44, Fig. 3). These grains are single crystals. Sometimes their boundaries have irregular embayments infilled with clear micrite. It suggests the replacements of quartz by calcium carbonate. Such features, caused by high Ph values, resulting from biological activity are known from Recent reefs from the Red Sea (FRIEDMAN & *al.* 1974.)

The quartz admixture is greater in a lower part of the Roztocze reefs. Towards the top it decreases, indicating that the source of quartz was probably the Oligocene substrate.

In the upper portion of the reef other types of quartz grains with a size range of 0.1 to 1.5 mm (mean 0.5 mm) appear (Pl. 44, Fig. 3). These grains are well rounded but poorly sorted and show undulose light extinction under crossed nicols. Their source must be different and it seems that the continuing transgression encountered new source which supplied quartz grains of this second type.

Detrital glauconite is also a very common component of internal sediment and causes green colour of the reef rock in many places. Oxidizing envelopes are very common and sometimes the whole grain is replaced by iron oxides or hydroxides. All this indicates the secondary nature of the glauconite — probably from the Oligocene deposits.

The kind of biogenic grains present in the sediment depends on the size of the cavity in which the sedimentation took place. In large cavities measuring several centimeters or more, molluscan shells dominate together with other reef dwellers of large size (Pl. 4; Pl. 5, Fig. 2). In small pores the most common sedimentary particles are foraminifers (mainly miliolids and arenaceous), small fragments of coralline algae, bryozoans and echinoderms (Pl. 11, Fig. 1; Pl. 13, Fig. 2). In the washed samples of unconsolidated material plates of verrucid cirripedes, small brachiopods, bryozoans, and sessile foraminifers *Miniacina* (Pl. 31, Figs 1—4) are also common.

In all instances the sediments are derived from the reef dwelling organisms and only rarely the reef building ones. The same situation exists for the sand-size fraction of internal sediments in the Bermuda algal-cup reefs (*see* GINSBURG & SCHROEDER 1973).

In some cases internal sediments comprise pelloids with size range from 10 to 70 μm (Pl. 10, Fig. 2; Pl. 37, Figs 1 and 3). They may be regarded as Mg-calcite cement but those larger and of ellipsoidal shape are either fecal pellets of invertebrates and/or calcified algal remains, as is the case for such pelloids in the case of the Bermuda algal-vermetid reefs (*see* SCHROEDER 1972a, GINSBURG & SCHROEDER 1973). Recently, some calcite pelloids were recognized as products of the activity of boring sponges (*see* PETTA 1977).

POROSITY

The different kind of cavities, pores and caverns were typical elements of the algal-vermetid reefs from the Roztocze Hills. Such a porosity (primary and secondary) is also typical of other reef deposits ranging in age from the Cambrian to the Recent (*see* SCOFFIN 1972; SCOFFIN & GARRETT 1974; GINSBURG & SCHROEDER 1973; PEDLEY 1979; JAMES & KOBLUK 1978; JAMES & GINSBURG 1979). Primary synsedimentary pores were the place of accumulation of internal sediments, but larger ones formed suitable microenvironment for diverse reef-dwelling organisms.

In most cases primary pores are at present completely infilled with sediment and cements, but their history is easy to decipher. Secondary pores which originated by dissolution are still empty or only partly occluded by late sparry cement. The porosity analysis presented here is based on the genetic system of porosity classification of CHOQUETTE & PRAY (1970).

The most important role, among synsedimentary porosity, is played by pores which originated by the growth of the reef building organisms mainly the coralline algae (Pl. 3, Fig. 1; Pl. 6, Figs 1—2; Pl. 7, Fig. 2; Pl. 8, Fig. 1; Pl. 15, Fig. 2). Laminar pores originated (Pl. 15, Fig. 2) sized up to few centimeters (*mg-ms GF* pores) as effects of the growth of algal thalli. The other part of synsedimentary pores were cavities and caverns which developed by the differential growth of nearby parts of the reef. At first small depression developed where sediment accumulated, by subsequent overgrowth large cavities with size range from several centimeters up to 1 meter (*mg GF* pores) were formed. These type of large cavities are typical of Recent reefs (VASSEUR 1974, 1977; SCOFFIN & GARRETT 1974) as well as for fossil ones (SCOFFIN 1972).

Interparticle porosity was important in biocalcarenites from the internal sediments. It is now nearly completely occluded by cement (*ms BO*). The initial significant intraparticle porosity (empty shells of foraminifers, vermetids, bryozoans, etc.) is of no importance at present because it has been reduced by cementation. Shelter porosity was also noted, but it never played any important role. All the above porosity types are fabric selective. Synsedimentary porosity was increased both by the activity of organisms which formed selective (sponges) or nonselective borings (bivalves), the latter within the frame and internal sediments (Pl. 5, Fig. 1; Pl. 7, Fig. 1). It may be classified as the *ms-mg CH-VUG* porosity. At present, the synsedimentary pores are partly filled also with sediment and late cement.

Secondary porosity is represented mostly by selective moldic porosity which originated in a process of dissolution of the aragonitic shells of molluscs, mainly vermetids (*mg-ms MO* porosity) (Pl. 3, Fig. 2; Pl. 8, Fig. 2; Pl. 9, Fig. 1). Sporadic dissolution of micritic matrix also took place (*ms-CH* porosity). Secondary porosity is only slightly reduced by late sparry cement.

The existing porosity system developed mainly during sedimentation and in a telogenetic stage. Mesogenetic porosity is absent as the investigated rocks were never under significant sedimentary cover, but were moved into the meteoric zone shortly after deposition.

TYPES OF CEMENT

Recent submarine cements are built by aragonite (usually elongated crystals) and Mg-calcite (micrite and elongated to bladed crystals) (BRICKER 1971, MILLIMAN 1974. FRIEDMAN & *al.* 1974, FRIEDMAN 1975, JAMES & *al.* 1976, JAMES & GINSBURG 1979). The estimation of primary mineral composition of cement in fossil reefs is complicated by the diagenetic stabilization of aragonite and Mg-calcite, so that now usually only low-Mg calcite and/or dolomite is present (*see* HAVARD & OLDERSHAW 1976, BEBOUT & LOUCKS 1977, HILLEMAN & MAZZULLO 1977, SCHNEIDER 1977, TOOMEY 1981 and others). This primary composition may be only inferred in an indirect way. As nonstable minerals may be also dissolved in a diagenesis the share of early submarine cements decreases with time and its original content is difficult to estimate.

ARAGONITE CEMENTS

The most common type of aragonite cement is spherulitic cement built by long needle-like crystals, tightly packed in a spherulitic mode (Pl. 33, Figs 1—3; Pl. 34, Figs 1—4). Crystals are 50—150 μm long and 1—5 μm thick. In the thin section zonation, in the form of concentric zones a few μm thick and differently coloured, is visible in this type of cement. Generally it is yellow to light brown and very cloudy, and the cloudiness is caused by numerous impurities. This cement demonstrates clear preference in relation to the substrate and always occurs in close association with coralline algae, and usually fills its conceptacles (Pl. 34, Fig. 3) or small, isolated pores among their thalli. It never shows gravity orientation and aggregates grow even on the roof of pores.

The aragonitic mineral composition was confirmed by staining. In the *SEM* pictures corrosion — caused by dissolution, of individual crystals is visible (Pl. 34, Figs 1—2). Partly dissolved spherulites associated with subsequent equant cement precipitation may also be seen in thin section (Pl. 35, Fig. 2).

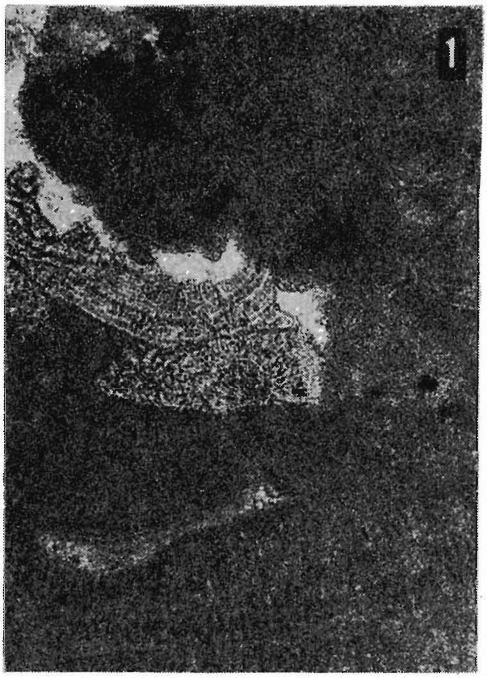
Aragonite needle cement, built by loose aggregates of needle-like aragonite crystals (Pl. 33, Fig. 4) is very rare. The aragonite crystals range from 30 to 200 μm in lentgh and are 2—4 μm thick. This type of cement is also associated with coralline algae.

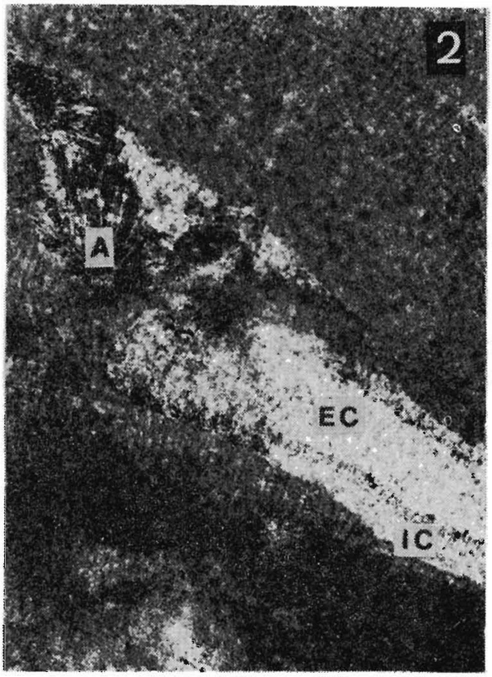
Aragonite spherulitic cement is common in the Recent algal-vermetid reefs from Bermuda (SCHROEDER 1972b, 1973) as well as from their Pleistocene counterparts (SCHROEDER 1973) and has only been rarely noted in coral reefs (SCHERER 1975). In nonreefal deposits it occurs in subfossil coralline algal deposits from Greece (RICHTER 1979), in the Pleistocene limestones from Kenya (SCHROEDER 1979) and even in the Recent coralline algal nodules from Skagerrak (ALEXANDERSSON 1974). In most of these occurrences it is closely associated with coralline algae. Only one fossil occurrence of this cement is known from the sponge-coral reefs in Cassian Beds of the Alpine Triassic (SCHERER 1977).

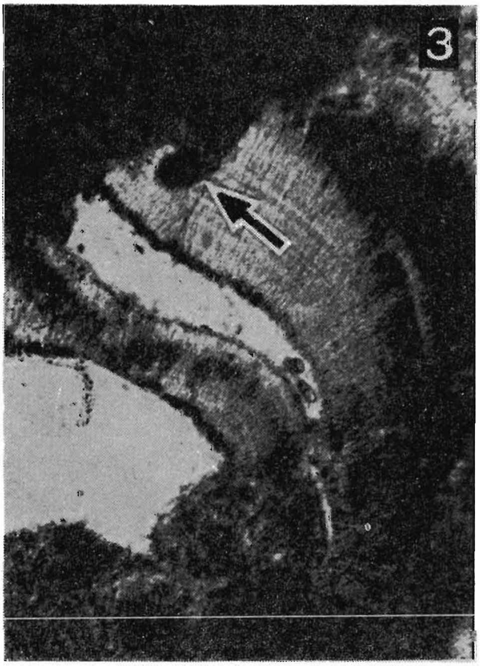
The association of this cement with coralline algae, its independence in relation to temperature and even to saturation of water with aragonite (Skagerrak case) indicate a strong microenvironmental control over its formation. The most important controlling factor is presumably of biochemical nature and tied to the biological activity of coralline algae and/or decomposition of organic matter (*cf.* ALEXANDERSSON 1972).

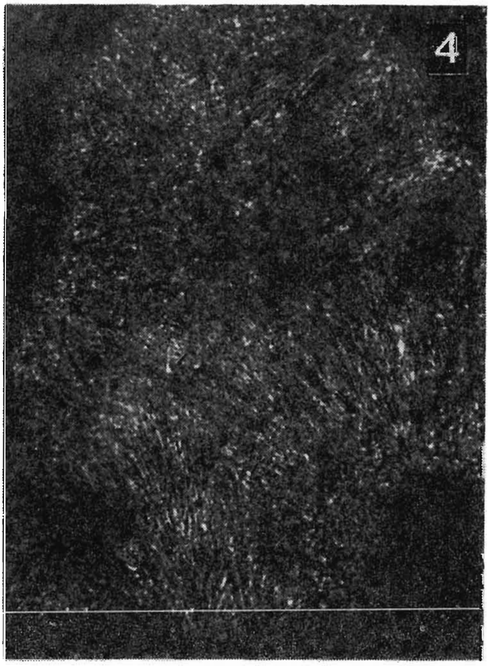
In the Roztocze reefs it always forms the first generation of cement and sometimes may be even covered by micritic internal sediment usually however, it completely fills pores. In places, on its corroded surface late equant cement is developed (Pl. 34, Fig. 4). A clear indication of its very early origin is the occurrence of algal borings in it (Pl. 33, Fig. 3). Based on these characters, the aragonite spherulitic cement is most likely an early submarine cement which was formed simultaneously with the reef growth.

Aragonite needle cement occurs in the very different Recent environments ranging from the intertidal zone (TAYLOR & ILLING 1969, BRICKER 1971 and others) and tropical and temperate shallow subtidal carbonate sedimentary environments (SHINN 1969, 1971; BRICKER 1971;









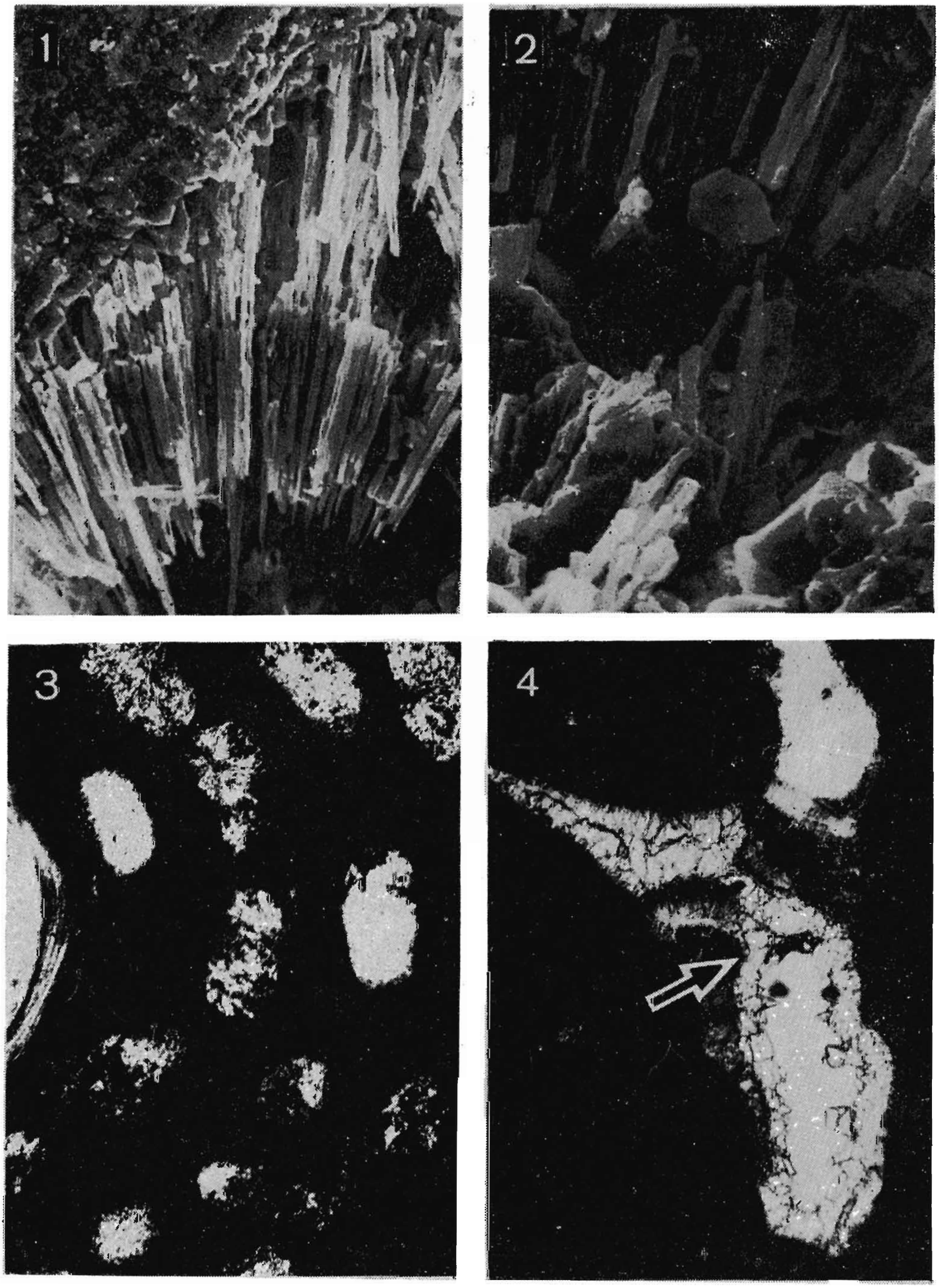
Submarine aragonite cements

1 — Aragonite spherulitic cement among algal thalli; thin section, ×100; Węglinek

2 — Aragonite spherulitic cement (*A*) and sequence of isopachous cloudy rim cement (*IC*) and blocky calcite cement (*EC*); thin section, ×100; Węglinek

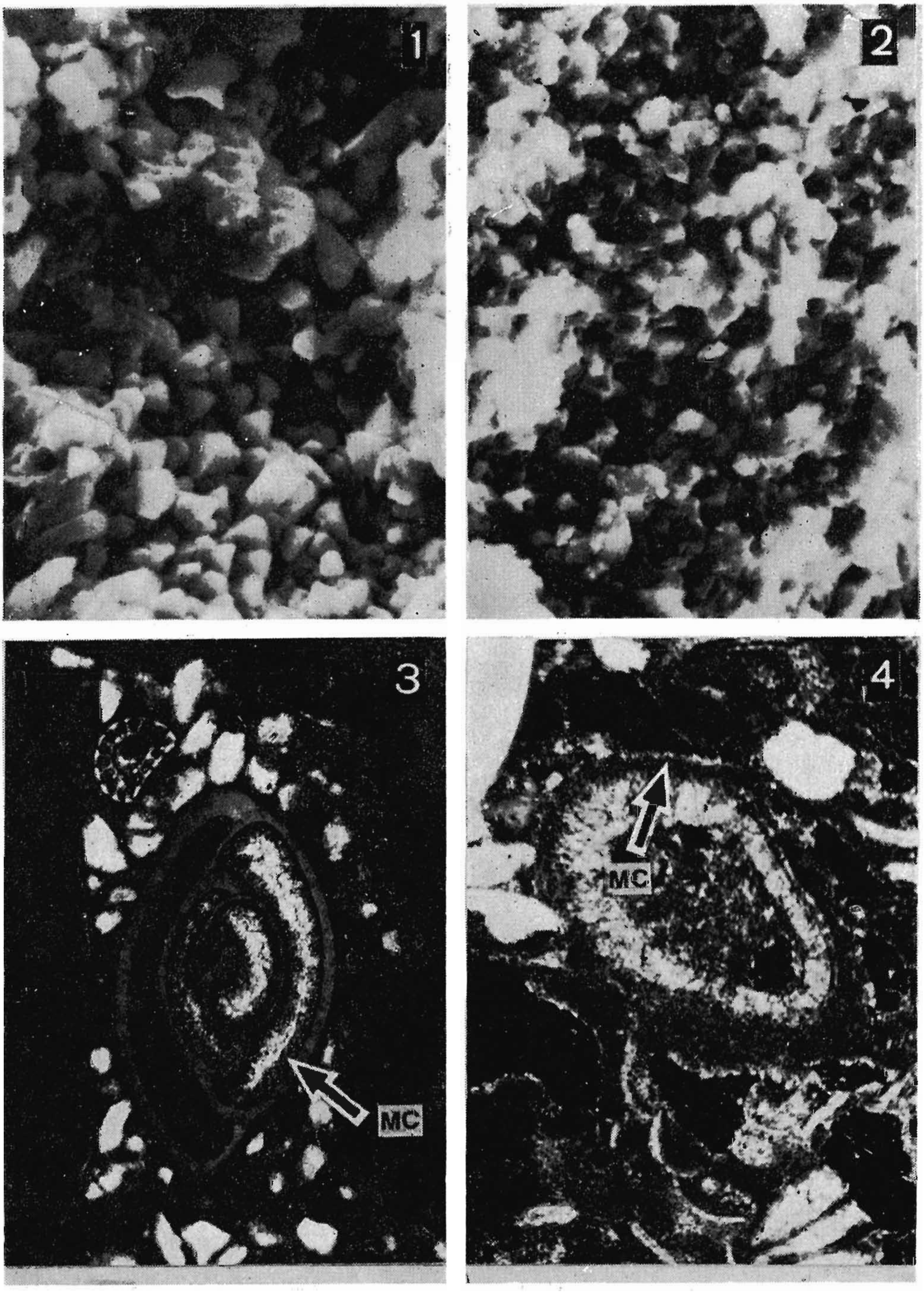
3 — Algal boring within aragonite spherulitic cement (*arrowed*); thin section, ×200; Węglinek

4 — Aragonite needle cement among algal thalli; thin section, ×250; Kamienna Hill



Aragonite spherulitic cement

1-2 — Aragonite spherulitic cement showing dissolution traces of individual needles; *SEM* ×240; Węglinek
3 — Aragonite spherulitic cement infilling conceptacles in algal thallus; thin section, ×25; Węglinek
4 — Diagenetic sequence: aragonite spherulitic cement, partly dissolved (*arrowed*), followed by equant calcite cement; thin section, ×100; Węglinek



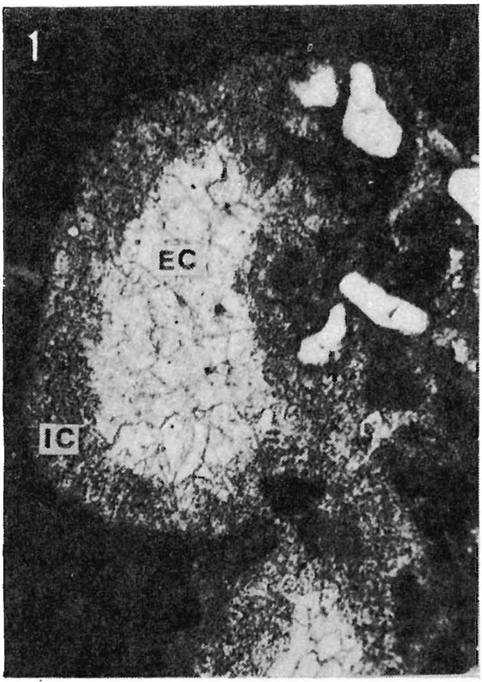
Micritic cement

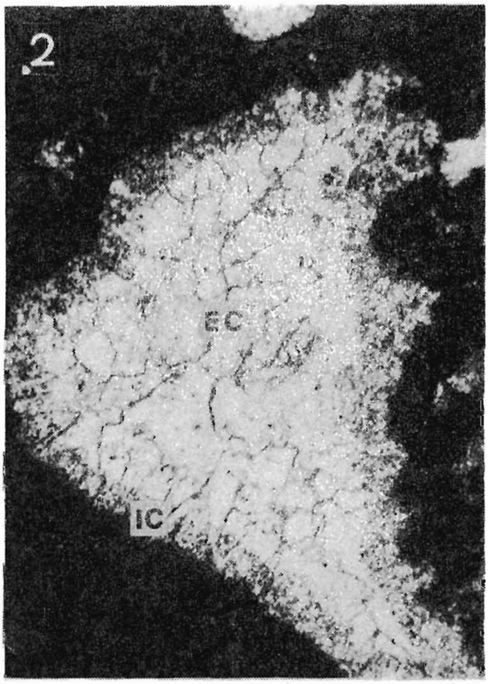
1 — Micritic cement lining interior of a foraminiferal test; *SEM* ×1800; Węglinek

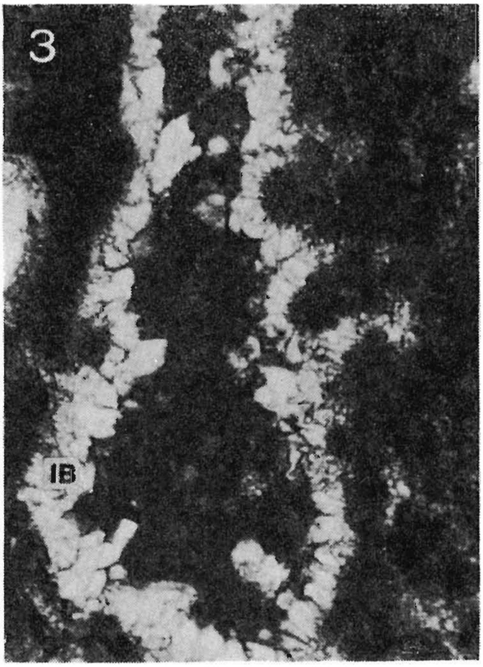
2 — Micritic cement between grains in the internal sediment; *SEM* ×1800; Węglinek

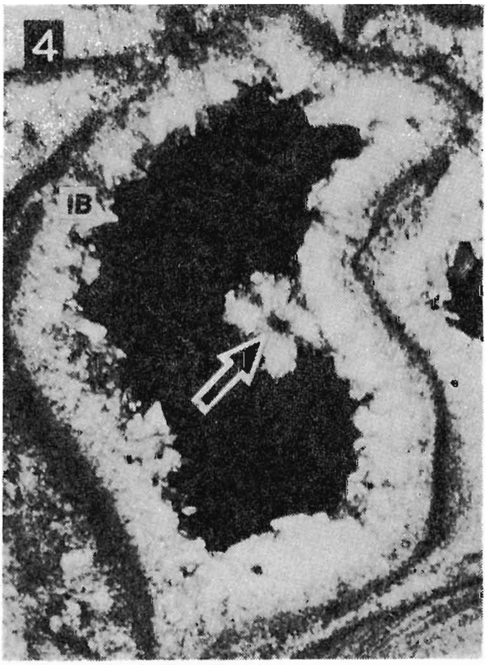
3 — Micritic cement lining interior of a foraminiferal test (*MC*, arrowed), void left, infilled with equant calcite cement; thin section, ×100, Węglinek

4 — Micrite cement (*MC*, arrowed) between grains in the internal sediment; thin section, crossed nicols, ×100; Węglinek







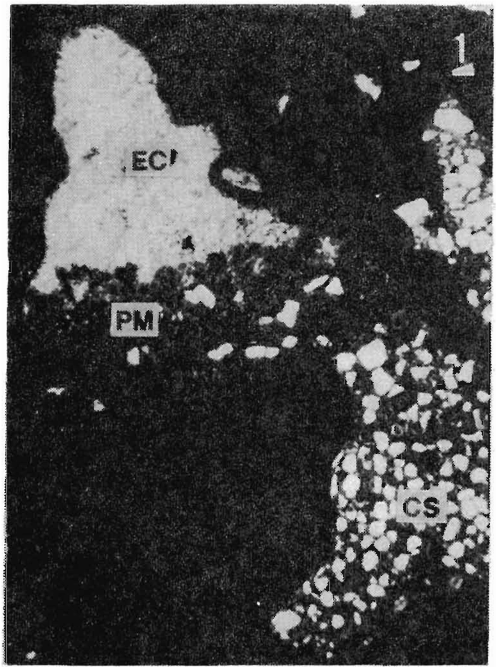


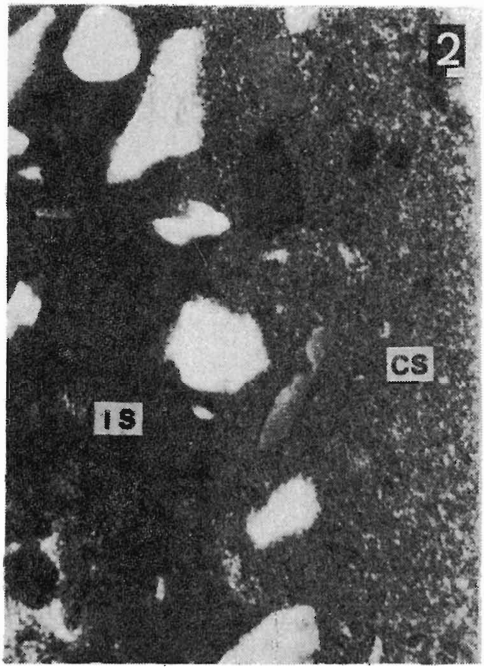
Diagenetic sequences in primary cavities

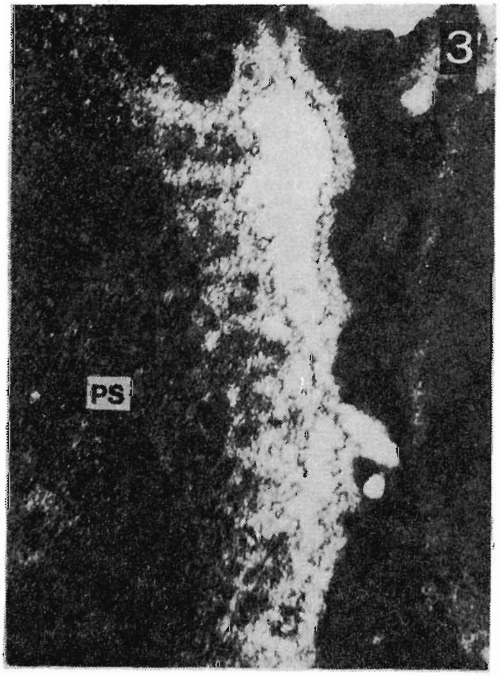
1-2 — Isopachous cloudy rim cement (*IC*) followed by equant calcite cement (*EC*); thin section, × 100; Węglinek

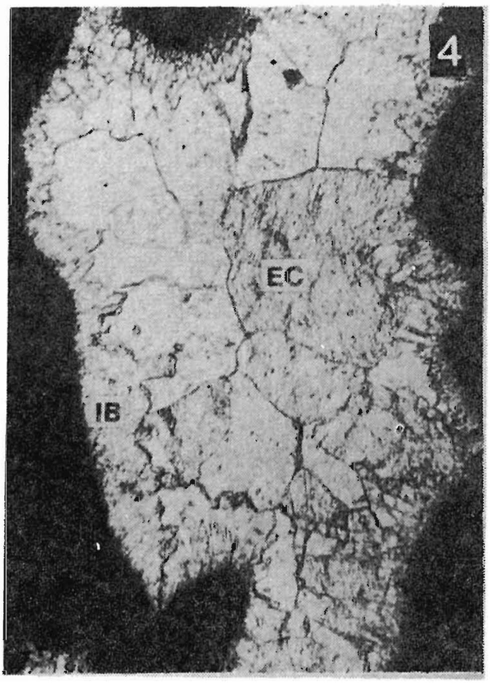
3 — Isopachous bladed (*IB*) and isometric calcite cement covered with micritic sediment; thin section, × 100; Węglinek

4 — Isopachous bladed or isometric calcite cement (*IB*) lining interior of bryozoan zooecium and algal filament (*arrowed*); thin section, crossed nicols, × 100; Węglinek







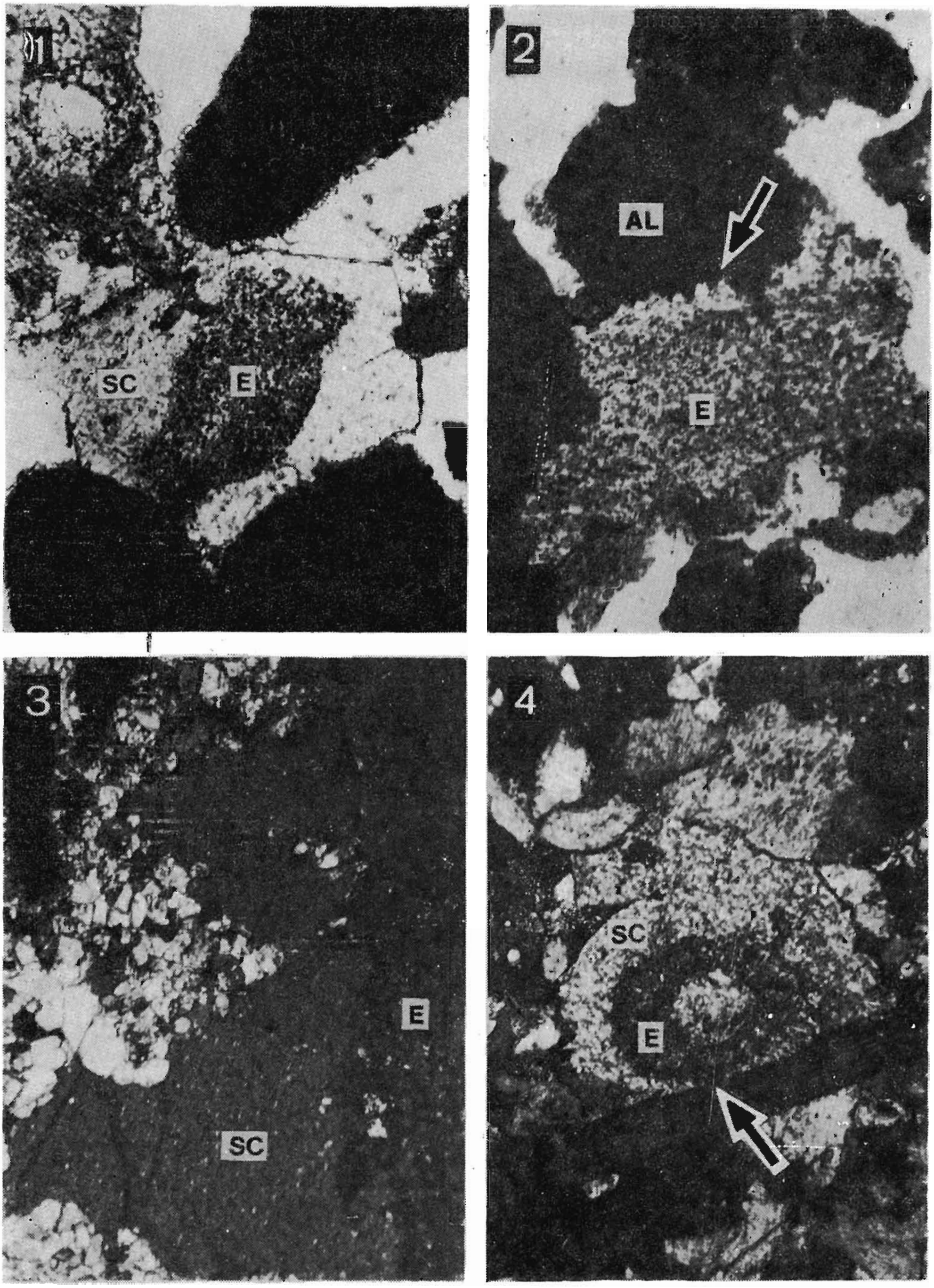


1 — Typical infilling of the primary cavity: calcareous sandstone (*CS*) passing into pelmicrite (*PM*) and followed by equant calcite cement (*EC*); thin section, ×25; Łychów

2 — Crystal *silt* (*CS*) resting on the erosional surface of internal sediment (*IS*); thin section, ×100; Węglinek

3 — Pelletal silt (*PS*) partly filling secondary cavity and followed by isometric isopachous cement; thin section, ×100; Węglinek

4 — Bladed isopachous cement (*IB*) followed by equant calcite cement (*EC*); thin section, ×100; Węglinek



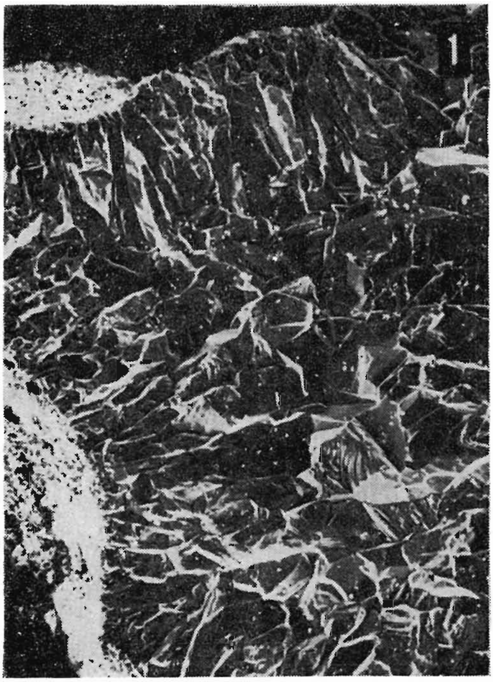
Syntaxial calcite on echinoderm clasts

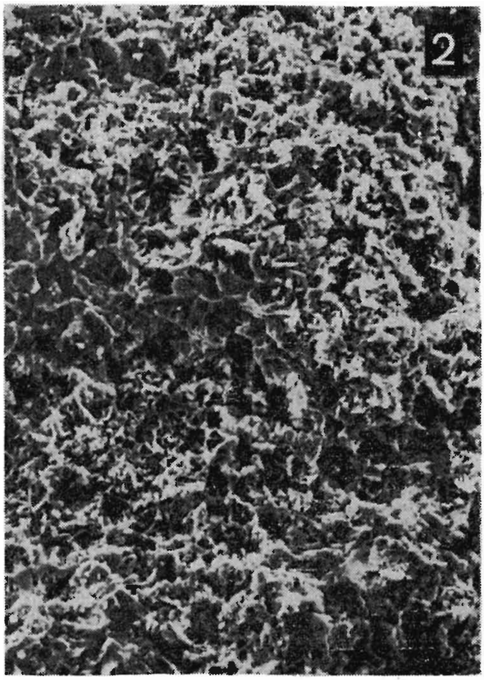
1 — Syntaxial calcite cement (*SC*) with well developed crystal faces on echinoderm clast (*E*); thin section, ×100; Łychów perireef biocalcarenites

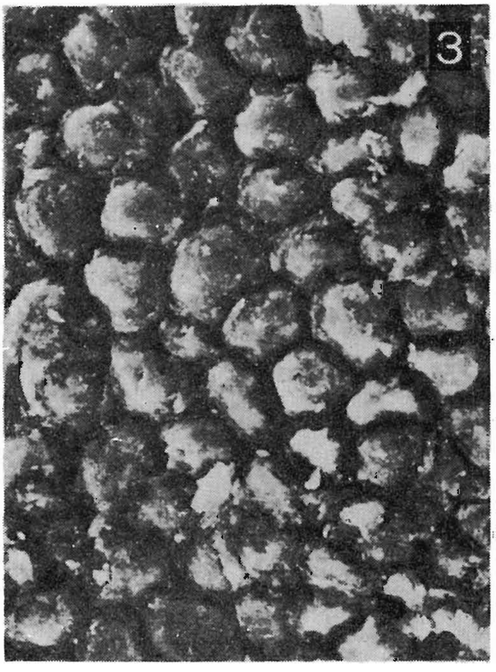
2 — Syntaxial calcite (*arrowed*) developed on echinoderm clast (*E*) clearly replacing algal clast (*AL*); thin section, ×100; Łychów, perireef biocalcarenites

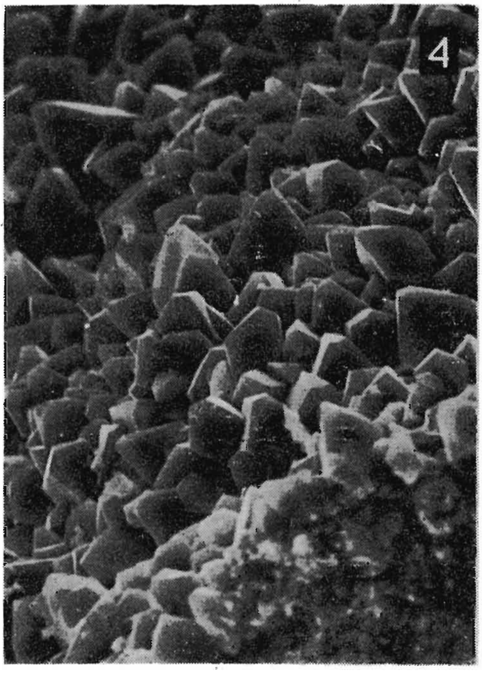
3 — Syntaxial calcite (*SC*) developed on echinoderm clast (*E*) and engulfing smaller calcite crystals; thin section, crossed nicols, ×100; Kamienna Hill

4 — Limiting of syntaxial growth of calcite by bioclast (*arrowed*; *E* echinoderm clast, *SC* syntaxial calcite); thin section, crossed nicols, ×100; Kamienna Hill

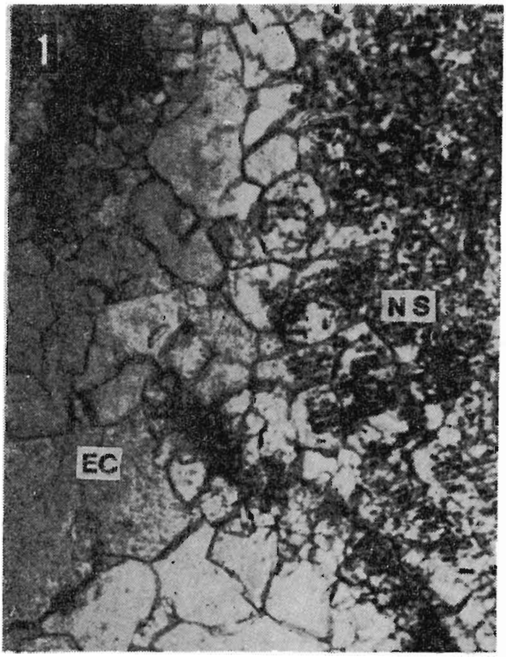


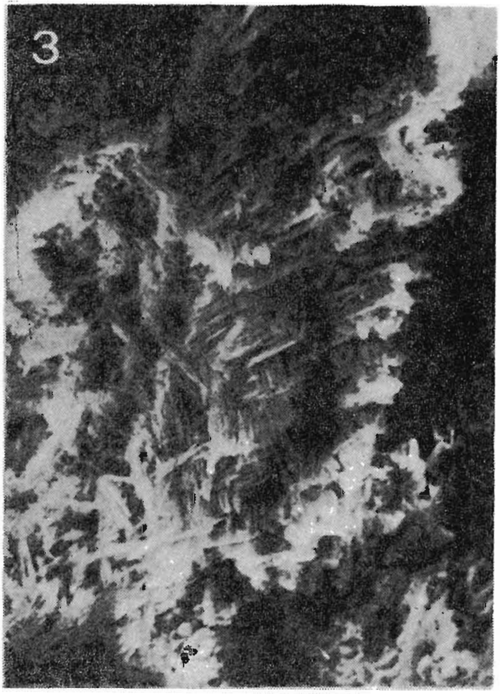


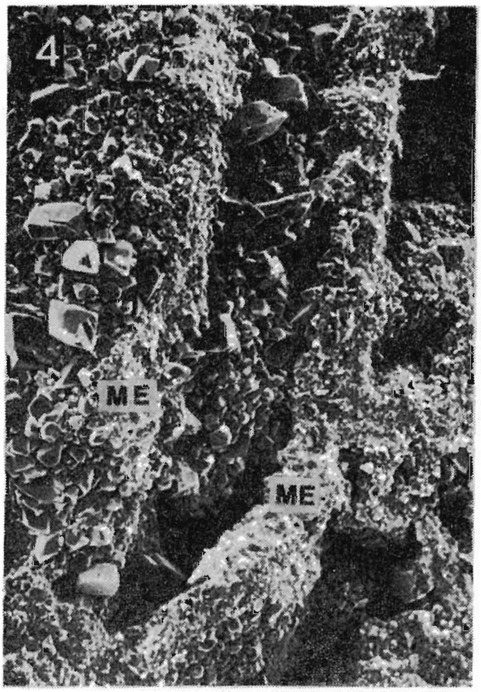




1 — Equant calcite cement infilling primary cavity; *SEM* ×100; Węglinek
2 — Spongy structure of isopachous cloudy rim cement; *SEM* ×200; Węglinek
3 — Micrite infilling algal cells; *SEM* ×900; Węglinek
4 — Rhombohedral crystals of equant calcite cement; *SEM* ×300; Węglinek





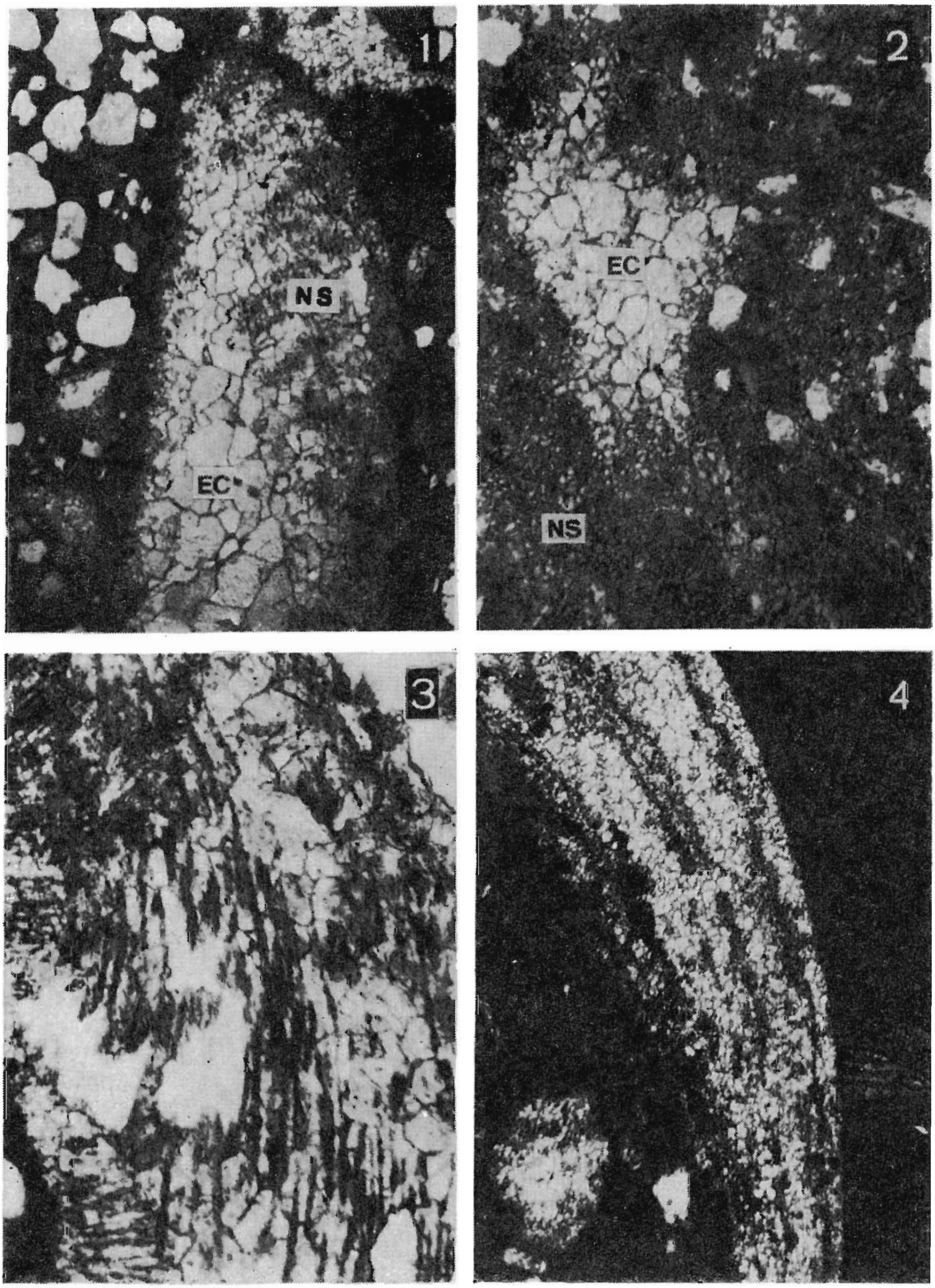


1 — Neomorphic sparite (*NS*), with relics of primary microstructure, and equant calcite cement (*EC*) replacing a molluscan shell; thin section, ×100; Radwanówka

2 — Equant calcite cement (*arrowed*) in the void left after dissolution of aragonite shell, a part of which is still preserved (*A*); thin section, ×100; Węglinek

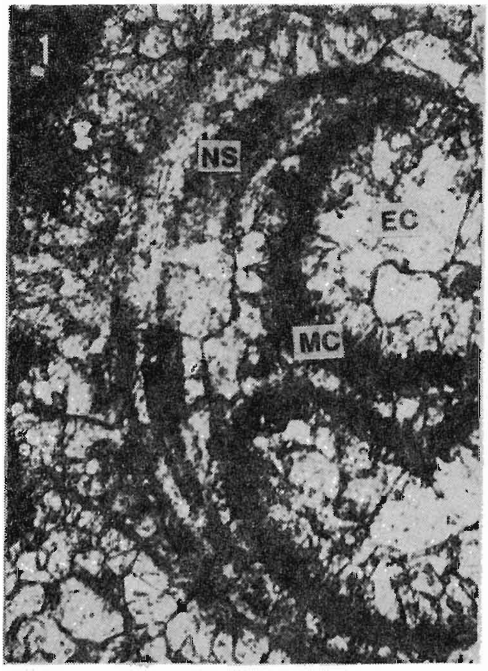
3 — Crossed-lamellar microstructure of vermetid shell with traces of leaching; *SEM* ×360; Węglinek

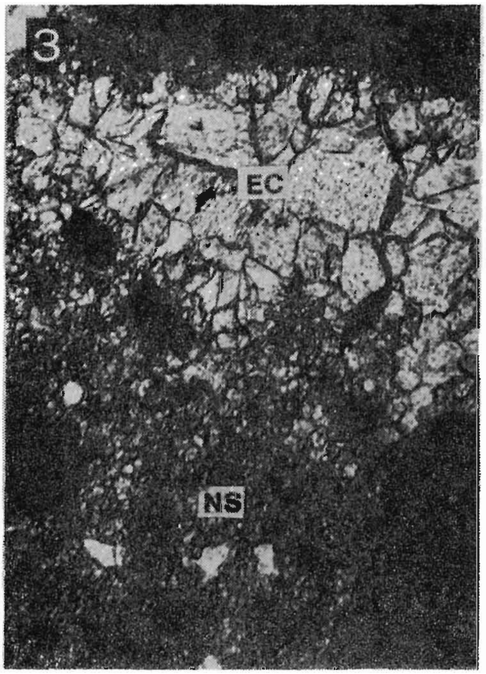
4 — Micritic envelopes (*ME*) on a vermetid shell, encrusted with equant calcite cement; *SEM* ×120; Węglinek

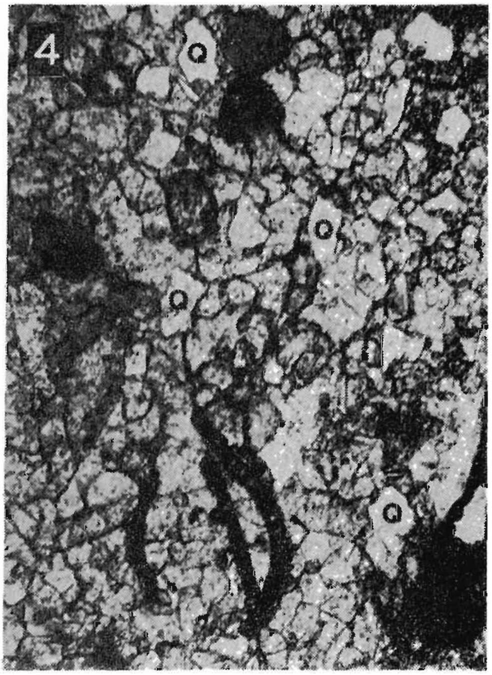


Neomorphism of shells and sediment

1 — Neomorphic sparite (*NS*) and equant calcite cement replacing a molluscan shell; thin section, ×100; Radwanówka
2 — Neomorphic sparite (*NS*) with floating quartz grains followed by equant calcite cement (*EC*); thin section, ×100; Radwanówka
3 — Relics of primary microstructure in the neomorphic sparite replacing a molluscan shell; thin section, ×100; Radwanówka
4 — Neomorphic sparite replacing aragonite lining of a bivalve boring; thin section, ×100; Węglinek





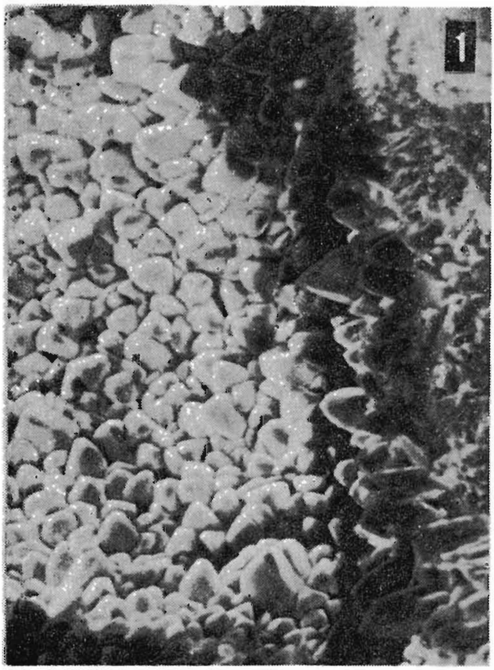


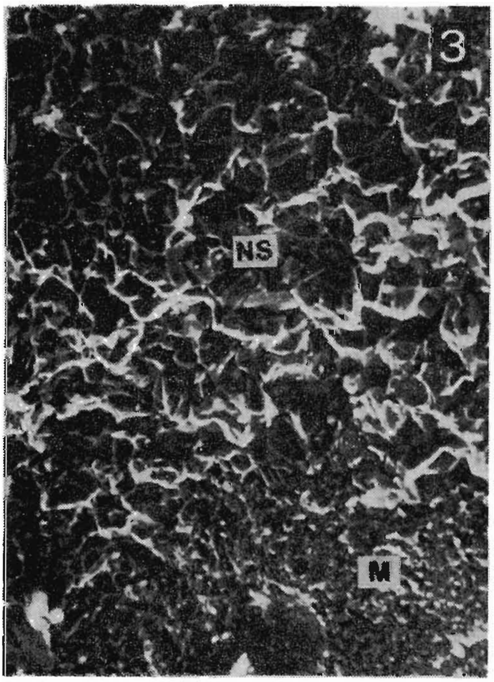
1 — Neomorphic sparite (*NS*) in a vermetid shell infilled with micritic (*MC*) and equant calcite (*EC*) cement; thin section, ×100; Łychów

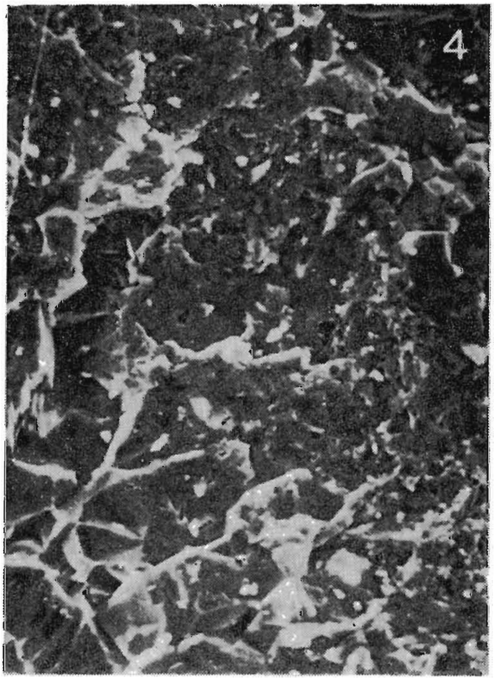
2 — Neomorphic replacement of the vermetid shell and cement infilling its interior; geopetal sediments and micritic envelopes are visible; thin section, ×30; Radwanówka

3 — Neomorphic sparite (*NS*) replacing micrite in the internal sediment followed by equant calcite cement (*EC*) in the primary cavity; thin section, ×100; Kamienna Hill

4 — Quartz grains (*Q*) and bioclasts floating in neomorphic sparite; thin section, ×100; Kamienna Hill



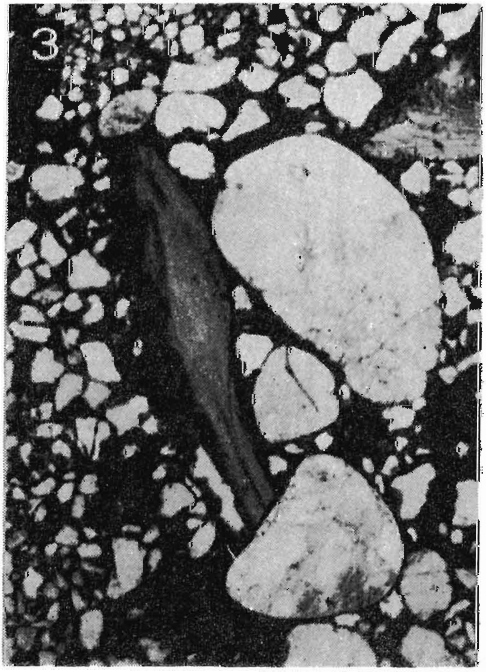




1-2 — Differently developed bladed isopachous calcite cement; *SEM*, Fig. 1 ×360, Fig. 2 ×300; Radwanówka

3 — Neomorphic sparite (*NS*) developing at expence of micrite (*M*); *SEM* ×240; Radwanówka

4 — Neomorphic sparite with relics of micrite; *SEM* ×350; Radwanówka



1 — Algal borings in a molluscan shell, infilled with authigenic glauconite; thin section, ×100; Węglinek
2 — Test of sessile foraminifer *Nubecularia* sp. with algal borings; thin section, ×100; Węglinek
3 — Differently sized and rounded quartz grains; thin section, ×100; Węglinek
4 — Syntaxial neomorphic sparite in the foraminiferal test; thin section, crossed nicols, ×100; Węglinek

JØRGENSEN 1976; JAMES & *al.* 1976; MACINTYRE 1977; JAMES & GINSBURG 1979; LAND & MOORE 1980) to deep-water environment (MILLIMAN & *al.* 1969, MILLIMAN 1971) and hypersaline lagoons (FRIEDMAN & *al.* 1973). It is also common in Recent algal-vermetid reefs (GINSBURG & *al.* 1971, SCHROEDER 1972b, FOCKE & GEBELEIN 1978, FOCKE 1978a). In fossil and subfossil deposits it has been noted only in a few cases (*see* SCHROEDER 1973, 1979; SCHERER 1977; RICHTER 1979; BUCHBINDER & FRIEDMAN 1980). Although it is a very rare type of cement in the rocks described here, by analogy with the Recent occurrences one may claim early submarine genesis for it.

In some bivalve borings in the algal-vermetid reefs from Roztocze, coatings of the wall were observed (Pl. 41, Fig. 4). At present they are built by neomorphic calcite, but the preserved traces of microstructure allow comparison with Recent counterparts which are built by aragonite spherulites organised in laminae (*see* SCHROEDER 1972b, Fig. 3). I suspect that the Badenian coatings were also aragonitic and formed very early during the reef growth and may also be regarded as a kind of early submarine cement.

ISOPACHOUS CLOUDY RIM CEMENT

This cement forms isopachytic encrustations of the walls of various types of synsedimentary pores, mainly the growth-framework pores and intraskeletal pores of bryozoans (Pl. 36, Figs 1—2). The thickness of the rim is 30 to 80 µm, and the width of individual crystals is 10 to 15 µm. Crystals are usually perpendicular to the substrate and the outer rim surface is regular. In thin section this cement is always very cloudy and yellow in colour. Sometimes it also cements pelloids and quartz grains in the internal sediment. Individual crystals, because of their cloudiness are very difficult to discern, even with crossed nicols. In *SEM* it has spongy structure (Pl. 39, Fig. 2) which is interpreted here as an effect of selective dissolution. A very similar spongy structure which originated by solution was noted by SCHROEDER (1979) in Mg-calcite palisade cement from the Quaternary deposits of Kenya. In thin section this cement closely resembles palisade cement (*see* SCHROEDER 1972a,b 1979) which occurs in Recent algal-vermetid reefs and is built by Mg-calcite. It is the most common Recent submarine cement (*see* JAMES &*al.* 1976, JAMES&GINSBURG 1979, MARSHALL & DAVIES 1981, TAYLOR & ILLING 1969, SHINN 1971a,b). Other fossil occurrences of cloudy rim cement are very common in deposits from the Cambrian to Miocene time (PURSER 1969, MEYERS 1974, HAVARD & OLDERSHAW 1976, PETTA 1977, ACHAUER 1977, PEDLEY 1979, JAMES & KOBLUK 1978, BURGESS 1979). It always forms the first generation of cement and is regarded as an early aragonite or Mg-calcite submarine cement.

The early submarine origin of this cement in the Roztocze rocks is also indicated by the fact that it is always the first generation of cement, that it cements grains in the internal sediment and contains numerous impuruties typical for the Recent submarine cements. It was precipitated under conditions of complete infilling of pores with water (phreatic zone) which is indicated by its isopachytic character. One may claim that it was primary Mg-calcite cement not aragonite. Other aragonite cements are still preserved in the same samples, so there is no reason for claiming preservation of one type of aragonite cement and the dissolution of another type. This Mg-calcite primary mineral composition is also suggested by the regular outer surface of the rim, caused by the regular development of individual crystals — a typical feature of Recent Mg-calcite cement. In aragonite needle cement this surface is irregular, the irregularity being caused by various lengths and orientations of individual crystals (*cf.* SCHROEDER 1972b).

MICRITIC CEMENTS

In biomicrites it is impossible, in thin section, to discriminate between micritic cement and detrital carbonate mud. As most of internal sediments are (or were) developed as biomicrites the importance this type of cement is difficult to evaluate. If micrite is present between grains and/or in the intraskeletal pores in the form of isopachytic encrustations, it may be regarded as cement

(Pl. 35, Figs 3—4). Sometimes the shells of foraminifers are broken together with such micritic rims which may indicate its early genesis (*cf.* SCHROEDER 1973). In *SEM* this micrite shows small 2—4 µm crystals with readily visible rhombohedral terminations (Pl. 35, Figs 1—2). Recent submarine Mg-calcite micritic cements are of the same morphological form (*see* SCHROEDER 1972b, 1973; GINSBURG & SCHROEDER 1973; ALEXANDERSSON 1974; JAMES & *al.* 1976; MACINTYRE 1977; JAMES & GINSBURG 1979). One may also regard micritic cement from the Badenian algal-vermetid reefs as a primary Mg-calcite cement. The fact that it is always the first generation of cement is also a point in favor of an interpretation of early genesis.

Micritic envelopes present in these rocks can also be regarded as early submarine cement though their origin depends mostly on the biological activity of microorganisms (BATHURST 1975, LLOYD 1971, KOBLUK & RISK 1977). Micritic envelopes are common around vermetid shells (Pl. 40, Fig. 4) and sometinmes may be present around coralline algae. In Recent sediments they are built by Mg-calcite which allows their preservation in a fossil state (WINLAND 1968). The micrite infilling and/or encrusting algal filaments observed in thin sections may be also regarded as micritic cement. Also some pelloids, with size range 10 to 60 µm, observed in synsedimentary pores (Pl. 36, Fig. 3) may be considered as a special type of micrite cement. Pelloids of this size and occurrence are very common in Recent reef sediments (MACINTYRE & *al.* 1968, JAMES & *al.* 1976, MACINTYRE 1977, MARSHALL & DAVIES 1981), and have also been noted in the Miocene reefs of Malta (PEDLEY 1979). In Recent sediments they are formed by Mg-calcite and considered as a special type of micritic cement (ALEXANDERSSON 1978, MACINTYRE 1977, MARSHALL & DAVIES 1981). LAND & MOORE (1980) propose a more complex genesis for such pelloids introducing a hypothesis of passive precipitation of small calcite crystals, and their subsequent reworking by filter-feeding invertebrates into micritic pellets of large size. These pelloids are interpreted as early submarine cement which is also confirmed by the fact that they are sometimes cemented by cloudy rim cement (Pl. 36, Fig. 2), the submarine origin of which is not doubted.

SYNTAXIAL SPARITE CEMENT

This type of cement is especially common in biocalcarenites (Pl. 38, Figs 1 and 4) surrounding and covering the reef limestones. Its best development, as usual, is on echinoderm grains (*cf.* EVAMY & SCHERMAN 1965, BATHURST 1975). However, it is not always easy to determine if syntaxial sparite is of cement or neomorphic origin. In a situation when sparite has developed crystals faces at its boundaries, there is no doubt that it represents cement. Sometimes syntaxial sparite has very irregular boundaries and engulfs even small crystals with different optical orientation (Pl. 38, Fig. 3). Such syntaxial crystals are not true cement crystals but at least partly developed through a neomorphic process. It may have initially grown as a cement but later started to increase its volume at the expence of neighbouring smaller crystals and changed their optical orientation in what should be regarded as a neomorphic process. This is confirmed by the observation that pores of such geometry as occupied by some syntaxial calcite are difficult to explain. When the development of syntaxial sparite is limited by sedimentary grain its cement character is also confirmed. In some situations, however, syntaxial sparite replaces coralline algal clasts (Pl. 38, Fig. 2) and in such cases neomorphic origin seems more probable (*cf.* BATHURST 1975).

Syntaxial sparite is also common in foraminifer tests (Pl. 44, Fig. 4; *cf.* KENDALL 1976, BURGESS 1979). As microstructure of the test is prismatic, cement crystal orientation is governed by them and cement shows undulose extinction under crossed nicols. This is caused by the presence of subcrystals with a slightly different optical orientation.

Syntaxial cement is regarded as a relatively early cement, in some cases even as submarine cement (EVAMY & SCHERMAN 1965, REIJERS 1972, SCHNEIDER 1977, BURGESS 1979), but is more typically formed in the fresh water phreatic zone (LONGMAN 1980).

EQUANT CEMENT

Equant sparite cement is the most common cement type in the algal-vermetid reefs from Roztocze. It is built (Pl. 36, Figs 1—2; Pl. 37, Fig. 4; Pl. 39, Fig. 1) by large blocky crystals 50 to 500 μm in size, is clear, and lacks impurities and iron in its lattice. This lack of trace amounts of iron indicates oxydizing environments during its formation. In early stages its crystals may be slightly elongated. Usually however, they are isometric. Their tips have crystal faces, visible in *SEM*, in the form of rhombohedrons (Pl. 39, Fig. 4) or of the rhombohedron sets rotated (*see* SCHROEDER 1973). This cement sometimes has typical drusy character eg. shows centripetal growth of crystal size which indicates quick nucleation. In other places, however, large blocky crystals are developed directly on the substrate. In places these crystals are proceeded by a thin fringe of very small sparite crystals. Sometimes these two types of cement are differentiated (*see* SCHNEIDER 1977) and for centripetally growing cement crystals, fresh-water phreatic genesis is suggested. The second type with large blocky crystals, is regarded as having formed during burial in late diagenesis. As there is no deep burial in the late diagenetic history of the investigated rocks, these differences could be explained by differences in the diagenetic microenvironment. Equant sparite cement postdates compaction as indicated by its occurrence in compactional cracks of algal thalli (Pl. 26, Fig. 4). Such equant sparite cement is a typical feature of a fresh-water phreatic zone (LAND 1970, 1971; MULTER 1971; BADIOZAMANI & *al.* 1977; LONGMAN 1980), however, very similar sparry cement, without drusy character, was also found in a marine environment (SCHROEDER 1972b). In some cases pores may be lined (especially secondary pores), in a very irregular manner, with small rhombohedral sparite crystals of strongly varying size (Pl. 37, Fig. 3; Pl. 40, Fig. 4) indicating quickly varying environmental parameters. It may be regarded as an initial stage of equant cement formation, however its vadose origin can not be excluded.

ISOMETRIC TO BLADED RIM CEMENT

This common type (Pl. 36, Figs 3—4; Pl. 37, Fig. 4; Pl. 43, Figs 1—2) is always calcitic and isopachytic in character. The size range of crystals is from 10 to 35 μm in width and from 95 to 155 μm in length for more bladed forms, and 30×60 μm for more isometric forms (Pl. 36, Figs 3—4). Crystals are clear and without any impurities. This cement usually forms the first generation, predating equant cement (Pl. 37, Fig. 4) or occurs alone. Sometimes it forms the second generation postdating cloudy rim cement, and sometimes may be covered by micrite of internal sediment (Pl. 36, Fig. 3). If an equant cement is present, no optical continuity between it and bladed cement exists (Pl. 37, Figs 3—4) what indicates a break between crystalization of these types of cements.

This cement shows some similarities to palisade cement, as described by SCHROEDER (1972a,b) however it lacks any impurities. Scalenohedral calcite cement from the Devonian reefs of Germany, is also similar (*see* SCHNEIDER 1977). According to SCHNEIDER (1977), it was originally Mg-calcite cement of sub- to intertidal origin. In the case described here its marine origin seems improbable, as no impurities which are typical for marine cements are present. It is rather an early cement which originated presumably by mixing relict marine waters and fresh-water shortly after regression of the sea, but a genesis during shallow burial is also possible.

PRESERVATION OF SHELLS

All primary calcitic, low and high magnesian, biogenic remains are preserved with all details of original microstructure. No neomorphic changes were observed under the light microscope. Coralline algae show no diagenetic changes except of (Pl. 39, Fig. 3) infilling of cells by micritic cement of a very small size (*cf.* JAMES & *al.* 1976, GIRAUD & CABIOCH 1979).

Primary aragonitic skeletons may be preserved with original microstructure and mineralogical composition (Pl. 40, Fig. 3), they may be neomorphosed (Pl. 41, Figs 1 and 3; Pl. 42, Fig. 1) or dissolved leaving empty pores (Pl. 8, Fig. 2) or secondarily infilled by equant calcite cement (Pl. 40, Figs 2 and 4; Pl. 41, Fig. 1). The diagenesis of vermetid shells serves as the best example of this variation. The quick changes over centimeter-scale distance, where aragonitic shells are either preserved or dissolved are very characteristic. This indicates the important role of microenvironment in diagenesis.

NEOMORPHISM

The only neomorphic process considered in this paper is agrading neomorphism (FOLK 1965, BATHURST 1975). No feature which may be regarded as degrading neomorphism was noted. Micritization is considered as a process of biogenic destruction and cementation and is treated elsewhere.

Neomorphism differs from dissolution with the later cement precipitation mainly in the scale of the zone of reaction of diagenetic solution and calcium carbonate precipitation. A thin film solution zone is usually regarded as producing neomorphic effects. This zone should be about 1 μm (PINGITORE 1976). Recently, however, *SEM* investigations (WARDLAW & *al.* 1978) showed that such zone of dissolution/precipitation is not visible. If it exists at all, it should be smaller than 100 Å.

The best material with which to study neomorphism in the investigated rocks are vermetid shells. Changes in these shells started relatively early when other components of the rock were still not neomorphosed.

In some cases the micritic matrix of internal sediment is also neomorphosed (Pl. 41, Fig. 2; Pl. 42, Figs 3—4; Pl. 43, Figs 3—4). When large, up to 100 μm in diameter neomorphic crystals originated, it is difficult to differentiate equant cement from neomorphic calcite (*see* for example Pl. 42, Fig. 4; Pl. 43, Fig. 2).

Recrystalized aragonitic molluscan shells are built by large neospar crystals (Pl. 41, Figs 1 and 3; Pl. 42, Fig. 1) usually slightly brown in colour with pseudopleochroic features, caused by organic substance dispersed in the calcite (HUDSON 1962). Traces of original microstructure, usually as linear inclusions that cut crystal boundaries point to the neomorphic origin of these crystals. Sometimes intermediate stages are present (*i.e.*, shell is partly built by neomorphic calcite and partly by original aragonite crystals-corroborated by positive reaction with FEIGEL'S solution). In other cases neomorphic calcite crystals and cement calcite (sparite) occur in the same shell (Pl. 40, Fig. 1; Pl. 41, Fig. 1). The interpretation of this feature involves changing diagenetic environment which caused partial neomorphism and/or dissolution of the shell with later sparry cement precipitation (*see* SCHROEDER 1979). In many cases it is difficult to decide if the sparry calcite is of neomorphic origin or if it represents cement; it is especially difficult when no relict structures are visible and the drusy character of sparite is poorly developed (Pl. 42, Fig. 2). The only indications of the neomorphic character of sparite may be very irregular intercrystal boundaries and the size of individual crystals (smaller than in cement). The discrimination between neomorphic spar and sparry cement is also complicated by the presence of plane boundaries between crystals of neomorphic origin in vermetid shells (*cf.* SCHROEDER 1973). This boundary shape is caused by the existence of control over neomorphic process by primary boundaries existing in the shell and is associated with organic films.

The observed neomorphic sequence always begins within aragonite vermetid shells. In the early stage of this process, when only part of the shell is recrystalized to low magnesian calcite, the control of primary microstructure over the shape of neomorphic crystals is visible. Crystals with plane boundaries, restricted to one of the structural units of the shell originate then. Later stages are characterized by large crystals that do not respect primary structural boundaries. Usually there is no optical continuity between the neomorphic crystals within the shell and the sparry cement inside the shell — this indicates an interval of time between the process of cementation and neomorphism (*cf.* SCHROEDER 1973).

PINGITORE (1976), in his investigation of coral diagenesis, observed different diagenetic structures in fresh water vadose and phreatic zones. These structures permitted a discrimination between these two zones in a fossil state. However, because PINGITORE'S work was based on corals his interpretations are not directly applicable to other microstructural types of skeletons.

The vadose zone is characterized by a clear differentiation of the neosparite of the skeleton from the blocky cement that infills intraskeletal pores (the blocky cement having smaller crystal size; PINGITORE 1976). In our case the cement crystals are much coarser than the neospar crystals and there is no cross-cutting mosaic (*see* PINGITORE 1976), situation different from that observed by PINGITORE. Thus, it is not clear which diagenetic environment is responsible for the neomorphism of vermetid shells. The presence of sharp boundaries between sparite and neosparite and common relict structures may indicate the vadose zone (*cf.* PINGITORE 1976). The absence of other features typical for this environment makes that conclusion uncertain. Our observations, however, suggest that the criteria given by PINGITORE (1976) are not directly applicable to every type of skeleton, and it seems that microstructure plays an important role in diagenetic behaviour of aragonite skeletons. In the particular case the picture is additionally complicated by overprint of different diagenetic regimes.

It is also very diffcult to differentiate orthosparite and neosparite when they cooccur in the matrix of internal sediment. Relicts of micrite (Pl. 41, Fig. 2; Pl. 42, Figs 2—3) and strongly irregular intercrystaline boundaries indicate a neomorphic origin (BATHURST 1975) for most of sparitic matrices of internal sediments .Sometimes micrite is preserved, the situation where only microsparite to neosparite is present (Pl. 42, Fig. 3; Pl. 43, Fig. 3) is most common. The neospar crystals are usually up to 100 μm but microspar with isometric crystal of about 10 to 20 μm is also present (Pl. 41, Fig. 2; Pl. 42, Fig. 3).

Some patches of sparite (Pl. 41, Fig. 2; Pl. 42, Fig. 3) were recognized as orthosparite (equant cement), despite their occurrence within undisputable neospar areas. Its cement origin is indicated by the larger cement crystal size (over 100 μm), not observed in neospar, the presence of plane intercrystaline boundaries, the drusy character of the spar patches as well as by the absence of any relict structures. It is also possible that some other areas of sparite built by small crystals have an orthosparite character, but their size precludes its characterization from only thin section observations. STEINEN (1978) has shown that such spar patches, in thin section looking exactly like neospar, in reality may be considered as cement because they have developed crystal faces visible in the *SEM* images.

Commonly, micrite, microsparite and neosparite co-occur even in one thin section. This coexistence was probably caused by differences in clay content and/or microporosity of the rock (*cf.* LONGMAN 1977, LONGMAN & MENCH 1978). In our case microporosity seems decisive because the clay content is very small.

Neomorphism does not affect primary calcite skeletons as scallop shells or lithothamnian algae.

It seems that microspar formation is a relatively late process and occurs after mineralogical stabilization of micrite (*see* LONGMAN & MENCH 1978) and is controlled by the presence of fresh water in a phreatic zone (JACKA & BRAND 1977).

TRACE ELEMENTS

A few spectrographical analyses were made to provide data on the distribution of such trace elements as strontium, magnesium, and manganese.

The strontium concentration in the investigated rocks ranges from 200 ppm to 900 ppm (average 590 ppm). This variation of strontium abundances depends on the degree of diagenetic changes of the sample used. Those samples which contain low quantities of strontium are strongly altered diagenetically and important quantities of late sparry cements are present. This is the case for Kamienna Hill and Łychów samples. It is a typical diagenetic feature (GAVISH & FRIEDMAN 1969, KINSMAN 1969). All the samples investigated contain mainly coralline algae and micritic internal sediments (or sparry matrix). Recent coralline algae usually contain 2200–2700 ppm of strontium (CHILLINGAR & *al.* 1967, MORROW & MAYERS 1978). Recent carbonate muds may also contain large quantities of this trace element depending on aragonite and calcite contents. DEAN & EGGLESTONE (1975) have found 2200–8000 ppm of strontium in different internal sediments in Recent Bermuda algal-vermetid reefs — higher values always being associated with high aragonite contents. Based on this observation one may claim that the important decrease of strontium in the Roztocze rocks followed mineralogical stabilization because its primary quantities were most likely around 2000–3000 ppm, considering that Mg-calcite dominated in the samples. Other Miocene limestones with high coralline algae contents have much lower, usually 100–200 ppm of strontium (IMREH & BEDELEANI 1967), extremes are 10 and 1000 ppm. Coralline algae from the Ukraine, however, contain comparable amounts of this trace element (*see* MASLOV 1962).

As it was shown by MORROW & MAYERS (1978) the early diagenetic (stabilization of Mg-calcite and aragonite and equant sparite cement crystalization), decrease of strontium is to about 400 ppm, if the primary sediment contained a mixture of Mg-calcite with a high strontium content and some aragonite. This is the case observed in here.

Magnesium contents range from 0.4% to 1.7% (average 1.17%). The lowest amounts of Mg in the samples are associated with low Sr content which indicates diagenetically advanced samples that contain important amounts of late equant cement and neomorphic spar.

The primary content of magnesium was without doubt up to several per cent as coralline algae are built of Mg-calcite. This suggests that during diagenesis the amount of Mg in the sediment also decreased, so that at present only low Mg-calcite (containing about 2 mole % of $MgCO_3$) is present (*see* Text-fig. 14). The spectrographic analyses have shown, however, much higher values for Mg. The source of magnesium should be looked for in clay minerals, glauconite and dispersed dolomite. This is confirmed by the weak reflex of dolomite on some rentgenograms (*see* Text-fig. 14).

Manganese values are from 850 to 1300 ppm, average 1170 ppm. This variation is low and no clear correlation with other trace elements is shown. Shallow water sediments contain as a rule low concentration of Mn (FRIEDMAN 1968, DAVIES 1972, BENCINI & TURI 1974, PASCAL 1979, FLÜGEL 1982) but it is caused by their mainly aragonitic mineralogy, as aragonite contains much less manganese in its structure than does calcite (DEER & *al.* 1962, PINGITORE 1978). The Roztocze sediments contained predominantly Mg-calcite, so they should have contained more manganese than shallow-water deposits with predominantly aragonitic composition. Recent coralline algae have the Mn content about 200 ppm (CHILLINGAR & *al.* 1967), and a similar value was noted in a specimen from the Badenian of the Ukraine (MASLOV 1962). As suggested by the data presented above, most of the manganese in the rock samples has a secondary origin. Because the distribution coefficient of manganese in calcite is higher than one (PINGITORE 1978, LORENS 1981) and fresh water is richer in this element than sea water (GARRELS & MACKENZIE 1972, MEYERS 1974), calcite which crystallizes from meteoric water will be enriched in this trace element relative to marine calcite and aragonite. This explains the relatively high values of manganese in the rocks studied here. Part of manganese may occur, of course, outside calcite structure in glauconite and clay minerals or even as manganese minerals (*see* OSMÓLSKI & PILICHOWSKA 1978), but because the amount of glauconite and clay minerals is very small in the rocks studied here, the contribution of manganese from them is neglibile.

RECONSTRUCTION OF THE REEF DEVELOPMENT

The origin and development of the Roztocze algal-vermetid reefs was controlled by the spreading of the Badenian transgression which entered a topographically varied substrate. Initially sedimentation took place only in the depressions (Text-fig. 15*A*); later the spread of the transgression also buried positive elements and when the terrigenous influx decreased reef growth began. The reefs developed only in places where positive elements of the substrate occurred (Text.fig. 15*B*—*C*). The controlling factor of reef development was presumably the topographic differentiation of sea bottom and/or shore character, which regulated hydrodynamic regime and stimulated reef growth. The present hypsometric position of the reef limestones is very similar, except of Radwanówka, where secondary tectonic displacement has caused them to lie higher. As no major facies differences between various reef deposits were observed, it seems reasonable to conclude that the reefs developed at the same depth. The few meters thickness of the reef is the effect of the reef growth caused by a rise of sea level during the development of transgression. The rise of sea level is the main factor controlling the growth of Recent algal-vermetid reefs (SAFRIEL 1974, ZIMMERMANN 1980).

The Roztocze reefs originated by growth of superimposed laminar and complex coralline algal thalli and sessile vermetid gastropods. The porous framework gathered detrital grains (carbonate mud, bioclaste, quartz grains), the quantity of which was,

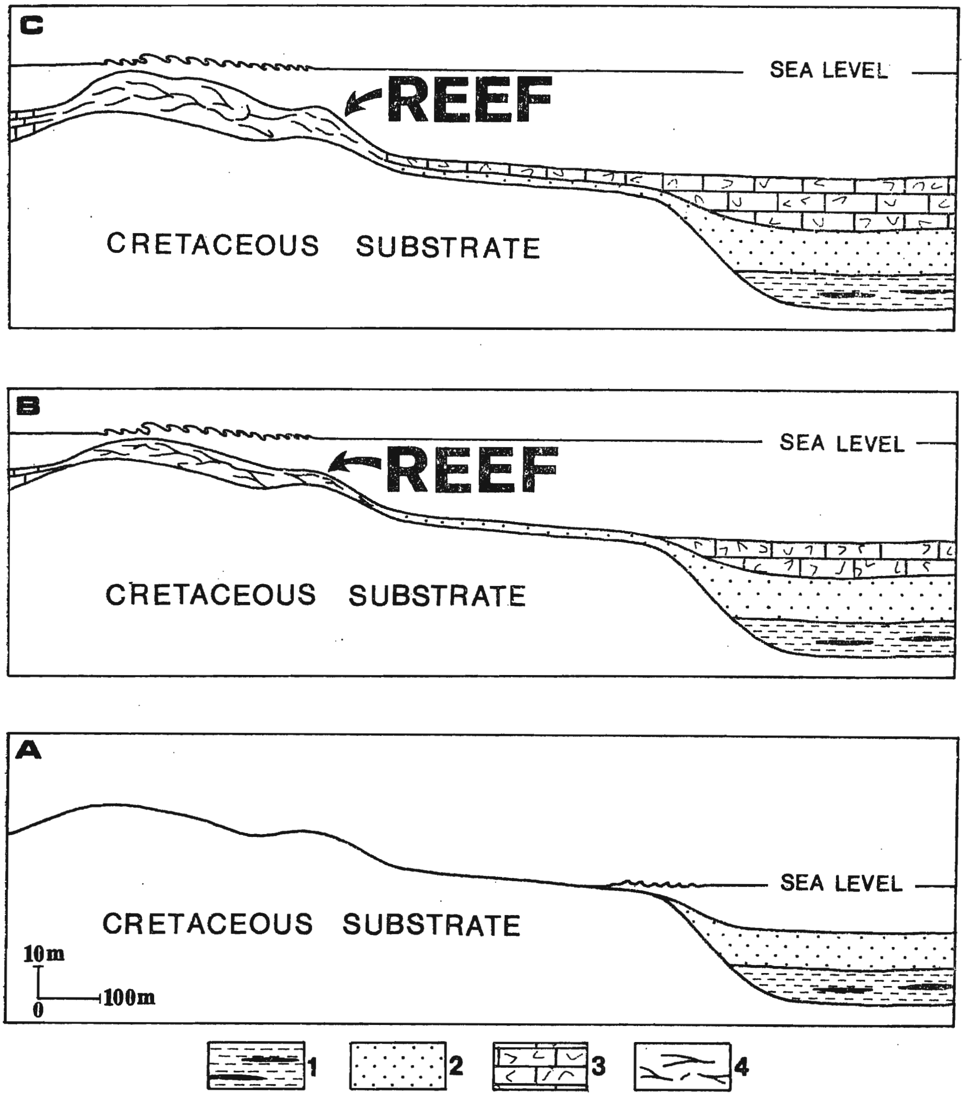


Fig. 15. Facies relationships during successive (A, B, C) developmental stages of the algal-vermetid reef, based on geological data from the Węglinek area

1 — clays with brown-coal intercalations, 2 — quartz sands, 3 — lithothamnian biocalcarenites, 4 — algal-vermetid reef

however, relatively small. According to the classification of RIDING (1977) the Roztocze framework should be regarded as solid-frame. Today, algal-vermetid reefs have similar structure and occur in the wave-breaking zone in coral reefs (PORTER 1972; GLYNN 1973; ADEY 1975; GEISTER 1975, 1977, 1980, 1983; ADEY & BURKE 1976). The structure of the reef was strengthened by early submarine cementation.

The reef frame was suitable habitat for diverse reef-dwelling organisms, especially encrusting forms such as bryozoans, serpulids, foraminifers and some molluscs (which were the secondary reef builders). Other animals simply inhabited suitable microenvironments of hard-bottom and numerous sheltered cavities. The activity of bioeroders (*Gastrochaena, Lithophaga, Cliona*) was low, contrary to the situation in Recent reefs where they are even growth limiting factor (GINSBURG & SCHROEDER 1973, BROMLEY 1978). Noncalcifying algae grew on the reef and in pockets of sand occurring in the reef, as is known also from Recent algal-vermetid reefs (GINSBURG & SCHROEDER 1973, ADEY & BURKE 1976, ZIMMERMANN 1980)

Simultaneously with reef growth on the positive elements of the bottom of the Badenian sea, biodetrital sedimentation took place in the depressions. Mostly coralline algal biocalcarenites and marls with coralline algae (Text-fig. 15*C*) were deposited. The large quantities of detrital quartz in a lower part of the reefs suggest, however that reef growth started earlier when sands had been accumulating in the depressions (Text-fig. 15*B*).

The cessation of the reef growth was relatively abrupt, presumably as an effect of tectonic movements that lowered the level of the bottom. Biodetrital sedimentation developed throughout the study area after termination of reef growth. The reef remained, however, above local wave base.

With the termination of reef growth the subsequent molluscan assemblage differed from that inhabiting the reef during its growth. It seems that the epi-reef assemblage was closely associated with noncalcifying algae and the presence of those algae was a controlling factor in its development.

It is difficult to estimate the synsedimentary relief of the studied reefs. If the reef was only a very low relief biohermal structure one might expect intercalations of detrital sediments, caused for example by storms, of non-reef provienience which were not observed. Recent algal-vermetid cup reefs have considerable relief and form well marked morphological features (SHINN 1971b, STEPHENSON & STEPHENSON 1972, GINSBURG & SCHROEDER 1973, GYGI 1975, ZIMMERMANN 1980, BOSENCE 1983b). Only in one case were deposits which may be regarded as reef talus recognized. But considering Recent reefs, where this zone forms very narrow belt (*cf.* SCOFFIN & GARRETT 1974, LONGMAN 1981), exposure of such deposits would be expected to be rare in poorly outcroped fossil reefs.

Very similar coralline algal constructions commonly occur today in the tropics as algal ridges (WIENS 1962; GLYNN 1973; LITTLER & DOTTY 1975; ADEY & BURKE 1976; GEISTER 1977, 1983; TAYLOR 1978; BOSENCE 1983b) or algal cup reefs (SHINN 1971b, GINSBURG & SCHROEDER 1973, GYGI 1975). Though smaller in size, coralline algal constructions with abundant vermetids, grow on the rocky shorelines in the Mediterranean Sea (PÉRÈS & PICARD 1964; SAFRIEL 1966, 1974; ZIMMERMANN 1980), Carribean (BOYD & *al.* 1963; FOCKE 1977, 1978) and Brasil (KEMPF & LABOREL 1968, JINDRICH 1983). All the occurrences listed above come from the intertidal to very shallow subtidal zone. Some data on the bathymetry of the Badenian reefs are suggested by the taxic composition of the coralline algae. The most common genus in the reefs is the alga *Lithothamnium*, today characteristic of the shallow subtidal zone (WRAY 1977). The species *Lithothamnium lenormandii* even lives up to 3 meters above mean sea level in the Mediterranean Sea, while *Archaeolithothamnium* and *Lithophyllum* dominate in the subtidal zone (LEMOINE 1940).

All known Recent algal bioherms of this type (except for the Tunisian micro-atolls which are lagoonal and contain no vermetids; THORNTON & *al.* 1978), occur in settings with strong wave action. The growth forms of algae from the Badenian reefs (*i.e.*, laminar to complex encrusting thalli) are also identical to those in Recent algal ridges and cup reefs (*compare* Pl. 9, Figs 1—2; Pl. 12, Figs 1—2 and GINSBURG & SCHROEDER 1973, BOSENCE 1983b). TAYLOR (1978) and BOSENCE (1983b) observed that in the algal ridges of Pacific and Indian oceans coralline algae have distinct branches in the highest energy zone while non-branched forms dominate in more sheltered situation. Similarly ADEY & VASSAR (1975) noted that branched forms of *Lithophyllum congestum* occur mainly in the most exposed parts of algal ridge on the St. Croix Island — at mean sea level. The same species also occurs below mean sea level where the wave action is weaker, but there it lacks well developed branches. The very dense and diverse algal frame of the reef points to a high energy of environment (BOSENCE 1983b). All these data suggest that the Roztocze reefs grew in an environment of relatively high energy.

All the most common molluscan genera of the reef assemblage live today at shallow depths, commonly in water not deeper than several meters. Taxonomically comparable assemblages live today on coral reefs, more particularly on algal ridges (*see* TAYLOR 1968, 1971, 1978; FISHER & SALVAT 1971) in a very turbid environment. The assemblage of boring organisms of the same as in the Badenian reefs is characteristic of very shallow depths in modern reefs (BROMLEY 1978). The growth-forms of bryozoans found in the algal-vermetid reefs from Roztocze indicate a shallow water and high energy of environment during reef growth.

Based on the above discussion and all the data presented in this paper, a very shallow water, most probably from the mean sea level down to several meters in depth is postulated as the setting for the Badenian algal-vermetid reefs of the Roztocze Hills.

All dominating coralline algal genera live today in the Mediterranean Sea (MASLOV 1962, LEMOINE 1940). The genus *Lithothamnium* lives also in tropics, but in deeper waters or in cryptic habitats (ADEY & VASSAR 1975).

Most of the molluscs which inhabit the reefs live today in the Mediterranean Sea. Modern vermetids for example are common in tropical and warm seas, and their distribution is limited by 44° latitude (SAFRIEL 1975). The molluscan assemblage inhabiting the Badenian reefs is comparable with the tropical counterpart inhabiting algal-ridge (*see* FISHER & SALVAT 1971, TAYLOR 1978). As in the Roztocze reefs herbivorous gastropods which belong to Archaeogastropoda dominate the algal-ridge. The main difference between the Recent and Badenian molluscan assemblages is the high diversity of predatory gastropods on Recent algal-ridge and their rarity and low diversity in the Roztocze reefs. This may be an effect of lower (than tropical) temperature during the Badenian reef growth, as the role of predatory gastropods is a function of temperature (VERMEIJ 1978). Other modern assemblages comparable to the one described here occur on the algal reefs with *Vermicularia* from off the subtropical Carolinas (PEARSE & WILLIAMS 1951).

Keeping in mind all the above, it is postulated that the climate of Badenian during Roztocze reef growth was warm but not tropical, most probably very similar to the climate of the modern eastern part of the Mediterranean Sea.

The growth rate of Recent coralline algae varies in a broad limit from 0.3—0.5 mm/y in arctic regions up to 5—6 mm/y in tropical regions. This rate depends also on hydrodynamic regime and rate of bioerosion (mainly by echinoids, some fish and gastropods). In places with low wave action bioeroders may lower this rate in the tropics to 0.5—2 mm/y (ADEY & VASSAR 1975). Based on these data an estimate of the growth duration of the Badenian reefs is possible. Considering the thickness of the reef as 10 m and the volume of algae as about 50%, the algal component is about 5 m. As bioerosion was of no significance and climate intermediate between tropical and cold, the rate of growth of algae may be estimated as 2—3 mm/y, which gives about 1700—2500 years as a period of reef development during the Upper Badenian in Roztocze.

The presence in the reef of diversified coralline algae, brachiopods, echinoids and other fauna indicates normal marine salinity in this time. It is confirmed by early submarine aragonite and probably Mg-calcite cements. HAŁAS & *al.* (1979), however, based on the isotopic investigations of reef limestones from Kamienna Hill postulate a strong of fresh water influence on the sedimentary basin in which those rocks originated. This follows evidently from the fact that the isotopic composition of the rock bears an overprint of later diagenetic environments and may not characterize the composition of the water during the deposition of the sediments (*cf.* HUDSON 1977). In an extreme case the effects of late diagenetic overprint may dominate the isotopic results. In this particular case the reef limestones are diagenetically advanced and contain large quantities of neomorphic spar and late equant calcite cement which originated in fresh water phreatic environments. Thus, the isotopic composition suggests a fresh water overprint of diagenetic origin, not of synsedimentary character.

DIAGENESIS OF THE REEF BODIES

The macro- and microscopic analyses of the Roztocze reefs indicate that diagenetic history of the reef rocks differs in different areas, so the regions are treated separately here.

Various diagenetic schemes for carbonate rocks (*see* BATHURST 1975, LONGMAN 1980) display numerous exceptions. The diagenetic types in the rocks studied, are thought to have resulted from uniform sedimentary and early cementation (submarine) conditions, overprinted by subsequent diversity (*see* Text-fig. 16).

The reef limestones from Węglinek (*3* in Text-fig. 16) show early submarine diagenetic effects operated simultaneously with reef growth and sedimentation (stages *I* to *III* after LONGMAN 1980).

Aragonite cements, micritization, micritic cements and isopachous cloudy rim calcite cement (probably former Mg-calcite) were observed — all are attributed to submarine stage of diagenesis. Well developed early submarine cementation requires the saturation of marine solutions in calcite

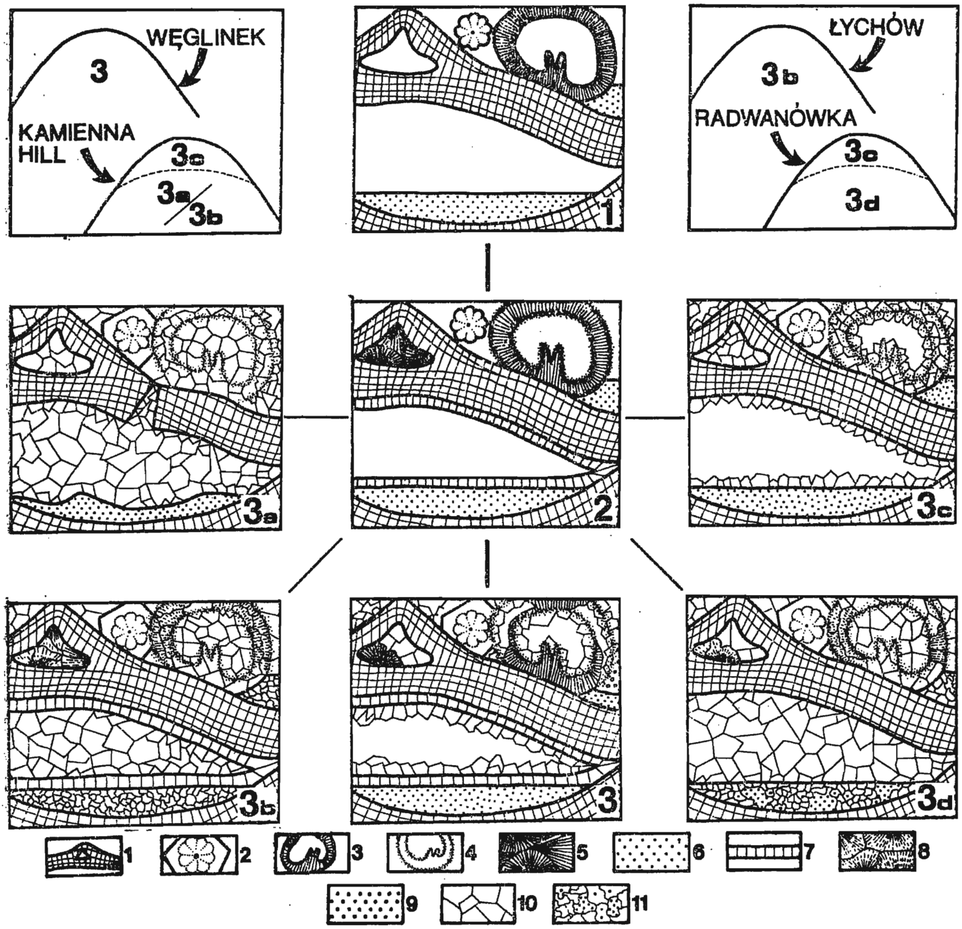


Fig. 16. Diagenetic types of the studied algal-vermetid reef rocks; distribution of diagenetic types in relation to the reef bodies is shown on insets

1 — algal thalli, **2** — echinoderm fragments with syntaxial cement, **3** — vermetid shell with preserved original microstructure and composition, **4** — micritic envelopes (exemplified by a vermetid shell), **5** — aragonite spherulitic cement, **6** — micrite (both cement and sediment), **7** — calcite isopachous cloudy rim cement, **8** — neomorphic calcite after aragonite, **9** — crystal and/or pelletal silt, **10** — equant calcite cement, **11** — neomorphic calcite after micrite (with patches of micrite still preserved); detailed explanations in the text and aragonite and sufficient quantities of solution for movement through porous reef structure (such movement of solution may be produced by strong wave action; *cf.* JAMES & *al.* 1976). Because early cements are rarely covered by sediment it seems that detrital sedimentation was relatively quick and prevented cementation in early stages (*1* in Text-fig. 16). Only when pores became cut off from the surface and sediment supply decreased, did intensive cementation begin (*2* in Text-fig. 16).

It seems that shortly after submarine cementation (or even at the same time) part of the reef might have been emergent for a short period as is indicated by pelletal silt (*see* DUNHAM 1969) laid down on the eroded surface of some internal sediments.

The preservation of aragonite, the large primary porosity still present and the occurrence of equant calcite cement only in small pores suggest that the dominant diagenetic effects are from a fresh-water vadose zone. Fresh-water phreatic effects are of limited importance and are indicated by dissolution of some aragonite, the precipitation of equant calcite cement and the stabilization of Mg-calcite cements and skeletons. As a result, the decrease of Mg and Sr contents is observed (although the decrease is not so great as in other sections). The drusy character of equant calcite cement is regarded as indicative of the fresh-water phreatic zone (LAND 1970, 1971; LOUCKS 1977; LONGMAN 1980).

The syntaxial calcite cement on echinoderm fragments and inside foraminiferal tests and the rare neomorphism of aragonite vermetid shells are also associated with the influence of solution in the phreatic zone. In a vadose meteoric zone the main diagenetic agent is rain-water, which is strongly undersaturated in respect to $CaCO_3$, percolating down through the sediment. In effect, dissolution is important but diagenetic processes proceed much more slowly and are less intense than in a fresh-water phreatic zone (STEINEN 1974, MATTHEWS 1974, LONGMAN 1980). The slowness of the diagenesis may be explained by the very short time of contact of diagenetic solution with sediment. This is the main factor governing the preservation of aragonite in the Węglinek profile. Other cases of preservation of metastable aragonite grains due to the lower rate of diagenesis in the vadose zone are given by STEINEN & MATTHEWS (1973), STEINEN (1974), and BUCHBINDER & FRIEDMAN (1980).

Meniscal and gravitational cements typical of the vadose environment (PURSER 1969, DUNHAM 1971, MÜLLER 1971) are absent in the Węglinek sections. This may be explained by a relatively humid and cold climate during diagenesis, while the previously described the above cements come from warm climates.

The rare neomorphism of vermetid shells depended on the porosity of rocks and saturation of diagenetic solution in aragonite and calcite (*cf.* LONGMAN 1977) as well as on the Mg/Ca ratio (FOLK & LAND 1975).

The occasional internal cementation of aragonitic vermetid shells by equant calcite (*cf.* SCHROEDER 1973) could be explained by the strong calcite supersaturation of diagenetic solution and the protective effect of organic matrices.

The limestones from Węglinek are very porous, and porosity is similar to that of the synsedimentary stage. This is an effect of the poor occlusion of pores by meteoric cements and of added moldic porosity. The diagenetic development of the rock could be compared with stages *IV* and *V* in LONGMAN'S (1980) scheme.

There are differences in the diagenesis of biocalcarenites that infill the large cavities in the reef. In places where aragonite is preserved, sediment is poorly cemented and micritic cement dominates. In other places where aragonite was dissolved, sediment is well cemented and equant calcite cement is common. This observation indicates selectivity of cementation and the dependence of type of cement in the rock on the local diagenetic environment, as well as showing that biogenic aragonite was the main local source of $CaCO_3$ for the late cement.

The reef limestones from Radwanówka (*3c—d* in Text-fig. 16) are much more diagenetically advanced than those from Węglinek. They are throughly cemented and contain only low-magnesian calcite.

Traces of early submarine cementation are rare but there is little doubt that this rarity is a secondary feature and one may suppose submarine cementation similar to that present in the Węglinek section. A cover of biocalcarenites is present in this area and indicates that some processes could have place during shallow burial, but no particular features typical for this stage are recognized.

The upper portion of the reef limestones (thickness about 2 m) is very porous, all aragonite is dissolved and equant calcite cement is relatively poorly developed (*3c* in Text-fig. 16). Such a set of features may indicate both vadose and fresh-water phreatic influences with solutions undersaturated with respect to $CaCO_3$ (LONGMAN 1980). The absence of aragonite and cements typical for the vadose zone (but see also earlier discussion on the absence of vadose cement) suggests that the part of section under consideration most probably experienced diagenesis in the upper part of an active fresh-water phreatic zone, affected by solutions poorly saturated in $CaCO_3$. This is supported by the presence of the micrite and absence of neomorphism.

The lower part of Radwanówka section (*3d* in Text-fig. 16) has strongly reduced porosity because of the occlusion of most primary pores by late equant calcite cement. Vermetid shells are dissolved (except micritic envelopes) and infilled by equant calcite cements as well. Nearly all the micrite in internal sediments is neomorphosed and occurs as microspar or neospar. These features indicate that dominant part of diagenesis took part in a fresh-water phreatic zone. Solutions were initially undersaturated with respect to aragonite at least and dissolved the aragonitic shells. Later, solutions became supersaturated in $CaCO_3$ and molds were infilled with equant cement and neomorphism of micrite took place. At present the whole section is in a vadose zone but no special features, what may have been caused by the quick saturation of percolating waters in a soil zone, are visible.

The reef limestones from Kamienna Hill (*3a—c* in Text-fig. 16) show diagenetic features similar to these described above. However, lateral differences exist which may have been caused by the migration of fresh-water lenses. Generally they are at the *V* and *VI* diagenetic stages of LONGMAN (1980).

In a central area of outcrops upper parts of the reef limestones are very porous because most primary pores are left empty and additionally pores from dissolution are very common (mostly molds after aragonite shells). Micrite is preserved and no neomorphism was noted (*3c* in Text-fig. 16). These features suggest that the main diagenetic imprint come from the upper, undersaturated in $CaCO_3$ part of a fresh-water phreatic zone. The lower part of the section (*3b* in Text-fig. 16) in this area shows low porosity as most pores (both primary and secondary) are occluded with equant calcite cement. The micrite is nearly entirely neomorphosed to micro- and neospar and some nondissolved aragonitic shells are also neomorphosed. All this indicates the dominant influence of an active fresh-water phreatic zone, with changing degrees of saturation in $CaCO_3$, during diagenesis.

Some sections in southern part of Kamienna Hill show changing diagenetic environments (*3a* in Text-fig. 16). Most pores are occluded with equant calcite cement which is also present in molds after vermetid shells. Near the boundary with the overlying biocalcarenites the dissolution of micrite from internal sediment was observed, postdated by crystalization of equant calcite cement. Compactional features although, poorly developed, were also noted. This may indicate that the rocks were influenced by diagenetic solutions that were strongly undersaturated in $CaCO_3$ before equant calcite crystalization, probably before mineralogical stabilization. Such features are characteristic of both the vadose and upper part of the fresh-water phreatic zone, but the subsequent diagenetic overprint prevents determination. Later these rocks come into an active fresh-water phreatic zone with solutions saturated with $CaCO_3$. This interval resulted in the precipitation of the equant cement. At present the whole Kamienna Hill section is in the vadose zone.

The reef limestones from Łychów (*3b* in Text-fig. 16) are also strongly advanced in diagenesis and contain only low-magnesian calcite and may be compared with LONGMAN's (1980) stage *VI*.

Early submarine diagenesis is suggested by the neomorphosed cloudy rim cement and micritic envelopes but it seems probable that other types of cement were also present and were dissolved later. These limestones are of low porosity because nearly all pores are occluded by equant calcite cement. Vermetid shells are neomorphosed, as is the micrite in the internal sediment. All these features indicate (*see* LONGMAN 1980) the dominant diagenetic influence of a fresh-water phreatic environment saturated in $CaCO_3$.

The clear contrast with the reef limestones is shown by the biorudites from the reef talus. They are very porous, no aragonite is preserved, and cement present only in subordinate amounts. The small quantity of micrite of unknown affinity is present both within and between particles. Compactional features are common and may indicate poor early submarine cementation. All the above characters suggest that fresh-water phreatic influences with solutions undersaturated in $CaCO_3$ predominated in the diagenesis of these rocks. Poorly developed cementation by late equant calcite cement was probably caused by the undersaturation of diagenetic solutions associated with rapid flow in a very porous (primary) rock. The poorly developed early submarine cementation could have been caused by instability of biorudite grains in sedimentary environment preventing nucleation of cement.

The other general problem is the source of the $CaCO_3$ in late equant calcite cement. Considering the density differences of aragonite and calcite (FYFE & BISCHOFF 1965, BERNER 1971, LIPMANN 1973) it seems that most of $CaCO_3$ necessary for cementation by late cements could be delivered from a local source *i.e.* aragonitic shells and cements.

Varied diagenetic fabrics of carbonate rocks within a single section have also been described by LAND (1970), STEINEN (1974), MATTHEWS (1974), STEINEN & MATTHEWS (1973), BUCHBINDER & FRIEDMAN (1980), and ACHAUER (1977). These authors attribute the variation to the migration of zones of differing diagenetic solutions.

The above presented scheme of diagenesis needs time frame to be well understood. An attempt to build such time frame is presented below (Text-fig. 17).

During Upper Badenian time, when the reef was growing, the processes of submarine cementation were actively operating together with biogenically induced micritization (Text-fig. 17*A*). By the uppermost Badenian reef growth had ceased and the reef was capped by bedded sediments. As an effect, the circulation of solutions within the reef body became restricted and a decrease of the rate of cementation occurred (Text-fig. 17*B*). In the Early Sarmatian the marine regression in a Carpathian Foredeep (RADWAŃSKI 1977a, b) brought the deposits into a meteoric zone with varied vadose and phreatic diagenetic environments and clearly differentiated types of diagenetic processes operated (Text-fig. 17*C*). As would be expected the boundary between phreatic and vadose zones migrated over time and was dependent on local conditions causing varied diagenetic fabric in different areas. This diagenetic stage continued until the Pleistocene when probably all the rocks briefly came into the phreatic zone as an effect of ice covering. After the recession of the last icesheet, a drop of the water table associated with the uplift of the whole Roztocze region occurred (MALINOWSKI 1977). This uplift probably even started in the Sarmatian but is most visible since Early Holocene time. The associated with the uplift lowering of the water table was about 40 m (MALINOWSKI 1977) and caused the entire reef section to come into the vadose zone. Only the extent of the

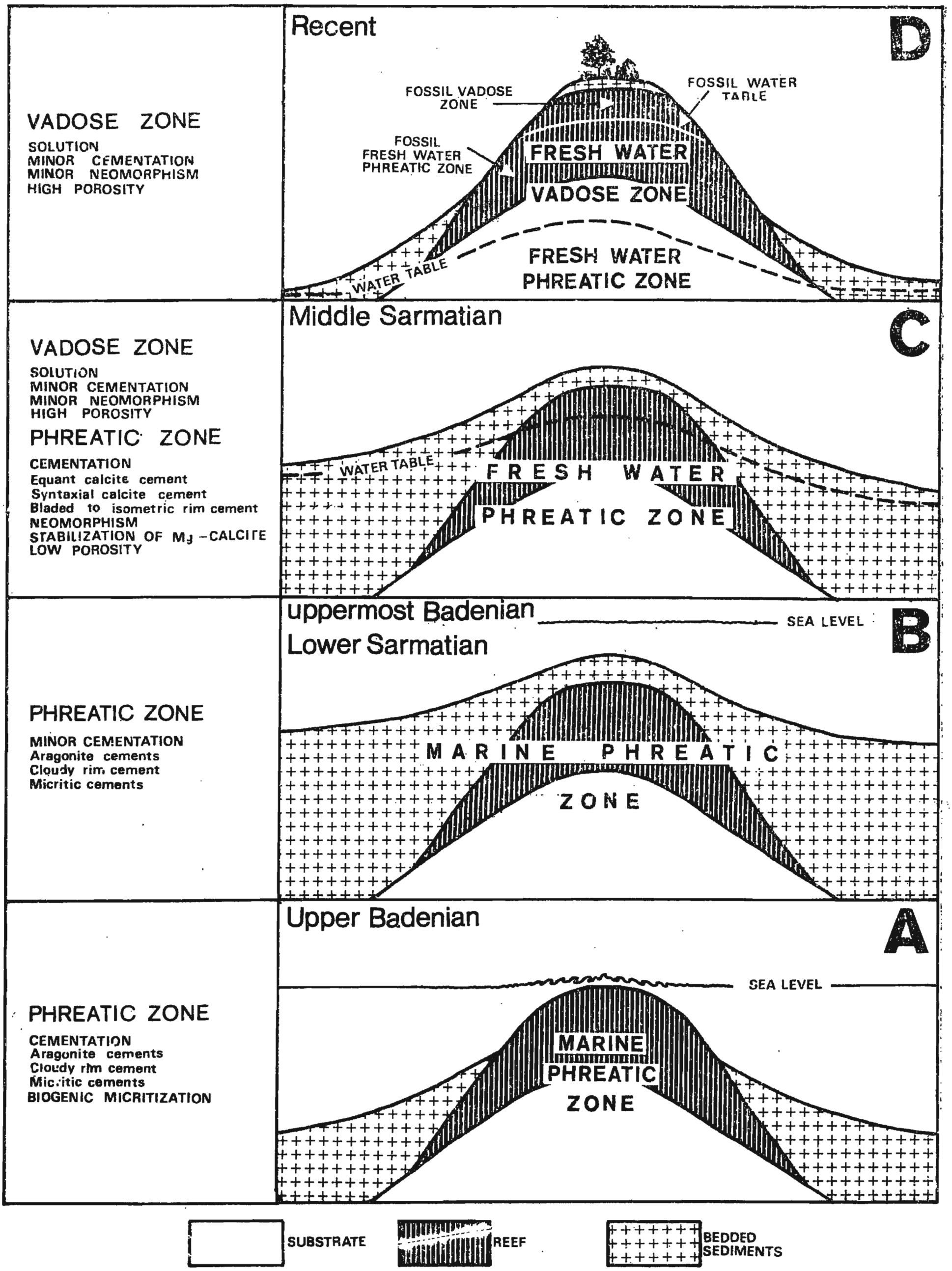


Fig. 17. Timing of diagenesis and its typical processes and products in the studied algal-vermetid reefs of the Roztocze Hills

ancient water table and thus the zone between the fossil vadose and phreatic zones is observable in the studied Roztocze reefs (Text-fig. 17*D*).

The main features of the present-day land morphology which governs the ground water table and the position of different diagenetic zones in the Lublin Upland, the Roztocze Hills including, have developed prior to the Pleistocene first glaciation (JAHN 1956, MARUSZCZAK 1972). Thus, one may expect that the general diagenetic pattern of the investigated Roztocze reefs was established as early as in the Pliocene. During glaciation times the base of erosion and the associated water table level migrated several times, being probably similar to those presently observed already in the older part of the Great (Holstein) Interglacial, and thus the primary diagenetic zonation within the reefs has become more or less distinctly obliterated. To a lesser extent, the late diagenetic processes continue within the Roztocze reefs until the present days.

Acknowledgements

Important part of this Ph. D. thesis was done at the Institute of Geology, University of Warsaw. Subsequently it was finished at the Institute of Paleobiology, Polish Academy of Sciences. Substantial help and supervision by Professor A. RADWAŃSKI (University of Warsaw) is warmly acknowledged. Warm thanks are also due to Docent W. BAŁUK (University of Warsaw) for help in identifying some molluscs, and to my wife, M.A. BITNER M. Sc. (University of Warsaw) for identifying brachiopods and encouregements during long time of these studies. Thanks are also due to Dr. J. GEISTER (Bern), Dr. Ch.-W. DULLO (Erlangen), and R. GYGI (Basel) for supplying samples of Recent algal-vermetid rocks and discussions. Many improvements were possible due to critical reading of the early drafts of this paper by Dr. J. DZIK and Dr. K. MAŁKOWSKI (Institute of Paleobiology), and Docent J. TRAMMER (University of Warsaw). Dr. K. FLESSA (University of Arizona) improved the English language and made valuable comments. Photographs of polished surfaces were taken by K. ZIELIŃSKA and M. DZIEWIŃSKI, whereas drawings were done by Dr. J. DZIK, D. SŁAWIK and E. GUTKOWSKA-LESZAK.

Institute of Paleobiology
of the Polish Academy of Sciences,
Al. Żwirki i Wigury 93,
02-089 Warszawa, Poland

REFERENCES

ABBOTT, T.R. 1974. American seashells, pp. 1–663. New York.

ACHAUER, C.A. 1977. Contrast in cementation, dissolution and porosity development between two Lower Cretaceous reefs of Texas. *In*: D.G. BEBOUT & R.G. LOUCKS (*Eds*), Cretaceous carbonates of Texas and Mexico: Applications to subsurface exploration. *Texas Univ. Bur. Econ. Geol., Rept. Investigations*, **89**, 127–137. Austin.

ADEY, W.H. 1965. Studies of *Lithophyllum* and related genera. *Colorado School of Mines Quart.*, **60**, 1–105. Golden.

— 1975. The algal ridges and coral reefs of St. Croix: their structure and Holocene development. *Atoll Res. Bull.*, **187**, 1–67. Washington.

— & BURKE, R. 1976. Holocene bioherms (algal ridges and bank-barrier reefs) of the eastern Caribbean. *Geol. Soc. Amer. Bull.*, **87**, 95–109. New York.

— & MACINTYRE, I. G. 1973. Crustose coralline algae: a re-evaluation in the geological sciences. *Geol. Soc. Amer. Bull.*, **84**, 883–903. New York.

— & VASSAR, J.M. 1975. Colonization, succession and growth rates of tropical crustose coralline algae (Rhodophyta, Cryptonemiales). *Phycologia*, **14**, 55–69. Berkeley.

ALEXANDERSSON, T. 1972. Intragranular growth of marine aragonite and Mg-calcite: evidence of precipitation from supersaturated sea water *J. Sedim. Petrol.*, **42**, 441–460. Tulsa.

— 1974. Carbonate cementation in coralline algal nodules in the Skagerrak, North Sea: biochemical precipitation in undersaturated waters. *J. Sedim. Petrol.*, **44**, 7–26. Tulsa.

— 1978. Distribution of submarine cements in a modern Caribbean fringing reef, Galeta Point, Panama; Discussion. *J. Sedim. Petrol.*, **48**, 665–683. Tulsa.

AREŃ, B. 1962. The Miocene of the Lublin Roztocze Range between the Sanna and Tanew Rivers. *Prace I. G.*, **30**, (3) 5–77. Warszawa.

BADIOZAMANI, K., MACKENZIE, P.T. & THORSTENSON, D.C. 1977. Experimental carbonate cementation: salinity, temperature and vadose-phreatic effects. *J. Sedim. Petrol.*, **47**, 529–542. Tulsa.

BAŁUK, W. 1975. Lower Tortonian gastropods from Korytnica, Poland; Part I. *Palaeont. Polon.*, **32**, 1–186. Warszawa.

— & RADWAŃSKI, A. 1968. Lower Tortonian sands at Nawodzice (southern slopes of the Holy Cross Mountains), their fauna and facies development. *Acta Geol. Polon.*, **18** (2), 447–471. Warszawa.

— & — 1977. Organic communities and facies development of the Korytnica Basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geol. Polon.*, **27** (2), 85–123. Warszawa.

— & — 1979. Shell adaptation and ecological variability in the pelecypod species *Sphenia anatina* (BASTEROT) from the Korytnica basin (Middle Miocene; Holy Cross Mountains, Central Poland). *Acta Geol. Polon.*, **29** (3), 269–286. Warszawa.

BATHURST, R.G.C. 1975. Carbonate sediments and their diagenesis. *Develop. in Sedim.*, **12**, pp. 1–658. Amsterdam.

BEBOUT, D.G. & LOUCKS, R.G. (*Eds*). 1977. Cretaceous carbonates of Texas & Mexico. Application to subsurface exploration. *Texas Univ. Bur. Econ. Geol.*, *Rept. Investigations*, **89**, 1–332. Austin.

BENCINI, A. & TURI, A. 1974. Mn distribution in the Mesozoic carbonate rocks from Lima Valley, Northern Apenines. *J. Sedim. Petrol.*, **44**, 774–782. Tulsa.

BERNER, R.A. 1971. Principles of chemical sedimentology, pp. 1–240. New York.

BIELECKA, M. 1959. Main problems of the Tertiary in the Zaklików region (Lublin Plateau). *Kwart. Geol.*, **3**, 638–661. Warszawa.

— 1967. The Tertiary of the south-western part of the Lublin Upland. *Biul. Inst. Geol.*, **206**, 115–188. Warszawa.

BLANC-VERNET, L. 1969. Contribution à l'étude des Foraminifères de Méditerranée. *Rec. Trav. Stat. Mar. Endoume*, **48**, 5–281. Marseille.

BOLTOVSKOY, E. & WRIGHT, R. 1976. Recent foraminifera, pp. 1–515. Hague.

BOSENCE, D.W.J. 1979. Live and dead faunas from coralline algal gravels, Co. Galway, Ireland. *Palaeontology*, **22**, 449–478. London.

— 1983a. Coralline algae from the Miocene of Malta. *Palaeontology*, **26**, 147–173. London.

— 1983b. Coralline algal reef frameworks. *J. Geol. Soc. London*, **140**, 365–376. London.

— & PEDLEY, H.M. 1979. Palaeoecology of a Miocene coralline algal bioherm, Malta. *Bull. Cent. Rech. Explor.-Prod. Elf-Aquitaine*, **3**, 463–470. Pau.

— & — 1982. Sedimentology and palaeoecology of Miocene coralline algal biostrome from the Maltese Islands. *Palaeogeogr., Palaeoclim., Palaeoecol.*, **38**, 9–43. Amsterdam.

BOUCOT, A.J. 1981. Principles of benthic marine paleoecology, New York.

BOYD, D.W., KORNICKER, L.S. & REZAK, R. 1963. Coralline algal microatolls near Cozumel Island, Mexico. *Contr. Geol.*, **2**, 105–108. Laramie.

BRAND, V. & VEIZER, J. 1980. Chemical diagenesis of a multicomponent carbonate system. 1: Trace elements. *J. Sedim. Petrol.*, **50**, 1219–1236. Tulsa.

BRASIER, M.D. 1975. An outline history of sea grass communities. *Palaeontology*, **18**, 681–703. London.

BRICKER, O.P. (*Ed.*). 1971. Carbonate cements. *John Hopkins Univ. Stud. Geol.*, **19**. Baltimore.

BROMLEY, R.G. 1978. Bioerosion of Bermuda reefs. *Palaeogeogr., Palaeoclim., Palaeoecol.*, **23**, 169–197. Amsterdam.

BUCHBINDER, B. 1977. Systematics and paleoenvironments of the calcareous algae from the Miocene (Tortonian) Tziqlag Formation, Israel. *Micropaleontology*, **23**, 415–435. New York.

BUCHBINDER, L.G. & FRIEDMAN, G.M. 1980. Vadose, phreatic and marine diagenesis of Pleistocene-Holocene carbonates in a borehole: Mediterranean coast of Israel. *J. Sedim. Petrol.*, **50**, 395–407. Tulsa.

BURCHETTE, T.P. & RIDING, R. 1977. Attached vermiform gastropods in Carboniferous marginal marine stromatolites and biostromes. *Lethaia*, **10**, 17–28. Oslo.

BURGESS, C.J. 1979. The development of a Lower Jurassic carbonate tidal flat, Central High Atlas, Marocco, 2: Diagenetic history. *J. Sedim. Petrol.*, **49**, 413–428. Tulsa.

BUZAS, M.A., SMITH, R.V. & BEEM, K.A. 1977. Ecology and systematics of foraminifera in two *Thalassia* habitats, Jamaica, West Indies. *Smiths. Contrib. Paleobiol.*, **31**, 1–139. Washington.

CARRIKER, M.R. & YOCHELSON, E. 1968. Recent gastropod boreholes and Ordovician cylindrical borings. *U. S. Geol. Surv. Prof. Paper*, **593-B**, 1–26. Washington.

CARTER, J.G. 1978. Ecology and evolution of the Gastrochaenacae (Mollusca, Bivalvia) with notes on the evolution of the endolithic habitat. *Bull. Peabody Museum of Nat. Hist., Yale Univ.*, **41**, 1–92. New Haven.

CAULET, J.-P. 1967. Les sédiments meubles à Brachiopodes de la marge continentale algérienne. *Bull. Mus. Nat. Hist. Natur.*, **39**, 779–792. Paris.

CHILLINGAR, G.V., BISSELL, H.J. & FAIRBRIDGE, R.W. 1967. Carbonate rocks. Physical and chemical aspects. *Develop. in Sedim.*, **9B**, pp. 1–413. Amsterdam.

CHOQUETTE, P.W. & PRAY, L.C. 1970. Geologic nomenclature and classification of porosity in sedimentary carbonates. *Amer. Assoc. Petrol. Geol. Bull.*, **54**, 207–250. Tulsa.

CONTI, S. 1946. Le Corallinacae del calcare miocenico (Leithakalk) del bacino di Vienna. *Publ. Istit. Geol. Univ. Genova, Ser. A*, **1–2**, 31–68. Genova.

COX, K.W. 1962. California abalones. Family Haliotidae. *Fish. Bull. Dept. Fish. Game*, **118**. Sacramento.

CUFFEY, R.J. 1972. The role of bryozoans in modern coral reefs. *Geol. Rundsch.*, **61**, 542–550. Stuttgart.

— 1977. Bryozoan contribution to reefs and bioherms through geologic time. *Studies in Geology*, **4**, 181–194. Tulsa.

— , FONDA, S., KOSICH, D.F., GEBELEIN, C.D., BLIEFNICK, D.M. & SOROKA, L.G. 1977. Modern tidal-channel bryozoan reefs of at Joulter Cays (Bahamas). *Proc. Third Inter. Coral Reef Symp.*, 339–346. Miami.

DAVIES, P.J. 1972. Trace element distribution in reef and subreef rocks of Jurassic age in Britain and Switzerland. *J. Sedim. Petrol.*, **42**, 183–194. Tulsa.

DAVITASHVILI, L.S. & MERKLIN, R.L. (*Eds*). 1966. Spravochnik po ekologii morskikh dvustvorok, pp. 1–349. Moskva.

— & — 1968. Spravochnik po ekologii morskikh brukhonogykh, pp. 1–169. Moskva.

DEAN, W.E. & EGGLESTONE, J.E. 1975. Comparative anatomy of marine and fresh water algal reefs. *Geol. Soc. Amer. Bull.*, **86**, 665–676. New York.

DEER, W.A., HOWIE, R.A. & ZUSSMAN, J. 1962. Rock-forming minerals .**5**, 1–371. London

DENIZOT, M. & MASSIEUX, M. 1965. Présence de *Peyssonelia antiqua* dans le calcaire „Ypreso-Lutetien" de la Montagne d'Alaric. *Rev. Micropaléontologie*, **8**, 96–102. Paris.

DODD, J.R. & STANTON, R.J. Jr. 1981. Paleoecology, concepts and applications, pp. 1–559. New York.

DUFFUS, J.H. 1969. Association of marine Mollusca and benthic algae in the Canary Island Lanzacote. *Proc. Malacol. Soc. London*, **38**, 343–349. London.

DULLO, W.C. 1983. Fossildiagenese im miozänen Leitha-Kalk der Paratethys von Österreich: Ein Beispiel für Faunenverschiebungen durch Diageneseunterschiede. *Facies*, **8**, 1–112. Erlangen.

DUNHAM, R.J. 1969. Early vadose silt in Townsend Mound (reef), New Mexico. *In*: G.M. FRIEDMAN (*Ed.*), Depositional environments of carbonate rocks. *Soc. Econ. Paleont. Mineral. Spec. Publ.*, **14**, 139–181. Tulsa.

— 1971. Meniscus cement. *In*: O.P. BRICKER (*Ed*)., Carbonate cements. *John Hopkins Univ. Stud. Geol.*, **19**, 297–300. Baltimore.

DZIK, J. 1979. Some terebratulid populations from the Lower Kimmeridgian of Poland and their relations to the biotic environment. *Acta Palaeont. Polon.*, **24** (4), 473–492. Warszawa.

EDGELL, H.S. & BASSON, P.W. 1975. Calcareous algae from the Miocene of Lebanon. *Micropaleontology*, **21**, 165–184. New York.

EVAMY, B.D. 1969. The precipitational environment and correlation of some calcite cements deduced from artificial staining. *J. Sedim. Petrol.*, **39**, 787–793. Tulsa.

— & SHEARMAN, D.J. 1965. The development of overgrowths from echinoderm fragments. *Sedimentology*, **5**, 211–233. Amsterdam.

FAGERSTROM, J.A. 1964. Fossil communities in paleoecology: their recognition and significance. *Geol. Soc. Amer. Bull.*, **75**, 1197–1216. Boulder.

FELL, B. 1975. Introduction to marine biology. New York.

FISHER, J.C. & SALVAT, B. 1971. Paléoécologie et écologie des Mollusques dans les complexes récifaux coralliens. *Haliotis*, **1**, 65–103. Paris.

FLÜGEL, E. 1982. Microfacies analysis of limestones, pp. 1–633. Berlin.

FOCKE, J.W. 1977. The effect of a potentially reef-building vermetid-coralline algal community on an eroding limestone coast, Curaçao, Netherlands Antilles. *Proc. Third Inter. Coral Reef Symp.* ,239–245. Miami.

— 1978a. Limestone cliff morphology on Curaçao (Netherlands Antilles), with special attention to the origin of notches and vermetid/algal surf benches („cornices", „trottoirs"), *Zt. Geomorph. N. F.*, **22**, 329–349. Berlin.

— 1978b. Limestone cliff morphology and organisms distribution on Curaçao (Netherlands Antilles). *Leidse Geol. Med.*, **51**, 131–150. Leiden.

— & GEBELEIN, C.D. 1978. Marine lithification of reef rock and rhodolites at a fore-reef slope locality (—50 m) off Bermuda. *Geologie en Mijnbouw*, **57**, 163–171. Leidschendam.

FOLK, R.L. 1965. Some aspects of recrystalization in ancient limestones. *In*: L.C. PRAY & R.C. MURRAY (*Eds*), Dolomitization and limestone diagenesis. *Soc. Econ. Paleont. Mineral. Spec. Publ.*, **13**, 14–48. Tulsa.

— & LAND, L.L. 1975. Mg/Ca ratio and salinity: Two controls over crystalization of dolomite. *Amer. Assoc. Petrol. Geol. Bull.*, **59**, 60–68. Tulsa.

FRENEIX, S. 1975. Au sujet du phyllum *Neopycnodonte navicularis — Neopycnodonte cochlear. VI Congr. Reg. Comm. Meditt. Neogene Stratigr.*, 443–449. Bratislava.

FRETTER, V. & GRAHAM, A. 1962. British Prosobranch molluscs, pp. 1–755. London.

— & — 1976. The prosobranch molluscs of Britain and Denmark, Part 1: Pleurotomariacea Fissurellacea and Patellacea. *J. Moll. Stud., Supl.*, **1**, 1–37. London.

— & — 1977. The prosobranch molluscs of Britain and Denmark. Part 2. Trochacea. *J. Moll. Stud., Supl.* **3**, 37–99. London.

FRIEDBERG, W. 1914. Mollusca miocaenica Poloniae, pars *1*: Gastropoda et Scaphopoda, **3**, 241–360. Lwów.

FRIEDMAN, G.M. 1968. Geology and geochemistry of reefs, carbonate sediments and waters, Gulf of Aqaba (Elat), Red Sea. *J. Sedim. Petrol.*, **38**, 895–919. Tulsa.

— 1975. The making and unmaking of limestones or the downs and ups of porosity. *J. Sedim. Petrol.*, **45**, 379–398. Tulsa.

— , AMIEL, A.J. BRAUN, M. & MILLER, M. 1973. Generation of carbonate particles and laminites in algal mats, examples from sea-marginal hypersaline pools, Gulf of Aqaba, Red Sea. *Amer. Assoc. Petrol. Geol. Bull.*, **57**, 541–558. Tulsa.

— , — & SCHNEIDERMAN, N. 1974. Submarine cementation in reefs: example from the Red Sea. *J. Sedim. Petrol.*, **44**, 816–825. Tulsa.

FÜRSICH, F.T. 1977. Corallian (Upper Jurassic) marine benthic associations from England and Normandy. *Palaeontology*, **20**, 337–385. London.

FYFE, W.S. & BISCHOFF, J.L. 1965. The calcite-aragonite problem. *Soc. Econ. Paleont. Mineral. Spec. Publ.*, **12**, 3–13. Tulsa.

GARRELS, R.M. & MACKENZIE, F.T. 1972. Evolution of sedimentary rocks, pp. 1–272. New York.

GAVISH, E. & FRIEDMAN, G.M. 1969. Progressive diagenesis in Quaternary to Late Tertiary carbonate sediments: sequence and time scale. *J. Sedim. Petrol.*, **39**, 980–1006. Tulsa.

GEISTER, J. 1975. Riffbau und geologische Entwicklungsgeschihte der Insel San Andres (Westlisches Karibisches Meer, Kolumbien). *Stuttgarter Bertr. Naturk. Ser. B*, **15**, 1–203. Stuttgart.

— 1977. The influence of wave exposure on the ecological zonation of Caribbean coral reefs. *Proc. Third Inter. Coral Reef Symp.*, **1**, 23–29. Miami.

— 1980. Calm-water reefs and rough-water reefs of the Caribbean Pleistocene. *Acta Palaeont. Polon.*, **25**, 541–556. Warszawa.

— 1983. Holozäne westindische korallenriffe: Geomorphologie, Ökologie und Fazies. *Facies*. **9**, 173–284. Erlangen.

GINSBURG, R.N. MARSZALEK, D.S. & SCHNEIDERMAN, N. 1971. Ultrastructure of carbonate cements in a Holocene algal reef of Bermuda. *J. Sedim. Petrol.*, **41**, 472–482. Tulsa.

— & SCHROEDER, J. 1973. Growth and submarine fossilization of algal cup reefs, Bermuda. *Sedimentology*, **20**, 575–614. Oxford.

GIRAUD, G. & CABIOCH, J. 1979. L'example des corallinacées actuelles. *Bull. Cent. Rech. Explor.-Prod. Elf-Aquitaine*, **3**, 601–610. Pau.

GLYNN, P.W. 1973. Aspects of the ecology of coral reefs in the western Atlantic region. *In*: O.A. JONES & R. ENDEN (*Eds*), Biology and geology of coral reefs; II. *Biology*, **1**, 271–325. New York.

GOLDSMITH, J.R., GRAF, D.L. & JOENSUU, O.I. 1955. The occurrence of magnesian calcites in nature. *Geochim. Cosmochim. Acta*, **7**, 212–230. New York.

GOLONKA, J. 1981. The algae and the biosedimentation of Miocene limestones of the environs of Rzeszów. *Biul. Inst. Geol.*, **332**, 5–52. Warszawa.

GUNATALIKA, A. 1976. Thallophyte boring and micritization within skeletal sand from Connemara, W. Ireland. *J. Sedim. Petrol.*, **46**, 548–554. Tulsa.

GYGI, R.A. 1975. *Sparisoma viridae* (BOATERRE), the stoplight parrotfish, a major sediment producer on coral reefs of Bermuda? *Eclogae Geol. Helv.*, **68**, 327–359. Basel.

HAGEMAN, J. 1976. The internal morphology of *Miniacina miniacea* (PALLAS). *Proc. Kon. Ned. Akad. Wetensch. Ser. B*, **79**, 29–35. Amsterdam.

HAŁAS, S., LIS, J., SZARAN, J., TREMBACZOWSKI, A., WOŁĄCEWICZ, W. & ŻUK, W. 1979. Isotopic composition of carbon and oxygen in limestones of the Lublin Highland. *Przegl. Geol.*, **3**, 162–163. Warszawa.

HASEGAWA, S. & TAKAYANAGI, Y. 1981. Notes on Homotrematid foraminifera from Toyama Bay, Central Japan. *Sci. Rep. Tohoku Univ. Sendai Second Ser. (Geology)*, **51**, 67–86.

HAVARD, C. & OLDERSHAW, A. 1976. Early diagenesis in back-reef sedimentary cycles, Snipe Lake Reef complex, Alberta. *Bull. Canadian Petrol. Geol.*, **24**, 27–69. Calgary.

HILLEMAN, M.E. & MAZZULLO, S.J. (*Eds*), 1977. Upper Guadalupian facies, Permian Reef Complex, Guadalupe Mountains, New Mexico and West Texas. *1977 Field Conference Guidebook, Permian Basin Sect. Soc. Econ. Paleont. Min. Publ.*, **77–16**, 1–508. Midland.

HOFFMAN, A. 1977. Synecology of macrobenthic assemblages of the Korytnica Clays (Middle Miocene; Holy Cross Mountains, Poland). *Acta Geol. Polon.*, **27** (2), 227–280, Warszawa.

— 1979. Community paleoecology as an epiphenomenal science. *Paleobiology*, **5**, 357–379. Chicago.

— , PISERA, A. & RYSZKIEWICZ, M. 1974. Predation by muricid and naticid gastropods on the Lower Tortonian molluscs from the Korytnica Clays. *Acta Geol. Polon.*, **24** (1), 249–-260. Warszawa.

— , — & STUDENCKI, W. 1978. Reconstruction of a Miocene kelp-associated macrobenthic ecosystem. *Acta Geol. Polon.*, **28**, (3) 377–388. Warszawa.

HOFFMEISTER, J.E., STOCKMAN, K.W. & MÜLTER, H.G. 1967. Miami Limestone of Florida and its recent counterparts Bahamian. *Geol. Soc. Amer. Bull.*, **78**, 175–190. Boulder.

HOWE, M.A. 1934. Eocene marine algae (Lithothamniae) from the Sierra Blanca limestone. *Bull. Geol. Soc. Amer.*, **45**, 507–518. Boulder.

HUDSON, J.D. 1962. Pseudo-pleochroic calcite in recrystalized shell-limestone. *Geol. Mag.*, **99**, 492–500. Cambridge.

— 1977. Stable isotopes and limestone lithification. *J. Geol. Soc. Lond.*, **133**, 637–660. London.

HUGHES, N.R. 1979. Coloniality in Vermetidae (Gastropoda). *In*: G. LARWOOD & B.R. ROSEN (*Eds*), Biology and systematics of colonial organisms. *Sys. Assoc. Spec. Vol.*, **11**, 243–253. London.

HUNTER, W.R. 1949. The structure and behaviour of *Hiatella gallicina* (LAMARCK) and *Hiatella arctica* (LINNE) with special reference to the boring habit. *Proc. Roy. Soc. Edinb. B*, **63**, 271–289. Edinburgh.

IMREH, J. & BEDELEANI, I. 1967. Etude géochimique des calcaires tortoniens de la bordure occidentale du Basin Transylvanic (Roumanie). *Bull. Serv. Cart. d'Alsace et de Lorraine*, **20**, 223–234. Strasbourg.

IWASIŃSKA, I., NARKIEWICZ, M. & PISERA, A. 1981. On occurrence, diagenesis and identification of magnesian calcite. *Przegl. Geol.*, 3, 113–118. Warszawa.

JACKA, A.D. & BRAND, J.P. 1977. Biofacies and development and differential occlusion of porosity in a Lower Cretaceous (Edwards) reef. *J. Sedim. Petrol.*, **47**, 366–381. Tulsa.

JACKSON, J.B.C. 1977. Composition on marine hard substrata: The adaptive significance of solitary strategies. *American Naturalist*, **111**, 743–767. Chicago.

— , GOREAU, T.F. & HARTMAN, W.D. 1971. Recent brachiopod-coralline sponge communities and their paleoecological significance. *Science*, **173**, 623–625. New Yorlk.

— & BUSS, L. 1975. Allelopathy and spathial competiton among coral reef invertebrates. *Proc. Nat. Acad. Sci.*, **72**, 5160–5163. Washington.

JAHN, A. 1956. Geomorphology and Quaternary history of the Lublin Upland. *Prace Geogr.*, **7**, 1–453. Warszawa.

JAKUBOWSKI, G. & MUSIAŁ, T. 1977. Lithology and fauna from the Upper Tortonian sands of Monastyrz and Długi Goraj (Southern Roztocze — Poland). *Prace Muzeum Ziemi*, **26**, 63–126. Warszawa.

— & — 1979a. Lithology and fauna of the Middle Miocene deposits of Trzęsiny (Roztocze Tomaszowskie Region, South-eastern Poland). *Prace Muzeum Ziemi*, **32**, 37–70. Warszawa.

— & — 1979b. Middle Miocene sandy and carbonate deposits of Huta Lubycka and Huta Różaniecka (Roztocze Rawskie Region, South-eastern Poland) and their fauna. *Prace Muzeum Ziemi*, **32**, 71–100. Warszawa.

JAMES, N.P. & GINSBURG, R.N. 1979. The seaward margin of Belize barrier and atoll reefs. *Int. Assoc. Sedim. Spec. Publ.*, **3**, pp. 1–191. Oxford.

— , — , MARSZALEK, D.S. & CHOQUETTE, P.W. 1976. Facies and fabric specifity of early subsea cementation in shallow Belize (Br. Honduras) reefs. *J. Sedim. Petrol.*, **46**, 523–544. Tulsa.

— & KOBLUK, D.R. 1978. Lower Cambrian patch reefs and associated sediments: southern Labrador, Canada. *Sedimentology*, **25**, 1–35. Oxford.

JANAKEVITSCH, A.N. 1977. Srednemiocenovye rify Moldavii, pp. 1–116. Kishinev.

JINDŘICH, V. 1983. Structure and diagenesis of recent algal-foraminiferal reefs, Renando de Noronha, Brazil. *J. Sedim. Petrol.*, **53**, 449–459. Tulsa.

JOHNSON, J.H. 1957. Calcareous algae of Spain. *U. S. Geol. Surv. Prof. Paper*, **280**-E, 209–-246. Washington.

— 1962. The algal genus *Lithothamnium* and its fossil representatives. *Colorado School of Mines Quart.*, **57**, 1–111. Golden.

— 1963. The algal genus *Archaeolithothamnium* and its fossil representatives. *J. Paleont.*, **37**, 175–211. Lawrence.

— 1964a. Fossil and recent calcareous algae from Guam. *U. S. Geol. Surv. Prof. Paper*, **403-G**, 1–40. Washington.

— 1964b. Miocene coralline algae from northern Iraq. *Micropaleontology*, **10**, 477–485. New York.

— 1964c. Paleocene calcareous red algae from northern Iraq. *Micropaleontology*, **10**, 207–216. New York.

— STEWART, W.A. 1953. Eocene coralline algae from the Meganos Formation, California. *J. Paleont.*, **27**, 130–136. Lawrence.

JØRGENSEN, N.O. 1976. Recent high magnesian calcite/aragonite cementation of beach and submarine sediments from Denmark. *J. Sedim. Petrol.*, **46**, 940–951. Tulsa.

KAUFFMAN, E.G. & SCOTT, R.W. 1976. Basic concepts of community ecology and paleoecology. *In*: R.W.SCOTT & R.R. WEST (*Eds*), Structure and classification of paleocommunities, pp. 1–28. Stroudsburg.

KEEN, M. 1960. Vermetid gastropods and marine intertidal zonation. *The Veliger*, **3**, 1–2. Berkeley.

KELLY, S.R.A. 1980. *Hiatella* — a Jurassic bivalve squatter? *Palaeontology*, **23**, 769–781. London.

KEMPF, M. & LABOREL, J. 1968. Formation de vermets et d'algues calcaires sur les côtes du Brésil. *Rec. Trav. St. Mar. End. Bull.*, **43**, 9–23. Marseilla.

KENDALL, A.C. 1976. Origin of fibrous calcite cements that apparently replace foraminiferal tests. *J. Sedim. Petrol.*, **46**, 545–547. Tulsa.

KINSMAN, D.J. 1969. Interpretation of Sr^{+2} concentration in carbonate minerals and rocks. *J. Sedim. Petrol.*, **39**, 486–508. Tulsa.

KOBLUK, D.R. & RISK, M.J. 1977. Micritization and carbonate-grain binding by endolithic algae. *Amer. Assoc. Petrol. Geol. Bull.*, **61**, 1069–1082. Tulsa.

KOROLYUK, I.K. 1952. Podolskye toltry i uslovya ikh obrazovanya. *Trudy Inst. Geol. Nauk SSSR*, **110** (56), 1–115. Moskva.

KOWALEWSKI, K. 1925. Sprawozdanie z badań geologicznych części południowo-zachodniej Wyżyny Lubelskiej. *Pos. Nauk. Państw. Inst. Geol.*, **11**, 15–18. Warszawa.

KRACH, W. 1962a. Stratigraphy and fauna of the Miocene in the vicinity of Zaklików and Modliborzyce (Lublin Upland). *Prace I.G.*, **30** (3), 417–429. Warszawa.

— 1962b. Esquisse de la stratigraphie du Miocène de la Pologne méridionale. *Ann. Soc. Géol. Pol.*, **32** (4), 529–557. Kraków.

— 1981. The Baden reef formations in Roztocze Lubelskie. *Prace Geol. PAN*, **121**, 5–115. Kraków.

KÜHNELT, W. 1933. Bohrmuschelstudien, II. *Palaeobiologica*, **5**, 371–408. Wien.

LABOREL, J. 1977. Are reef-building vermetids disappearing in the south Atlantic? *Proc. Third Int. Coral Reef Symp.*, 233–237. Miami.

— 1979. Fixed marine organisms as biological indicators for the study of Recent sea level and climatic variations along the Brazilian tropical coast. *Proc. 1978 Int. Symp. Coastal Evol. in the Quaternary*, 193–211. Sao Paulo.

— 1980. Les gastropodes vermetidés: leur utilisation comme marques biologiques de rivages fossiles. *Oceanis*, **5** *Fasc. Hors-Série*, 221–239. Marseille.

— & DELIBRIAS, G. 1976. Niveaux marins récents à vermetidae du littoral ouest African. *Ass. Sénégal. Et. Quatern. Afr. Bull. Liaison Sénégal*, **1** (47), 97–110.

LAGAAIJ, R. & GAUTIER, Y.V. 1965. Bryozoan assemblages from marine sediments of the Rhone delta, France. *Micropaleontology*, **11**, 39–58, New York.

LAND, L.S. 1967. Diagenesis of skeletal carbonates. *J. Sedim, Petrol.*, **37**, 914–930. Tulsa.

— 1970. Phreatic versus vadose meteoric diagenesis of limestones: evidence from a fossil water table. *Sedimentology*, **14**, 175–185. Amsterdam.

— 1971. Phreatic versus meteoric diagenesis of limestones: evidence from a fossil water table in Bermuda. *In:* O. P. BRICKER (*Ed.*), Carbonate cements. *John Hopkins Univ. Stud. Geol.*, **19**, 133–136. Baltimore.

— & MOORE, C. H. 1980. Lithification, micritization and syndepositional diagenesis of biolithites on the Jamaica island slope. *J. Sedim. Petrol.*, **60**, 357–369. Tulsa.

LEMOINE, M. 1917. Contribution à l'étude des corallinacées fossiles. III Corallinacées fossiles de la Martinique. *Bull. Soc. Géol. France, Sér. 4*, **17**, 256–279. Paris.

— 1923. Mélobésies miocènes recueillies par M. BOURCART en Albanie. *Bull. Soc. Géol. France, sér. 4*, **23**, 275–283. Paris.

— 1939. Les algues calcaires fossiles de l'Algérie. *Mat. Carte Géol. l'Algérie, sér. 1, Paléont.*, **9**, 1–128, Algér.

— 1940. Les algues calcaires de la zone néritique. *Mém. Soc. Bio-géogr.*, **7**, 75–238. Paris.

LEMOINE, M. 1970. Apparition de la structure monostromatique dans un thalle épais de *Dermatolithon* (Mélobésiées, Corallinacées). *Bull. Soc. Bot. France*, **117**, 547–562. Paris.

— 1976. Le genre *Lithoporella* FOSLIE (algue Rhodophycée, Corallinacée) au Tertiaire et Quaternaire. *Bull. Soc. Géol. France sér. 7*, **18**, 773–787. Paris.

— 1977. Étude d'une collection d'algues corallinacées de la région de Skopje (Yougoslavie). *Rev. Micropaléont.*, **20**, 10–43. Paris.

LESZCZYŃSKI, S. 1978. Algal limestones and rhodolites from Ciężkowice sandstones of the Silesian Unit (Polish Carpathians). *Ann. Soc. Géol. Pol.*, **48** (3–4), 391–405. Kraków.

LEWIS, J.B. 1960. The coral reefs and coral communities of Barbados. *Canad. J. Zool.*, **38**, 1133–1145. Ottawa.

LIPMANN, F. 1973. Sedimentary carbonate minerals, pp. 1–228. Berlin.

LITTLER, M. & DOTTY, M.S. 1975. Ecological components structuring the seaward edges of tropical Pacific reefs: the distribution, communities and productivity of *Porolithon*. *J. Ecol.*, **63**, 117–129. Cambridge.

LLOYD, R.M. 1971. Some observation of recent sediment alternation („micritization") and the possible role of algae in submarine cementation. *In:* O.P. BRICKER (*Ed.*), Carbonate cements. *John Hopkins Univ. Stud. Geol.*, **19**, 72–79. Baltimore.

LOGAN, A. 1975. Ecological observation on the recent articulate brachiopod *Argyrotheca bermudana* DALL from the Bermuda Platform. *Bull. Mar. Sci.*, **25**, 186–204. Miami.

— 1977. Reef-dwelling articulate brachiopods from Grand Cyman, B.W.I. *Proc. Third Int. Coral Reef Symp.*, 87–93. Miami.

— 1979. The Recent Brachiopoda of the Mediterranean Sea. *Bull. Int. Océanogr. Monaco*, **72** (1434), 1–112. Monaco.

LONGMAN, M.W. 1977. Factors controlling the formation of microspar in the Bromide Formation *J. Sedim. Petrol.*, **47**, 347–350. Tulsa.

— 1980. Carbonate diagenetic textures from nearsurface diagenetic environment. *Amer. Assoc. Petrol. Geol. Bull.*, **64**, 461–487. Tulsa.

— 1981. A process approach to recognizing facies of reef complexes. *In:* D.F. TOOMEY (*Ed.*), European fossil reef models. *Soc. Econ. Paleont. Mineral. Spec. Publ.*, **30**, 9–40. Tulsa.

— & MENCH, P.A. 1978. Diagenesis of Cretaceous limestones in the Edwards Aquifer system of South-Central Texas: a scanning electron microscopy study. *Sedim. Geol.*, **21**, 241–276. Amsterdam.

LORENS, R.B. 1981. Sr, Cd, Mn and Co distribution coefficients in calcite as a function of calcite precipitation rate. *Geoch. Cosmochim. Acta*, **451**, 553–561. New York.

LOUCKS, R.G. 1977. Porosity development and distribution in shoal-water carbonate complexes — subsurface Pearsall Formation (Lower Cretaceous), south Texas. *In:* D.G. BEBOUT & R.G. LOUCKS (*Eds*), Cretaceous carbonates of Texas and Mexico: Applications to subsurface exploration. *Texas Univ. Bur. Econ. Geol., Rep. Inv.*, **89**, 97–126. Austin.

MACGEACHY, J.K. & STEARN, C.W. 1976. Boring by macroorganisms in the coral *Montastrea annularis* on Barbados Reefs. *Int. Rev. Ges. Hydrobiol.*, **61**, 715–745. Leipzig.

MACINTYRE, I.G. 1977. Distribution of submarine cements in a modern Caribbean fringing reef, Galeata Point, Panama. *J. Sedim. Petrol.*, **47**, 503–516. Tulsa.

MALINOWSKI, J. 1977. The influence of the neotectonics on changes in hydrogeological conditions in the Roztocze area. *Kwart. Geol.*, **21** (1), 49–58. Warszawa.

MARSHALL, J.F. & DAVIES, P.J. 1981. Submarine lithification on winward reef slopes: Capricorn-Bunker Group, Southern Great Barrier Reef. *J. Sedim. Petrol.*, **51**, 953–960. Tulsa.

MARUSZCZAK, H. 1972. Wyżyny Lubelsko-Wołyńskie. *In:* M. KLIMASZEWSKI (*Ed.*), Geomorfologia Polski, tom **1**, 340–384. Warszawa.

MASLOV, V.P. 1956. Iskopaemye izvestkovye vodorosli SSSR. *Trudy Inst. Geol. Nauk. AN SSSR*, **160**, 1-301. Moskva.

— 1961. Vodorosli srednesarmatskikh biogermov Moldavii. *Izv. Moldav. Filj. Akad. Nauk SSSR*, **84**, 74–83. Kishinev.

— 1962. Iskopayemye bagranye vodorosli SSSR i ikh svaz s facyami. *Trudy Geol. Inst.*, **53**, 1–221. Moskva.

MASTRORILLI, V.I. 1967a. Nuovo contributo allo studio delle Corallinacee dell'Oligocene Ligure-Piemontese: I reparti della Tavoletta Ponzone. *Atti Ist. Geol. Univ. Genova*, **5**, 153–406. Genova.

— 1967b. Rinvenimento di Squamariacee dell'Oligocene del Bacino Ligure-Piemontese. *Att i Ist. Geol. Univ. Genova*, **5**, 139–150. Genova.

— 1973. Flore fossili a Corallinacee di alcuna localita Venete tra i Berici e l'Altopiano di Asiago. *Atti Soc. Ital. Sci. Nat. Mus. Storia Nat. Milano*, **114**, 209–292. Milano.

MATTHEWS, R.K. 1968. Carbonate diagenesis: equilibrium of sedimentary mineralogy to the subaerial environment; coral cap of Barbados, West Indies. *J. Sedim. Petrol.*, **38**, 1110–1119. Tulsa.

— 1974. A process approach to diagenesis of reefs and reef associated limestones. *In:* L.F. LAPORTE (*Ed.*), Reefs in time and space. *Soc. Econ. Paleont. Min. Spec. Publ.*, **18**, 234-256. Tulsa.

MEYERS, W.J. 1974. Carbonate cement stratigraphy of the Lake Valley Formation (Mississipian) Sacramento Mountains, New Mexico. *J. Sedim. Petrol.*, **44**, 837–867. Tulsa.

MILLIMAN, J.D. 1971. Carbonate lithification in the deep sea. *In:* O.P. BRICKER (*Ed.*), Carbonate cements. *John Hopkins Univ. Stud. Geol.*, **19**, 95–102. Baltimore.

— 1974. Marine carbonates. pp. 1–375. Berlin.

— , ROSS, D.A. & TEH-LUNG, K. 1969. Precipitation and lithification of deep sea carbonates in the Red Sea. *J. Sedim. Petrol.*, **39**, 724–736. Tulsa.

MORROW, D.W. & MAYERS, I.R. 1978. Simulation of limestone diagenesis — a model based on strontium depletion. *Can. J. Earth Sci.*, **15**, 376–396. Ottawa.

MORTON, J.E. 1965. Form and function in the evolution of Vermetidae. *Bull. Brit. Mus. Nat. Hist. (Zool.)*, **2**, 585–630. London.

— & MILLER, M. 1973. The New Zealand sea shore, pp. 1–653. London.

MUCHOWSKI, J. 1970. Influence of tectonics of the marginal zone in the Lublin Upland upon facial differentiation of the marine Miocene deposits. *Przegl. Geol.*, **8–9**, 398–400. Warszawa.

MÜLLER, G. 1971. "Gravitational" cement: an indicator for the vadose zone of the subaerial diagenetic environment. *In:* O.P. BRICKER (*Ed.*), Carbonate cements. *John Hopkins Univ. Stud. Geol.*, **19**, 301–302. Baltimore.

MULTER, G.H. 1971. Drusy mosaic growth in the Miami Limestone. *In:* O.P. BRICKER (*Ed.*), Carbonate cements. *John Hopkins Univ. Stud. Geol.*, **19**, 137–138. Baltimore.

MURRAY, J.W. 1973. Distribution and ecology of living benthic foraminiferids, pp. 1–274. London.

ORSZAG-SPERBER, F. & POIGNAT, A.F. 1972. Corallinacées du Miocène de la Plaine Orientale Corse. *Rev. Micropal.*, **15**, 115–124. Paris.

— , — & POISON, A. 1977. Paleogeographic significance of rhodolites: some examples from the Miocene of France and Turkey. *In:* E. FLÜGEL (*Ed.*), Fossil algae, pp. 286–294. Berlin.

OSMAN, R.W. 1977. The establishment and development of marine epifaunal community. *Ecol. Mon.*, **47**, 37–63. Durham.

OSMÓLSKI, T. & PILICHOWSKA, E. 1978. Hauerite and problems of manganese concentrations in Badenian clays of the Carpathian Foredeep. *Arch. Mineral.*, **34**, 5-18. Warszawa.

PARKER, R. 1959. Macro-invertebrate assemblages of central Texas coastal bays and Laguna Madre. *Amer. Assoc. Petrol. Geol. Bull.*, **43**, 2100–2166. Tulsa.

PASCAL, A. 1979. Utilisation des éléments traces dans la caractérisation des paléomilieux sédimentaires Urgoniens Basco-Cantabriques. *Géobios, Mem. Spécial*, **3**, 331–345. Lyon.

PEARSE, A.S. & WILLIAMS, L.G. 1951. The biota of the reefs off the Carolinas. *J. Elisa Mitchell Sci. Soc.*, **67**, 133–161. Chapel-Hill.

PEDLEY, H.M. 1976. A palaeoecological study of the Upper Coralline Limestone, *Terebratula — Aphelesia* Bed (Miocene, Malta) based on bryozoan growth-form studies and brachiopod distribution. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **20**, 209–234. Amsterdam.

— 1979. Miocene bioherms and associated structures in the Upper Coralline limestone of the Maltese Islands: their lithification and palaeoenvironment. *Sedimentology*, **26**, 577–591. Oxford.

PÉRÈS, J.M. & PICARD, J. 1964. Nouveau manuel de bionomie bénthique de la Mer Méditerranée. *Rec. Trav. Stat. Mar. Endoume*, **31**, 1–137. Marseille.

— & — 1969. Reflexions sur la structure trophique des édifices récifaux. *Mar. Biol.*, **3**, 227–232.

PETTA, T.J. 1977. Diagenesis and geochemistry of Glen Rose patch reef complex, Banders County, Texas. *In:* D.G. BEBOUT & R.G. LOUCKS (*Eds*), Cretaceous carbonates of Texas and Mexico: Applications to subsurface exploration. *Texas Univ. Bur. Econ. Geol., Rep. Inv.*, **89**, 138–167. Austin.

PHLEGER, F.B. 1960. Ecology and distribution of Recent Foraminifera, pp. 1–297. Baltimore.

PIANKA, E.R. 1974. Evolutionary ecology. New York.

PINGITORE, N.E. Jr. 1976. Vadose and phreatic diagenesis: processes, products and their recognition in corals. *J. Sedim. Petrol.*, **46**, 985–1006. Tulsa.

— 1978. The behaviour of Zn^{+2} and Mn^{+2} during carbonate diagenesis: theory and applications. *J. Sedim. Petrol.*, **48**, 799–814. Tulsa.

PISERA, A. 1978. Miocene reef deposits of the western Roztocze. *Przegl. Geol.*, **3**, 159–162. Warszawa.

POIGNAT, A.-F. 1979. Détermination générique des Corallinacées Mésozoiques et Cénozoiques. *Bull. Centr. Rech. Explor.-Prod. Elf-Aquitaine*, **3**, 757–765. Pau.

POORE, G.C.B. 1972. Ecology of New Zealand abalones. *N.Z.J. Mar. Freshw. Res.*, **6**, 11–22. Wellington.

PORTER, J.W. 1972. Ecology and species diversity of coral reefs on opposite sides of the isthmus of Panama. *Bull. Biol. Soc. Washington*, **2**, 89–116. Washington.

POUYET, S. 1973. Révision systématique des cellépores (Bryozoa, Cheilostomata) et des espèces fossiles européennes. Analyse de quelques populations à cellépores dans le Néogène du bassin Rhodanien. *Docum. Lab. Géol. Fac. Sci. Lyon*, **55**, 1–266. Lyon.

PURSER, B.H. 1969. Syn-sedimentary marine lithification of Middle Jurassic limestones in the Paris basin. *Sedimentology*, **12**, 205–230, Amsterdam.

RADWAŃSKI, A. 1964. Boring animals in Miocene littoral environment of southern Poland. *Bull. Acad. Polon. Sci., Sér. Sci. Géol. Géogr.*, **12** (1), 57–62. Warszawa.

— 1965. Additional notes on Miocene littoral structures of southern Poland. *Bull. Acad. Polon. Sci., Sér. Sci. Géol. Géogr.*, **13** (2), 167–173. Warszawa.

— 1967. Problems of Miocene littoral structures on the southern slopes of the Holy Cross Mts, Central Poland. *Ann. Soc. Géol. Pol.*, **37** (2), 169–175. Kraków.

— 1969. Lower Tortonian transgression onto the southern slopes of the Holy Cross Mts. *Acta Geol. Polon.*, **19** (1), 1–164. Warszawa.

— 1973. Lower Tortonian transgression onto the south-eastern and eastern slopes of the Holy Cross Mts. *Acta Geol. Polon.*, **23** (2), 375–434. Warszawa.

— 1977a. Present-day types of trace in the Neogene sequence; their problems of nomenclature and preservation. *In:* T.P. CRIMES & J.C. HARPER (*Eds*), Trace fossils **2** (*Geol. J. Spec. Issues*, **9**) 227–264. Liverpool.

— 1977b. Neogen. *In:* H. MAKOWSKI (*Ed.*), Geologia historyczna; pp. 731–769. Warszawa.

RAYNAUD, J.-P. 1969. Lamellibranches lithophages. Application à l'étude d'un conglomérat à cailloux perforés du Miocène du Midi de la France. *Trav. Lab. Paléont.*, **6**, 1–75. Orsay.

REIJERS, T.J.A. 1972. Facies and diagenesis of the Devonian Portilla Limestone Formation between the river Esla and the Embalse de la Luna, Cantabrian Mountains, Spain. *Leidse Geol. Med.*, **47**, 163–249. Leiden.

RICHTER, D.J. 1979. Die Stufen der meteorisch-vadosen Umwandlung von Mg-Calcite in rezenten bis pliozänen Biogenen Griechenlands. *N. Jb. Geol. Paläont. Abh.*, **158**, 277–333. Stuttgart.

RIDING, R. 1977. Reef concepts. *Proc. Third Int. coral Reef Symp.*, 209–213. Miami.

RIEDL, R. 1963. Cirripedia. *In:* R. RIEDL (*Ed.*), Fauna und Flora der Adria, pp. 252–258. Hamburg.

RHOADS, D.C., SPEDEN, I.G. & WAAGE, K.M. 1972. Trophic group analysis of Upper Cretaceous (Maastrichtian) bivalve assemblages from South Dakota. *Bull. Amer. Assoc. Petrol. Geol.*, **56**, 1100–1113. Tulsa.

SAFRIEL, U. 1966. Recent vermetid formation on the mediterranean shore of Israel. *Proc. Malac. Soc. London*, **37**, 27–34. London.

— 1974. Vermetid gastropods and intertidal reefs in Israel and Bermuda. *Science*, **186**, 1113–1115. New York.

— 1975. The role of vermetid gastropods in the formation of Mediterranean and Atlantic reefs. *Oecologia*, **20**, 85–100.

SCHALEKOVÁ, A. 1973. Oberbadenische Corallinaceen aus dem Steinbruch Rohožnik-Vajar an dem westhang der Kleinen Karpaten. *Acta Geol. Geograph. Univ. Comenianae Geologica*, **26**, 211–221. Bratislava.

SCHERER. M, 1975 Cementation and replacement of Pleistocene corals from the Bahama and Florida: Diagenetic influence of ncn-marine environment *N. Jb. Geol. Paläont. Abh.*, **149**, 259-285. Stuttgart.

— 1977. Preservation, alternation and multiple cementation of aragonitic skeletons from the Cassian Beds (U. Triassic. Southwestern Alps): Petrographic and geochemical evidence *N. Jb Geol. Paläont. Abh.*, **154**, 213-262. Stuttgart.

SCHLANGER, S.O. 1963. Subsurface geology of Eniwetok Atoll. *U.S. Geol. Surv. Prof. Papers*, **260-B**, 991–1066. Washington.

SCHNEIDER, W. 1977. Diagenese devonischer Karbonatkomplexe Mitteleuropas. *Geol. Jb., Reihe D*, **21**, 3–107. Stuttgart.

SCHOPF, T.M. 1969. Paleoecology of ectoprocts (Bryozoans). *J. Paleont.*, **43**, 234–244. Menasha.

SCHROEDER, J.H. 1972a. Calcified filaments of an endolithic alga in recent Bermuda reefs. *N. Jb. Geol. Paläont. Mh.*, **1**, 16–33. Stuttgart.

— 1972b. Fabrics and sequence of submarine carbonate cements in Holocene Bermuda cup reefs. *Geol. Rundsch.*, **61**, 708–730. Stuttgart.

— 1973. Submarine and vadose cements in Pleistocene Bermuda reef rock. *Sedim. Geol.*, **10**, 179–204. Amsterdam.

— 1979. Carbonate diagenesis in Quaternary beachrock of Uyombo, Kenya: sequences of processes and coexistence of heterogenic products. *Geol. Rundsch.*, **68**, 894–919. Stuttgart.

SCOFFIN, T.P. 1972. Cavities in the reefs of the Wenlock Limestone (Mid-Silurian) of Shropshire, England. *Geol. Rundsch.*, **61**, 565–578. Stuttgart.

— & GARRETT, P. 1974. Processes in the formation and preservation of internal structure in Bermuda patch reefs. *Proc. Second Int. Symp. Coral Reefs*, **2**, 429–448. Brisbane.

SCOTT, R.W. 1970. Paleoecology and paleontology of the Lower Cretaceous Kiowa Formation, Kansas. *Univ. Kansas Paleont. Contrib. Art.*, **52**, pp. 1–94. Lawrence.

— 1974. Bay and shoreface benthic communities in the Lower Cretaceous. *Lethaia*, **7**, 315–330. Oslo.

— 1976. Trophic classification of benthic communities. *In:* R.W. SCOTT & R.R. WEST (*Eds*), Structure and classification of paleocommunities, pp. 29–66. Stroudsburg.

— 1978. Approaches to trophic analysis of paleocommunities. *Lethaia*, **11**, 1–14. Oslo.

SHEPARD, S.A. 1973. Studies on southern Australian abalone (genus *Haliotis*). *Austral. J. Mar. Freshwater Res.*, **24**, 217–252. Melbourne.

SHIER, D.E. 1969. Vermetid reefs and coastal development in Ten Thousand Islands, Southern Florida. *Geol. Soc. Amer. Bull.*, **80**, 485–508. Boulder.

SHINN, E. 1969. Submarine lithification of Holocene carbonate sediments in the Persian Gulf. *Sedimentology*, **12**, 109–144. Amsterdam.

— 1971a. Holocene submarine cementation in the Persian Gulf. *In:* O.P. BRICKER (*Ed.*), Carbonate cements. *John Hopkins Univ. Stud. Geol.*, **19**, 63–65. Baltimore.

— 1971b. Aspects of diagenesis of algal cup reefs in Bermuda. *Transac. Gulf Coast Ass. Geol. Soc.*, **21**, 387–394.

SOLIMAN, G.N. 1969. Ecological aspects of some coral-boring gastropods and bivalves of the Northwestern Red Sea. *Amer. Zool.*, **9**, 887–894. Utica.

SOUAYA, F.J. 1963. On the calcareous algae Melobesioideae of Gebel Gharra (Cairo-Suez road) with a local zonation and some possible correlations. *J. Paleont.*, **37**, 1204–1216. Menasha.

STACH, L.W. 1939. Correlation of zoarial form with habitat. *J. Geol.*, **44**, 60–65. Chicago.

STANLEY, S.M. 1969. Post-Paleozoic adaptive radiation of infaunal bivalve Molluscs — a consequence of mantle fusion and siphon formation. *J. Paleont.*, **42**, 214–229. Menasha.

— 1970. Relation of shell form to life habits of the Bivalvia (Mollusca). *Mem. Geol. Soc. Amer.*, **125**, pp. 1–296. Boulder.

— 1972. Functional morphology and evolution of byssally attached bivalve molluscs. *J. Paleont.*, **46**, 165–212. Lawrence.

STANTON, R.J., Jr. 1976. Relationship of fossil communities to original communities of living organisms. *In:* R.W. SCOTT & R.R. WEST (*Eds*), Structure and classification of paleocommunities, pp. 107–141. Stroudsburg.

— & DODD, J.R. 1976. The application of trophic structure of fossil communities in paleoenvironmental reconstruction. *Lethaia*, **9**, 327–342. Oslo.

— & NELSON, P.C. 1980. Reconstruction of the trophic web in paleontology: community structure in the Stone City Formation (Middle Eocene, Texas). *J. Paleont.*, **54**, 118–135. Lawrence.

STARMÜHLNER, F. 1963. Bivalvia. Gastropoda. *In:* R. RIEDL (*Ed.*), Fauna und Flora der Adria, pp. 396–420 and 348–394. Hamburg.

— 1969. Zur Molluskenfauna des Felslitorals bei Rovinj (Istrien). *Malacologia*, **9**, 217–242. Philadelphia.

STEHLI, F.G. & HOWER, J. 1961. Mineralogy and early diagenesis of carbonate sediments. *J. Sedim. Petrol.*, **31**, 358–371. Tulsa.

STEINEN, R.P. 1974. Phreatic and vadose diagenetic modification of Pleistocene limestone: petrographic observations from subsurface of Barbados, West Indies. *Amer. Assoc. Petrol. Geol. Bull.*, **50**, 1008–1024. Tulsa.

— 1978. On the diagenesis of lime mud: Scanning electron microscopic observations of subsurface material from Barbados, W.I. *J. Sedim. Petrol.*, **48**, 1139–1148. Tulsa.

— & MATTHEWS, R.K. 1973. Phreatic vs. vadose diagenesis: stratigraphy and mineralogy of a cored borehole on Barbados, W.I. *J. Sedim. Petrol.*, **43**, 1012–1020. Tulsa.

STEINKER, D.C., WEIS, B.R. & WASZCZAK, R.F. 1977. Foraminiferal assemblages associated with South Florida reefs. *Proc. Third Int. Coral Reef Symp.*, 79–85. Miami.

STENZEL, H.B. 1971. Oysters. *In:* R.C. MOORE (*Ed.*), *Treatise on Invertebrate Paleontology*, Part N (Mollusca *6*, Bivalvia), *N*954–*N*1224. Lawrence.

STEPHENSON, T.A. & STEPHENSON, A. 1972. Life between tidemarks on rocky shores, pp. 1–425. San Francisco.

STUDENCKI, W. 1979. Sedimentation of algal limestones from Busko-Spa environs (Middle Miocene, Central Poland). *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **27**, 155–165. Amsterdam.

SZCZECHURA, J. 1982. Middle Miocene foraminiferal biochronology and ecology. *Acta Palaeont. Polon.*, **27**, 3–44. Warszawa.

— & PISERA, A. 1985. Microfauna and microfacies of the lithothamnian limestones from the Holy Cross Mts and Roztocze (Poland). *Zeszyty Nauk. AGH (Geologia).* Kraków.

SZULCZEWSKI, M. 1971. Upper Devonian conodonts, stratigraphy and facial development in the Holy Cross Mountains. *Acta Geol. Polon.*, **21** (1), 1–128. Warszawa.

— 1973. Famennian-Tournaisian neptunian dykes from Dalnia in the Holy Cross Mountains. *Acta Geol. Polon.*, **23** (1), 15–59. Warszawa.

TAYLOR, J.D. 1968. Coral reef and associated invertebrate communities (mainly molluscan) around Mahe, Seychelles. *Phil. Trans. Roy. Soc. London*, **254**, 129–206. London.

— 1970. Feeding habits of predatory gastropods in a Tertiary (Eocene) molluscan assemblage from the Paris Basin. *Palaeontology*, **13**, 254–260. London.

— 1971. Reef associated molluscan assemblages in the Western Indian Ocean. *Symp. Zool. Soc. London*, **28**, 501–534. London.

— 1978. Faunal response to the instability of reef habitats: Pleistocene molluscan assemblages of Aldabra Atoll. *Palaeontology*, **21**, 1–30. London.

TAYLOR, J.M.C. & ILLING, L.V. 1969. Holocene intertidal calcium carbonate cementation, Quatar, Persian Gulf. *Sedimentology*, **12**, 69–107. Amsterdam.

TEISSEYRE, W. 1895. O charakterze fauny kopalnej Miodoborów. *Rozprawy Wydz. Mat.-Przyr. Akad. Um. Kraków*, **30**, 1–11. Kraków.

— 1900. Atlas geologiczny Galicji; Tekst do zeszytu ósmego, pp. 1–330. Kraków.

THOMAS, R.D.K. 1978. Shell form and the ecological range of living and extinct Arcoida. *Paleobiology*, **4**, 181–194. Chicago.

THORNTON, S.E., PILKEY, O.H. & LYNTS, G.W. 1978. A lagoonal crustose coralline algal micro-ridge: Bahiret el Bibane, Tunisia. *J. Sedim. Petrol.*, **48**, 743–750. Tulsa.

TOOMEY, D.F. (*Ed.*). 1981. European fossil reef models. *Soc. Econom. Paleont. Spec. Publ.*, **30**, 1–544. Tulsa.

VANNUCCI, G. 1970. Paleoalgologia. *In:* S. GIAMMARINO, S. NOSENGO & G. VANNUCCI (*Eds*), Risultanze geologico-paleontologiche sul conglomerato di Portofino (Liguria Orientale). *Atti Ist. Geol. Univ. Genova*, **7**, 328–363. Genova.

VASSEUR, P. 1974. The overhangs, tunnels and dark reef galleries of Tuléar (Madagascar) and their sessile invertebrate communities. *Proc. Second. Int. Coral Reef Symp.*, **2**, 143–159. Brisbane.

— 1977. Cryptic sessile communities in various coral formations on reef flats in the vicinity of Tuléar (Madagascar). *Proc. Third Int. Symp. Coral Reefs*, 95–100. Miami.

VERMEIJ, G.J. 1980. Biogeography and adaptation: Patterns of marine life, pp. 1–332. Cambridge.

WALKER, K.R. 1972. Trophic analysis: a method for studying the function of ancient communities. *J. Paleont.*, **46**, 82–93. Lawrence.

WARDLAW, N., OLDERSHAW, A. & STOUT, M. 1978. Transformation of aragonite to calcite in a marine gastropod. *Canad. J. Earth Sci.*, **15**, 1861–1866. Ottawa.

WARME, J.E. 1975. Borings as trace fossils and the process of marine bioerosion. *In:* R.W. FREY (*Ed.*), The study of trace fossils, pp. 181–227. New York.

— 1977. Carbonate borers — their role in reef ecology and preservation. *Studies in Geology*, **4**, 261–269. Tulsa.

— , EKDALE, S.F. & PETERSEN, C.H. 1976. Raw material of the fossil record. *In:* R.W. SCOTT & R.R. WEST (*Eds*), Structure and classification of paleocommunities, pp. 1–28. Stroudsburg.

WEIS, B.R. & STEINKER, D.C. 1977. Foraminifera from patch reef and outer reef sediments, Lower Florida Keys. *The Compass*, **54**, 87–105. Springville.

WIENS, H.J. 1962. Atoll environment and ecology, pp.1–532. New Haven.

WINLAND, H.D. 1968. The role of high-Mg calcite in the preservation of micrite envelopes and textural features of aragonite sediments. *J. Sedim. Petrol.*, **38**, 1320–1325. Tulsa.

WRAY, J.L. 1977. Calcareous algae. *Develop. in Palaeont. Stratigr.*, **4**, 1–185. Amsterdam.

YONGE, C.M. 1963. Rock boring organisms. *In:* R.F. SOGNALES (*Ed.*), Mechanism of hard tissue destruction, pp. 1–24. Washington.

ZIEGLER, A.M., WALKER, K.R., KAUFFMAN, E.G., GINSBURG R.N. & JAMES, N.P. 1974. Principles of benthic community analysis. *Sedimenta*, **4**, 1–168. Miami.

ZIMMERMANN, L. 1980. Ein neus Formenelement im litoralen Benthos des Mittelmeerraums: Die Klein-Atolle ("Boiler"-Riffe) bei Phalasarna (Westkreta). *Berliner Geogr. Stud.*, **7**, 135–153. Berlin.

A. PISERA

PALEOEKOLOGIA I LITOGENEZA BADEŃSKICH RAF GLONOWO-WERMETUSOWYCH ROZTOCZA ZACHODNIEGO

(Streszczenie)

Przedmiotem pracy jest analiza rozwoju badeńskich raf glonowo-wermetusowych Roztocza Zachodniego. Rafy te (*patrz* fig. 1—8), zbudowane głównie z laminarnych krasnorostów Corallinaceae oraz muszli wermetusów — osiadłych ślimaków *Petaloconchus intortus* (LAMARCK), zawierają zmienne ilości osadów wewnętrznych, zaś szkielet ich inkrustowany jest przez mszywioły, serpule, wąsonogi z rodzaju *Verruca*, oraz osiadłe otwornice (*patrz* pl. 1—16 oraz 31—32). Spośród 21 gatunków glonów rozpoznanych w osadach rafowych (*patrz* pl. 17—30) tylko siedem odgrywa znaczącą rolę; ich skład taksonomiczny jest zbliżony do znanego z równowiekowych osadów Ukrainy, niewiele natomiast jest form wspólnych z Basenem Wiedeńskim. Rozpoznano dwa zespoły ekologiczne fauny stowarzyszone z rafą (*patrz* fig. 9—13 oraz tab. 1—4): *zespół rafowy* zasiedlał rafę w czasie jej aktywnego wzrostu, zaś *zespół epirafowy* związany był z powierzchnią rafy po zakończeniu jej aktywnego wzrostu. Rozwój raf następował na wyniesionych częściach dna płytkiego zbiornika morskiego (fig. 15), w warunkach charakteryzujących się dużą energią hydrodynamiczną, przy normalnym zasoleniu i ciepłym klimacie zbliżonym do panującego obecnie we wschodniej części Morza Śródziemnego. Cementacja podmorska (*patrz* pl. 33—36) zapoczątkowała diagenetyczną ewolucję badanych raf, w obrębie których istotne były również procesy późnodiagenetyczne (*patrz* fig. 16 oraz pl. 37—44), związąne ze zmianami położenia zwierciadła wód gruntowych w warunkach lądowych panujących od górnego miocenu do czasów dzisiejszych (fig. 17).
