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Red-algal limestones in the Middle Miocene of the Carpathian Foredeep in Poland: facies variability and palaeoclimatic implications

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The distribution of red-algal limestones in the Middle Miocene marine deposits of the Carpathian Foredeep is described. Main facies types are briefly characterized, based on the morphology of red-algal thalli and major rock-forming fossil groups. The following facies have been recognized to date: algal-vermetid reefs, biohermal limestones, rhodolith pavement facies, branching algal facies, algal-bryozoan facies, and algal-amphisteginid facies. An organodetrital facies rich in red-algal fragments has also been reported. Basing on comparison with the present day, algal-vermetid reefs and biohermal limestones are referred to the shallowest, high-energy conditions, typical of intertidal to shallow subtidal zones. Rhodolith pavements, along with associated algal-bryozoan and algal-amphisteginid facies, formed in a wide range of environmental conditions: from nearshore to open marine, under various hydrodynamic regimes. The branching algal facies was confined to bottom elevations in open marine conditions. The red-algal limestones from the Middle Miocene of Poland are here recognized as a direct, close analogue of the recent *rhodalgal lithofacies*, typical of the temperate climatic zone, and thus indicating temperate depositional conditions. This interpretation conflicts with the traditional one based on faunal indicators suggesting subtropical to tropical conditions.

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INTRODUCTION

The purpose of this paper is threefold. Firstly, to change the terminology referring to red-algal limestones. Secondly, to present a systematic review of red-algal facies recorded in the Polish Miocene strata of the Carpathian Foredeep. And thirdly, to draw palaeoclimatological conclusions from the red-algal lithofacies, which differ from previous inferences drawn from other fossil evidence.

Let us first consider terminology. For more than a century the term "lithothamnian limestone" has been widely used by Polish geologists (e.g. B. Areń, 1962; M. Bielecka, 1967; J. Czarnocki, 1935; K. Kowalewski, 1930; A. Michalski, 1887) with reference to various red-algal limestones, though most frequently to those consisting of more or less spheroidal "balls" or "nodules" built of concentric growths of red-algal (corallinacean) thalli (e.g. A. Radwański, 1973). However, this informal term is both imprecise and misleading as it implies that the rock is composed predominantly of "lithothamnians", in other words, thalli representing the genus *Lithothamnion*. In fact, the genus *Lithothamnion* is only one of three dominant corallinacean genera (together with *Lithopyllum* and *Mesophyllum*) common in the Middle Miocene red-algal limestones, as proved by studies in different parts of the Carpathian Foredeep: the Korytnica Basin (A. Pisera, W. Studencki, 1989), the Wójcza–Pińczów Range (W. Studencki, 1988*a*, *b*), the Roztocze Hills (A. Pisera, 1985), and the Rzeszów Embayment (J. Golonka, 1981). Consequently, the term "lithothamnian limestone" should be abandoned (regardless of its long, traditional use) as being confusing and baseless, and should be replaced with a new, more accurate expression. "Red-algal limestone" would be equally general but correct. Where more or less spheroidal red-algal growths (rhodoliths) dominate, a better term is "rhodolith limestone".

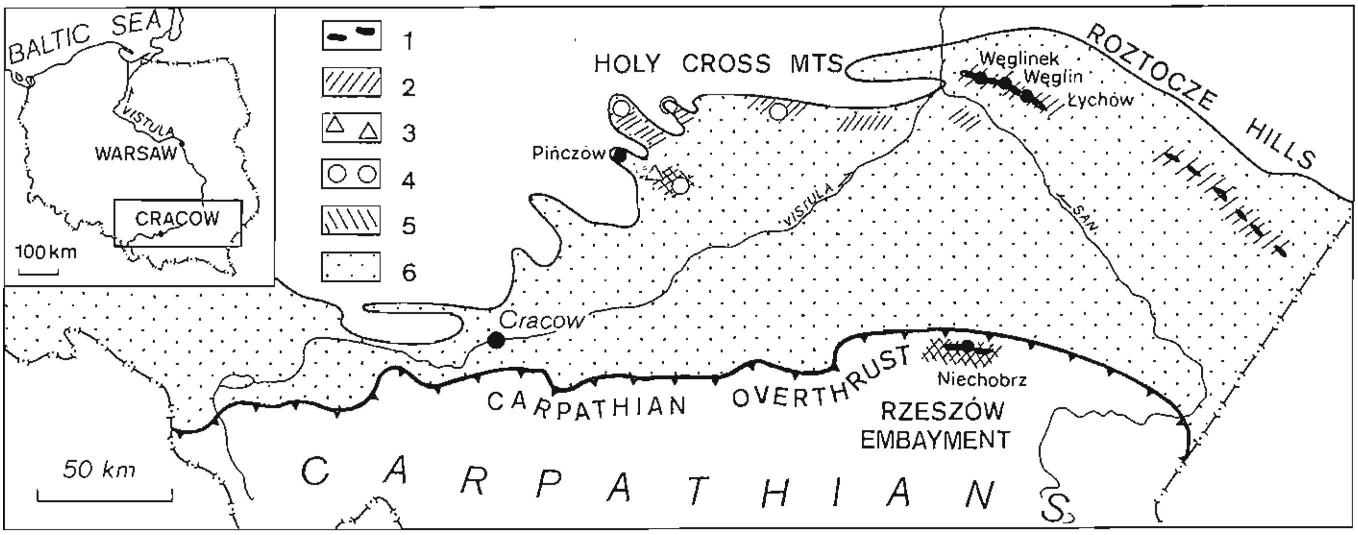

Fig. 1. Distribution of red-algal facies in the Middle Miocene (Badenian) deposits of the Carpathian Foredeep in Poland

1 — algal- and algal-vermetid reefs, 2 — rhodolith pavements, 3 — branching algal facies, 4 — algal-amphisteginid/heterosteginid facies, 5 — algal-bryozoan facies, 6 — present-day extent of the Middle Miocene deposits (from A. Radwański, 1977*b*)

FACIES VARIABILITY

Limestones consisting principally of red algae show some variability resulting, on the one hand, from the dimensions and morphology of algal buildups (reefs, rhodoliths) or individual thalli (branching growth forms) and on the other, from the presence of rock-forming organisms accompanying red algae (e.g. bryozoans, large foraminifera). Based on this, the following facies have been distinguished: algal-vermetid reefs (A. Pisera, 1985), biohermal limestones (J. Golonka, 1981), rhodolith pavement facies (A. Drewniak, 1994; W. Studencki, 1988*a*), branching algal facies (W. Studencki, 1988*a*), algal-bryozoan facies (A. Drewniak, 1994; W. Studencki, 1988*a*), and algal-amphisteginid facies (A. Drewniak, 1994). Moreover, red-algal fragments are often a dominant component of organodetrital limestones (A. Drewniak, 1994; W. Studencki, 1988*a*; J. Golonka, 1981; A. Radwański, 1973).

Red-algal limestones occur mainly along the northern margin of the Carpathian Foredeep (Fig. 1), both in the Lower and the Upper Badenian, although facies variability is different in each of these stages (Fig. 2).

ALGAL-VERMETID REEFS

A belt of algal-vermetid reefs is conspicuous in the Upper Badenian of the Roztocze Region (T. Musiał, 1987; A. Pisera, 1985). The individual reefal buildups are large, stretching along several hundreds of metres, their thickness reaching 10–15 m. Laminar algal thalli, the main constructional element, constitute up to 70% of rock volume (although in some parts less than 20%). In the upper part of reefs thick algal crusts provided with short columns occur along with laminar thalli. Irregular shells of the sessile gastropod *Petaloconchus intortus* (previously attributed to the genus *Vermetus*, from which the reefs have taken their name) are a typical reef component. Their distribution is variable: from mass occurrence to absence in some parts of the buildups. In places algal thalli are intergrown with bryozoan colonies and with the encrusting foraminifer *Nubecularia*. The tubes of the polychaete *Pomatoceros triqueter bicanaliculatus* have also rock-forming importance.

A moderately diverse mollusean community has been reeorded in these algal-vermetid reefs (A. Pisera, 1985; B. Studencka, 1994). Unlike the Early Badenian Pińczów Limestones, where molluscs are common and variable but where aragonite shells are entirely leached (though the caleite shells of scallops and oysters are preserved), the Late Badenian reefs of Roztocze normally (though not always) display very well preserved molluscan aragonite shells. The molluscan assemblage is dominated by the gastropods *Astraea mamillaris, Bittium reticulatum, Haliotis* sp., as well as several trochid species, and the bivalves *Neopycnodonte navicularis, Crassodoma multistriata, Lima lima, Venus cincta, V. (Ventricoloidea) libella*, several species of Arcidae as well as a number of rock-boring speeies. Brachiopods are common.

Numerous primary and secondary pores and cavities are partly filled with internal sediment: heavily lithified biomicrite, and weakly cemented biocalcarenite. No stratification is observed in the reefal limestones.

Algal-vermetid reefs stretch along the margin of the Roztocze Hills, in the vicinity of Zaklików (T. Musiał, 1987; A. Pisera, 1985), and in the area of the Roztocze of Goraj, Tomaszów and Rawa (T. Musiał, 1987).

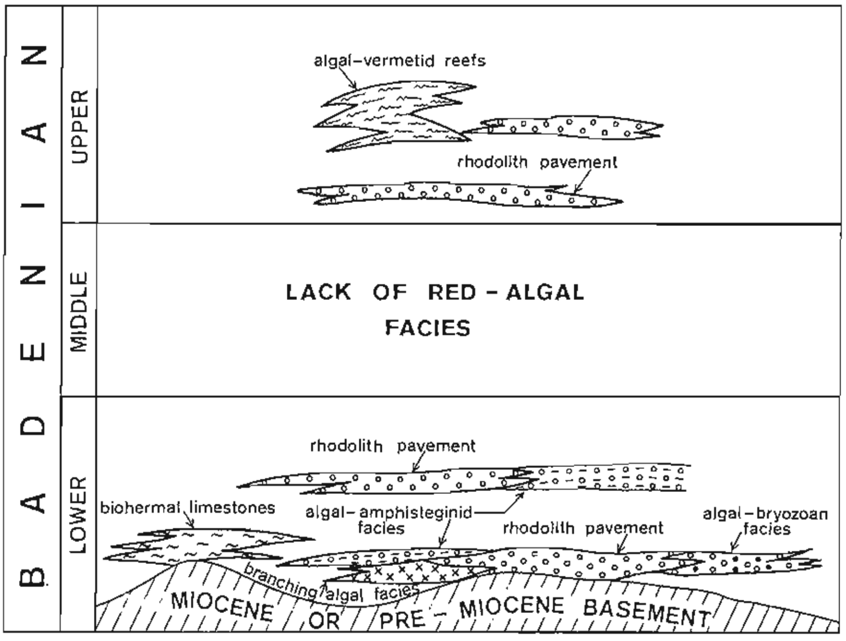

Fig. 2. Distribution of red-algal facies in the Lower and Upper Badenian deposits

BIOHERMAL LIMESTONES (ALGAL REEFS)

The biohermal limestone facies has been recognized in the Lower Badenian of the Rzeszów Embayment (J. Golonka, 1981) and it can probably be synonymized with the reefal facies. Crustose red algae are the main constructive element of carbonate buildups, which are 0.5–2.5 m thick. Along with algae, encrusting bryozoan colonies play a constructive role and are a rock-forming, sometimes even dominant, component. Representatives of the polychaete genera *Ditrupa, Serpula, Pomatoceros, Vermilia* are common while corals (*Orbicella*), bivalves, brachiopods, echinoids, and foraminifera including the encrusting genus *Gypsina* as well as the large foraminiferal genera *Amphistegina* and *Heterostegina* — play a subordinate role.

Pores and constructional voids are filled with detritus derived from fragmentation of skeletal elements of the organisms mentioned above as well as which calcitic spar and micrite, the latter being most probably the product of micritisation of skeletal grains. J. Golonka (1981) distinguished three microfacies types within the biohermal limestones, based on the ratio of the two main constructional elements. The algal microfacies is dominated by red-algal thalli, in the algal-bryozoan microfacies both components are equally important while in the bryozoan microfacies bryozoan colonies predominate.

In all outcrops — in Niechobrz and Olimpów — the biohermal facies invariably overlies rhodolithic limestones.

RHODOLITH PAVEMENT FACIES

This facies occurs both in the Lower and Upper Badenian deposits.

Its main components are densely packed rhodoliths: spheroidal, ellipsoidal and discoidal objects built of crustose, branching or columnar algal thalli. Rhodoliths are complex structures, with red-algal skeletons encrusted with bryozoans, polychaetes (*Serpula* sp., *Pomatoceros* sp.) and, occasionally, the encrusting foraminifer *Miniacina* sp. Balanid cirripeds are sometimes found attached to the surface of rhodoliths while inside, in constructional voids between irregular algal growths, the small brachiopods *Megathiris* and *Argyrotheca* occur along with gastropods and bivalves of uncertain affinity because their aragonite shells have been entirely leached out. Primary pores and voids (between algal branches and crusts) as well as secondary pores (bivalve and sponge borings) are filled with internal sediment variable in composition and grain size. Usually the present porosity of rhodoliths is reduced, consisting of incompletely filled intraskeletal pores, voids remaining after dissolved aragonite shells, borings, bryozoan zoecia, empty polychaete tubes and red-algal conceptacles.

The space between rhodoliths is filled with organodetrital deposits, variable in grain size, with a poor bivalve assemblage, consisting of three species: *Glycymeris deshayesi, Glossus humanus,* and *Gigantopecten nodosiformis* — a large scallop, typical of the Lower Badenian.

A. Drewniak (1994) distinguished three microfacies types within the rhodolith pavement faeies of the Pińczów Limestones, viz. nodular microfacies, and nodular-detrital, var. A and B microfacies, based on the nature of the intra- and inter-rhodolith sediment and on the amount of red-algal detritus in each sediment type.

The accumulations of rhodoliths may be stratified (which can be observed e.g. in the vicinity of Raków and in numerous outcrops in the Roztocze Region — see B. Areń, 1962; T.

Musiał, 1987), but often the rock is non-stratified (for example in Bukowa and Wiązownica — see A. Radwański, 1973).

The rhodolith pavement frequently forms thin intercalations within other sediments: in organodetrital facies of the Pińczów Limestones in Pińczów and Bogucice (A. Drewniak, 1994; W. Studencki, 1988*a*); in quartzose sands, e.g. in Nawodzice (W. Bałuk, A. Radwański, 1968), or in clays, e.g. in Węglin and Łychów (M. Bielecka, 1967). In other places (Bukowa, Wiązownica) the thickness of rhodolith limestones reaches several metres, attaining 8 m in Stalowa Wola (S. Pawłowski *et al.*, 1985). Their position in sections is not stable: rhodolith limestones have been reported from littoral deposits, in direct contact with a pre-Miocene substrate (A. Radwański, 1969), from different horizons within the Badenian sequence (J. Golonka, 1981) as well as from its top (W. Studencki, 1988*a*).

The rhodolith pavement facies occurs frequently in the Badenian strata of the Carpathian Foredeep: in the Lower Badenian of the Wójcza–Pińczów Range (A. Drewniak, 1994; W. Studencki, 1988*a*), in the vicinity of Rocky Bays: Chmielnik Bay and Piotrkowice Bay (A. Radwański, 1969), along the Raków–Klimontów Shore (A. Radwański, 1973), in the region of Stalowa Wola (S. Pawłowski *et al.*, 1985), in the Rzeszów Embayment (J. Golonka, 1981), and in the Upper Badenian of the Roztocze Region (M. Bielecka, 1967; T. Musiał, 1987).

BRANCHING ALGAE FACIES

The branching algal facies has been recorded in the Lower Badenian of the Wójcza–Pińczów Range (W. Studencki, 1988*a*).

The branching growth form dominates in the deposit though volumetrically it is not as abundant as rhodoliths in the rhodolith pavement facies. Crustose thalli are present, too, but only as a subordinate element. Algal thalli are preserved either intact or fragmented but they bear no traces of transport. They occur in layers 20–30 cm thick, intercalated with layers of organodetrital limestones, together forming complexes reaching 2–3 m in thickness. The spaces between algal branches are filled with fine- to medium-grained detrital sediment; the porosity is therefore much reduced and consists mainly of secondary pores which remained after leaching of aragonite molluscan shells.

The molluscan fauna is diversified albeit poorly preserved. Typical of this facies are bivalves, occurring sometimes in mass accumulations of three species: *Glycymeris deshayesi*, *Venus multilamella* and *Plagiocardium papillosum*, and gastropods representing the genus *Bittium*. Common are bryozoans (mainly spheroidal and crustose celleporid colonies), large foraminifera and polychaetes while the brachiopod *Terebratula styriaca* is infrequent.

The position of this facies in sections (between Busko Zdrój and Stopnica) is stable: it invariably underlies limestones representing either algal-bryozoan or rhodolith pavement facies.

ALGAL-BRYOZOAN FACIES

This facies is characterized by the most abundant fossil assemblage but two fossil groups, red algae and bryozoans, dominate (A. Drewniak, 1994; W. Studencki 1988*a*).

Red algae are present as rhodoliths (mainly small, spheroidal in shape, up to 10 cm in diameter), branching thalli and crustose thalli. As a rule, rhodoliths are encrusted with bryozoan colonies, with polychaete tubes often hidden within the irregularities of algal growths. Traces of activities of boring bivalves and sponges are common in rhodoliths. Branching and crustose thalli are usually fragmented but the latter happen to be preserved in place, being an in frequent but characteristic feature of the algal-bryozoan facies. Algal crusts occur either as simple, thin thalli (*ca.* 1 mm in thickness) overgrowing a detrital substrate and other algal laminae, or form complex structures attaining a thickness of several centimetres, built of crustose thalli with short columns, alternating with a fine-grained deposit containing rare bioclasts.

Large (up to several centimetres in diameter), spheroidal and thick-branched celleporid colonies, which constitute up to 40% of the rock volume (A. Drewniak, 1994), dominate among bryozoans. Other bryozoan colonies, though less important as rock-forming elements, show very strong taxonomic diversity; their growth forms are also fairly variable (W. Studencki, 1988*a*).

Large foraminifera — amphisteginids and heterosteginids — are a remarkable and easily recognizable element of the fossil assemblage. Brachiopods comprising the species *Argyrotheca subcordata*, *A. cistellula*, *Terebratula styriaca*, *Megathiris detruncata* and *Megerlia truncata* are common and well preserved. The bivalve assemblage is very rich (B. Studencka, W. Studencki, 1988), and includes the small species *Pododesmus squamus*, which is difficult to recognize but typical of the algal-bryozoan facies. The genera *Bittium* and *Petaloconchus* are most frequent among gastropods. Echinoids are represented mainly as isolated plates but complete, small examples of the genus *Echinocyamus* are not infrequent. Isolated, single plates of asteroids and crinoids are rare. The algal-bryozoan facies also contains cirripedes, polychaetes and decapod crustaceans.

The spaces between fossils are filled with unsorted sediment of variable grain size. The rock is fairly porous as a result of leaching of aragonite molluscan shells and because primary pores occur inside rhodoliths and bryozoan colonies.

The algal-bryozoan facies occurs in the Lower Badenian along the Wójcza–Pińczów Range, between Busko Zdrój and Stopnica (A. Drewniak, 1994; W. Studencki, 1988*a*), laterally adjoining the rhodolith pavement facies. This facies has also been observed by the present author in the area of the Rzeszów Embayment, near Niechobrz.

ALGAL-AMPHISTEGINID (HETEROSTEGINID) FACIES

There is no sharp borderline separating this facies from the, algal-bryozoan one described above, as the three basic

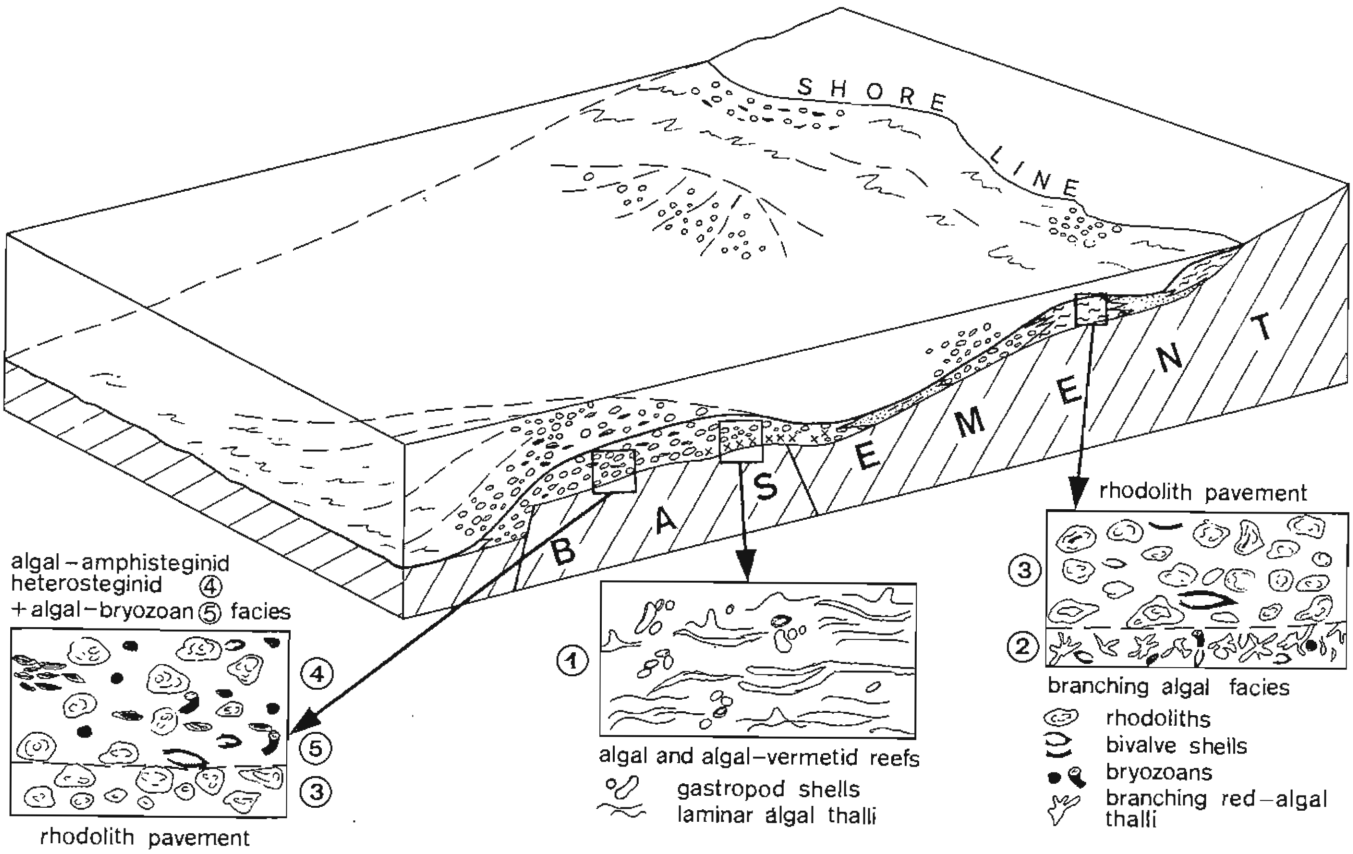

Fig. 3. Diagram to depict sedimentary environments and main features of red-algal facies

constituents, i.e. red algae, bryozoans, and large foraminifera co-exist in both, the rock being dominated, apart from algal thalli, either by bryozoan colonies or tests of foraminifera.

Of the two foraminiferal species, *Amphistegina mamilla* is distinctly more abundant than *Heterostegina costata*. The tests of both species, easily distinguishable from each other even without a magnifying glass (*A. mamilla* being lentil-shaped, 3–5 mm across, while *H. costata* is strongly flattened and 6–20 mm along the longer axis), are either dispersed among other skeletal remains or form monospecific accumulations.

The remaining elements of the fossil assemblage do not differ from those of the algal-bryozoan facies.

The algal-amphisteginid facies has been identified in the western part of the Pińczów Range (A. Drewniak, 1994), the main constituents being preserved there as fragmented skeletal remains. Its description and distribution should, however, be supplemented with additional data. Limestones with well preserved algal thalli (branching, crustose or rhodolith-forming) as well as intact tests of amphisteginids and heterosteginids occur also in the eastern part of the Wójcza–Pińczów Range (W. Studencki, 1988*a*), in Chomentów (A. Pisera, W. Studencki, 1989), Piotrkowice (A. Radwański, 1969) and in the area of Raków (personal observations), all localities being Lower Badenian in age.

DEPOSITIONAL ENVIRONMENT

In general, the red-algal limestones have formed in nearshore conditions or in an open marine environment, not distant from a shore (Fig. 3).

The depositional environment of the algal-vermetid reefs and biohermal limestones can be determined unequivocally. According to A. Pisera (1985), the development of reefs has taken place on the elevated parts of a shallow basin, in high energy conditions. This is supported by the close resemblance of the fossil algal structures to the algal ridges known from the outer rims of modern coral reefs, to unusual buildups — algal cups — reported from the Caribbean, as well as to littoral algal pavements covering the rocky shores of the Mediterranean. This kind of compact, laminar, purely algal and algal-vermetid constructions develop in present-day intertidal to shallow subtidal zones. Moreover, detailed analysis of the molluscan assemblages from the algal reefs of Roztocze revealed their similarity to recent molluscan communities inhabiting reefs at depths not exceeding several metres. These shallow-water features also include assemblages of boring animals typical of near-surface waters, and bryozoans showing growth forms indicative of shallow, high-energy waters (A. Pisera, 1985).

J. Golonka (1981) suggested that the biohermal limestones formed under conditions of high water turbulence, at depths less than 10 m, which led to the dominance of crustose, wave-resistant organisms, firmly attached to the substrate. The presence of corals in algal bioherms near Rzeszów suggests that only a fragment, an outer rim of a reef has been preserved, while its coral core was destroyed. These reefs developed in sublittoral to littoral zones, not far from the shores of a mainland or island chain. Their present-day counterparts may be found in the Caribbean, Mexican or California bays but not amongst the Pacific atolls or in Bahamas (J. Golonka, 1981).

The depositional environment of the rhodolith pavement is far more difficult to reconstruct as the presence of rhodoliths in itself does not allow for direct inferences. Abundant present-day rhodolith accumulations are recorded under different latitudes, and in a variety of shallow-water, i.e. less than 90 m deep, environments: in littoral zone and open-marine conditions — on the top and on slopes of shelf elevations more or less distant from the shore, on reef flats and around them (for a review see D. W. J. Bosence, 1983), and even within deltas (J. C. Braga, J. M. Martin, 1988).

Limestones of unquestionable littoral origin, with rhodoliths co-occurring with pebbles of the substrate rock or containing small pebbles as a core were reported from the Chmielnik Bay (A. Radwański, 1969), Korytnica Bay (A. Pisera, W. Studencki, 1989), and the Raków–Klimontów Shore (A. Radwański, 1973).

The rhodolith pavements known from the Pińczów Limestones (in particular those from the area between Busko Zdrój and Stopnica) were associated with bottom elevations, approximately 30 m in depth, characterized by moderate to high water-energy as indicated by the organisms that lived together with red algae (W. Studencki, 1988*a*). In the westernmost part of the Wójcza–Pińczów Range, only one microfacies type has been attributed to bottom elevations of moderate depth; the remaining two suggest deeper depositional conditions (A. Drewniak, 1994).

The association of the rhodolith pavement with bottom elevations is not always obvious. A. Radwański (1973) suggested that the clean "lithothamnian" facies of the Raków–Klimontów Shore has developed where the input of sandy material was fairly low, e.g. in shallower parts of the sea bottom characterized by good water circulation. But, the sandy and "lithothamnian" facies shows no clear link with the underlying geological structure.

The branching algal facies which constitutes an early stage in the succession of algal limestones in the eastern part of the Wójcza–Pińczów Range, was also depth-related (W. Studencki, 1988*a*). At present, facies consisting predominantly of branching algal thalli develop under variable climatic and bathymetric conditions, e.g. in Europe (where they are known under the name maërl): they range from the Mediterranean Sea in the south to Ireland and Scotland in the north, and from shallow nearshore environments down to depths of 70 m (e.g. J. J. Blanc, 1968; D. W. J. Bosence, 1980).

The algal-bryozoan and algal-amphisteginid limestones, which laterally adjoin each other and also adjoin the rhodolith facies, should be considered together. They formed within the same bathymetric range, differences in algal growth forms and in the ratio of the main accompanying animal groups resulting from variability in hydrodynamic conditions and — presumably — from the mosaic pattern of sea grass and soft-bodied algae which provided a substrate for amphisteginids.

Red algae are rather poor indicators of depositional conditions: neither particular species, which are difficult to identify in the fossil state, nor the growth forms directly indicate parameters of their environment. The best way to interpret the living conditions of the red algae is to understand the environmental requirements of other associated organisms, e.g. molluscs, bryozoans, large foraminifera, and to interpret the sediment between the macrofossils. Efforts to use the red algae as a sole basis for palaeoenvironmental reconstruction have generally been unsuccessful (A. Pisera, W. Studencki, 1989; A. Drewniak, 1994).

This review of the facies variability of red-algal limestones and of their depositional environments clearly shows how risky may be the use of improper and/or imprecise terminology which may lead, consequently, to simplified and misleading interpretations. Terms such as "coastal barrier of reefal type" or "typically littoral conditions", interpreted only on simple presence of limestones identified as "lithothamnian limestones" (see B. Kubica, 1992 as an example), should be considered with caution and may represent an overinterpretation. The term "lithothamnian limestone" may refer to all the red-algal facies discussed above. As shown in the bibliography below, red-algal limestones or even rhodolithic limestones may form in entirely different environments, for instance periodically emergent littoral platforms or reef flats on the one hand, and open-shelf elevations 50–80 m deep on the other.

RED-ALGAL LIMESTONES AS A PALAEOCLIMATIC INDICATOR

There exists a well-established idea in the Polish literature of the last three decades about the subtropical to tropical character of the Early Badenian fauna of the Carpathian Foredeep. It is based on the occurrence in the Lower Badenian deposits of abundant fossils, descendants of which inhabit present-day seas in tropical to subtropical zones. Climatic indicators suggesting warm conditions were identified among foraminifers (J. Szczechura, A. Pisera, 1986), bryozoans (W. Bałuk, A. Radwański, 1977, 1984*b*; N. Vávra, 1984), brachiopods (U. Radwańska, A. Radwański, 1984), decapod crabs (R. Förster, 1979; A. Radwański, 1977*a*), cirripedes (W. Bałuk, A. Radwański, 1967), polyplacophora (W. Bałuk, 1971), gastropods (W. Bałuk, G. Jakubowski, 1968; W. Bałuk, A. Radwański, 1977), holothurians (A. Walkiewicz, 1977), fishes (A. Jerzmańska, 1958; K. Pawłowska, 1960; A. Radwański, 1965; O. Schultz, 1977; U. Radwańska, 1992) and mammals (T. Czyżewska, A. Radwański, 1991). The autecologic a comparisons suggested in these papers may be supplemented with the comparison of the seagrass fossil assemblage from Korytnica to its recent counterpart from the Indian Ocean (A. Hoffman, 1977, 1979*b*).

The subtropical to tropical conditions in the Early Badenian are thus well documented by numerous and diversified palaeoclimatic indicators. But, even though well supported, this view cannot be considered indisputable. Firstly, cases of the ecological evolution of certain organisms from the Middle Miocene until the present have been reported, e.g. the bryozoan genus *Cupuladria* (A. Hoffman, 1979*a*; W. Bałuk, A. Radwański, 1984*a*, *b)* and the bivalve genus *Kelliella* (B. Studencka, 1987). Secondly, most interpretations of the subtropical to tropical character of the Middle Miocene fauna are based on the analysis of the peculiar fossil assemblage occurring in the small Korytnica Basin. Thirdly, Badenian fossil assemblages contain also elements suggesting a cooler climate, for example certain foraminifera (E. Odrzywolska-Bieńkowa, 1977), decapod crustaceans (P. Müller, 1996), and fishes (A. Jerzmańska, 1962; U. Radwańska, 1992).

The most convincing indicator of temperate climatic conditions may, however, be inferred from the general lithofacies resemblance of the Lower Badenian carbonate sediments common in the Carpathian Foredeep to deposits that are forming at present in the temperate climatic zone.

Such a link of lithofacies with broad palaeoclimatic zones has been shown by A. Lees and A. T. Buller (1972) who defined three basic lithofacies types among present-day carbonate sediments. For tropical conditions the *chlorozoan* lithofacies (Chlorophyta + Zoantharia) is typical, dominated by skeletal remains of reef corals and green algae, associated with molluscs, benthic foraminifera, echinoderms, bryozoans, sponges and red algae as well as inorganic carbonate grains. The other, *chloralgal* lithofacies (Chlorophyta), also occurs in subtropical to tropical zones but outside the areas where coral reefs occur, therefore its composition resembles the former one, other than coral grains being absent. The temperate zone is characterized by the *foramol* lithofacies (Foraminifera + Mollusca), dominated by skeletal remains of molluscs, foraminifera, bryozoans, cirripedes and red algae.

This subdivision has been refined (G. Carannante *et al.*, 1988) by subdividing the *foramol* lithofacies into the *rhodalgal* (Rhodophyta) and *molechfor* (Mollusca + Echinoidea + Foraminifera) lithofacies. The former is dominated by crustose red-algal thalli, bryozoans, large foraminifera and cirripedes. Deposits of this type form under moderate subtropical conditions, with increasing proportions of bryozoans indieating lower temperatures. Originally they have been reported from the Brazilian shelf and the Mediterranean Sea (G. Carannante *et al.*, 1988) and then recorded in the Australian shelf (L. B. Collins, 1988). The *molechfor* lithofacies is characterized by the abundance of molluscs, foraminifera, cirripedes and echinoids while crustose red algae are lacking.

The usefulness of this lithofacial approach to palaeoclimatic reconstructions has been successfully established for the Miocene (see e.g. A. R. MacGregor, 1983; L. Simone, G. Carannante, 1985, 1988; L. Scudeler-Baccelle, S. Reato, 1988; J. H. Nebelsick, 1989).

The red-algal limestones from the Lower Badenian deposits of Poland (regardless of their facies variability) closely correspond to the *rhodalgal* lithofacies as defined by G. Carannante *et al.* (1988), with its typical components: red algae, bryozoans, molluscs, echinoids, and large foraminifers being very common while indicators of warmer conditions — reef corals, green algae and inorganic carbonate grains — are entirely absent.

Lithofacies where red-algal grains are dominant or at least a very common component have been widely reported from mid-latitude areas, e.g. from Ireland (D. W. J. Bosence, 1980), Scotland (G. Farrow *et al.*, 1984; T. P. Scoffin, 1988) and New Zealand (C. S. Nelson *et al.*, 1988). However, these deposits can hardly be recognized as counterparts of the Lower Badenian red-algal limestones of the Paratethys because they lack one important component: large foraminifera, indicative of warmer conditions and diagnostic for the *rhodalgal* lithofacies.

Given the similarity of the Lower Badenian red-algal limestones from Poland to the present-day *rhodalgal* lithofacies, it is reasonable to assume that they have formed under similar climatic conditions (i.e. around the boundary between moderate and subtropical zones), moreover, the deposits of the *rhodalgal* lithofacies consist of skeletal remains of many groups of organisms, reducing the scope for errors in interpretation stemming from possible changes in ecological requirements of particular taxa since the Miocene. Such carbonate deposits seem particularly credible as palaeoclimatic indicator because of their widespread occurrence: the red-algal-bryozoan limestones with abundant molluscs, echinoderms, and large foraminifera are well known from both the Paratethys (V. P. Maslov, 1962; M. I. Voloshina, 1973; W. Dullo, 1983; J. H. Nebelsick, 1989) and the Mediterranean Basin (D. W. J. Bosence, H. M. Pedley, 1979; L. Simone, G. Carannante, 1985).

The location of the northern part of the Paratethys near the boundary of the moderate and subtropical zones is constrained by the occurrence of coral reefs in the Vienna Basin (W. Dullo, 1983) but not further to the north, in the Carpathian Foredeep. Nevertheless, the deposits of the Vienna Basin even with their coral reefs have been interpreted, on the basis of the red-algal-bryozoan limestones, as indicating moderate climatic conditions (J. H. Nebelsick, 1989).

These palaeoclimatic inferences, based on the affinities of the Badenian limestones to their present-day counterparts, are consistent with data from the fossil record in neighbouring land areas. Middle Miocene floras from Poland indicate warm temperate climatic conditions (comparable to those in southeast China today, or with the Mediterranean region) (A. Sadowska, 1986; W. Szafer, 1961), with distinct fluctuations towards both colder and warmer (subtropical) climatic conditions, depending on the investigated area and time interval (M. Piwocki, 1975; J. Oszast, L. Stuchlik, 1977; L. Stuchlik, 1980; M. Łańcucka-Środoniowa, 1984; A. Sadowska, 1986; A. Kohlman-Adamska, 1993). Palynological studies show that the climatie optimum, initiated in the Karpatian, was coming to a close in the Early Badenian, as indicated by the domination of palaeotropical species, with Arctic-Tertiary species still present (E. Planderová *et al.*, 1993).

A note of caution: such lithofacies methods should not be used as a sole basis of palaeoenvironmental interpretation because individual lithofacies types do not unequivocally indicate particular climatic conditions; for example, a *rhodalgal* lithofacies occurs also in the vicinity of coral reefs as well as in places where environmental conditions prevent the growth of hermatypic corals and green algae (G. Carannante *et al.*, 1988). The method is, however, worth using if inferences from the distribution of lithofacies types and from the analysis of large groups of fossils over broad areas are mutually consistent.

To summarise, data from marine carbonate deposits and information derived from neighbouring continental floras collectively indicate moderate to subtropical climatic conditions in the Lower Badenian of southern Poland, comparable to the present-day conditions in, for example, the Eastern Mediterranean Sea. This, of course, does not exclude the possibility that locally, in favourable topographic conditions (like the Korytnica Basin) and during climatic optima, specific biocoenoses comprising warm-water species could have developed. Nevertheless, palaeoclimatic indications based on such specific assemblages should not be generalized to a regional scale, in particular if more widespread marine lithofacies and continental floras show distinctly less warm conditions.

In general, it is advisable to avoid the term "tropical" when speaking about the climate of territories lying at latitudes as high as the northern margin of the Miocene Fore-Carpathian Basin (even if the recent relatives of some fossil indicators inhabit the equatorial zone). The word "tropical" implies inevitably that either the northern edge of the Paratethys has been located within the tropical zone (which does not hold true for the Middle Miocene given the continuous global trend towards a colder climate since the Late Eocene) or that it was influenced by warm currents flowing from the tropics. This, in turn, is equally unlikely because the connection of the Paratethys with the world ocean — although well documented for both western and eastern basin terminations — was limited to narrow straits (F. Rögl, F. F. Steininger, 1983; A. Bistricic, K. Jenko, 1985; L. A. Nevesskaja *et al.*, 1986) which makes free flow of tropical currents to the terminal basin north of the Carpathians highly improbable. Here, the water temperature was certainly not determined by southern currents. This scenario is consistent with the reconstructed climatic evolution of the northeastern Atlantic in the Tertiary, based on extensive palaeontological data (A. Lauriat-Rage *et al.*, 1993).

CONCLUSIONS

The term "lithothamnian limestone" denoting various types of red-algal limestones in Badenian strata within the Polish part of the Carpathian Foredeep should be abandoned as imprecise and confusing. Instead, the terms "red-algal limestone" or "rhodolith limestone" should be used.

The Badenian red-algal limestones of Poland closely resemble present-day carbonate deposits representing a *rhodalgal* lithofacies, best developed under moderate to subtropical conditions.

This lithofacial similarity, combined with consistent palaeoclimatic data from continental areas, suggests that the Badenian red-algal limestones were laid down in moderate to subtropical conditions in the Badenian sea north of the Carpathians, and not, as in earlier interpretations, under subtropical to tropical conditions.

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WAPIENIE KRASNOROSTOWE W ŚRODKOWYM MIOCENIE ZAPADLISKA PRZEDKARPACKIEGO NA TERENIE POLSKI: ZRÓŻNICOWANIE FACJALNE I IMPLIKACJE PALEOKLIMATYCZNE

Streszczenie

Wśród wapieni krasnorostowych, stanowiących częsty element przybrzeżnych serii miocenu zapadliska przedkarpackiego, opisano dotychczas następujące odmiany facjalne (nie obejmujące rozmaitych wapieni organodetrytycznych): rafy glonowo-wermetusowe, wapienie biohermowe, bruk rodolitowy, fację glonów gałązkowych oraz facje mieszane: glonowo-mszywiołową i glonowo-amfisteginową/heterosteginową.

Rafy glonowo-wermetusowe, o rozciągłości kilkuset metrów i miąższości do 15 m, znane są z górnego badenu Roztocza. Zbudowane są z laminarnie narastających plech krasnorostów, którym towarzyszą inkrustujące ślimaki, mszywioły, otwornice i wieloszczety.

Wapienie biohermowe, o miąższości do 2,5 m, występują w badenie zatoki rzeszowskiej. Tworzą je, obok naskorupiających krasnorostów, inkrustujące mszywioły i wieloszczety.

Bruk rodolitowy, facja o dużym rozprzestrzenieniu zarówno w dolnym, jak i w górnym badenie, tak wzdłuż północnej, jak i południowej krawędzi zapadliska przedkarpackiego, składa się z rodolitów — mniej lub bardziej kulistych tworów glonowych, zbudowanych z plech o zróżnicowanych formach wzrostu. Niewielki udział w budowie rodolitów mają mszywioły, wieloszczety, wąsonogi i otwornice. Warstwy bruku rodolitowego mają zmienną miąższość, od kilku centymetrów do 8 m.

Wapienie **facji glonów gałązkowych** zbudowane są z plech o gałązkowej formie wzrostu, nagromadzonych w cienkich ławicach, tworzących kompleksy o miąższości 2–3 m. Krasnorostom towarzyszą charakterystyczne dla tej facji, występujące masowo, mięczaki. Jej występowanie ograniczone jest do dolnego badenu Pasma Wójczo-Pińczowskiego.

W **facji glonowo-mszywiołowej** dominują krasnorosty (o różnych formach wzrostu) i mszywioły (głównie duże kolonie celleporów), a pozostałe skamieniałości — ramienionogi, mięczaki, duże otwornice, szkarłupnie — są niezwykle urozmaicone. Facja ta znana jest z dolnego badenu Pasma Wójczo-Pińczowskiego oraz zatoki rzeszowskiej.

Facja glonowo-amfisteginowa/heterosteginowa, charakterystyczna dzięki masowo nagromadzonym dużym otwornicom, zawiera podobny do poprzedniej zespół skamieniałości. Występuje w dolnym badenie południowego obrzeżenia Gór Świętokrzyskich.

Środowisko depozycji poszczególnych odmian facjalnych jest trudne do jednoznacznego odtworzenia. Jedynie w przypadku raf glonowo-wermetusowych i wapieni biohermowych można je określić jako płytkowodne, burzliwe. Pozostałe facje krasnorostowe tworzą się współcześnie w różnych warunkach: od strefy międzypływowej do głębokości kilkudziesięciu metrów, blisko brzegu i w warunkach otwartego morza. Z tego względu wysnuwanie wniosków paleogeograficznych na podstawie samej tylko obecności krasnorostów uznać należy za ryzykowne.

Powszechne występowanie w osadach dolnego badenu wapieni krasnorostowych i krasnorostowo-mszywiołowych z dużym udziałem mięczaków, jeżowców i dużych otwornic, przy braku natomiast szczątków korali, zielenic oraz nieorganicznych ziarn węglanowych, wskazuje na warunki klimatyczne typowe dla strefy umiarkowanej (na pograniczu ze strefą subtropikalną), nie zaś na klimat subtropikalny/tropikalny, jak sugerują rekonstrukcje oparte na analizie kopalnych zespołów fauny.