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LOWER PERMIAN PALAEOAPLYSINID BIOHERMS AND ASSOCIATED SEDIMENTS FROM CENTRAL SPITSBERGEN

Abstract

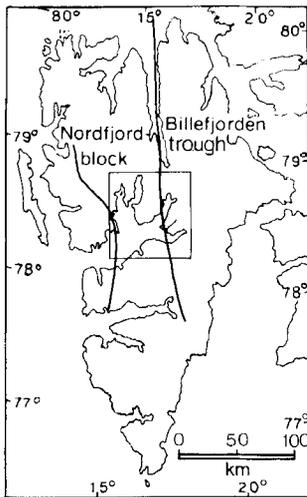
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Bioherms found in the Lower Permian Tyrrellfjellet Member of Central Spitsbergen contain bindstones produced by the ?hydrozoan taxon Palaeoaplysina. We briefly describe the bioherms' stratigraphical and environmental setting and note their development on hardground surfaces. The association of these structures with bituminous limestones is interesting in view of the petroleum resources of similar build-ups in the USSR.

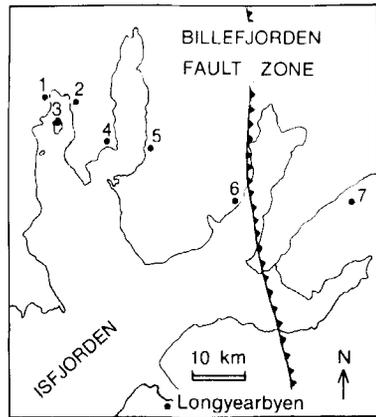
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Introduction

Svalbard displays a relatively complete Carboniferous and Permian succession, with carbonates dominating the Moscovian to Artinskian sequence in most exposure areas. This sequence has previously been regarded as devoid of reef- or reefoid structures, a feature noted by CUTBILL and CHALLINOR (1965 : 427). However, more detailed studies in recent years have revealed the presence of various types of carbonate buildups at several localities in central Spitsbergen. These occur in sequences of late Carboniferous and early Permian age. Dolomitized bioherms of Lower Permian age have also been observed on the island of Bjørnøya (AGDESTEIN 1980).



A



B

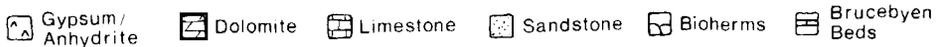
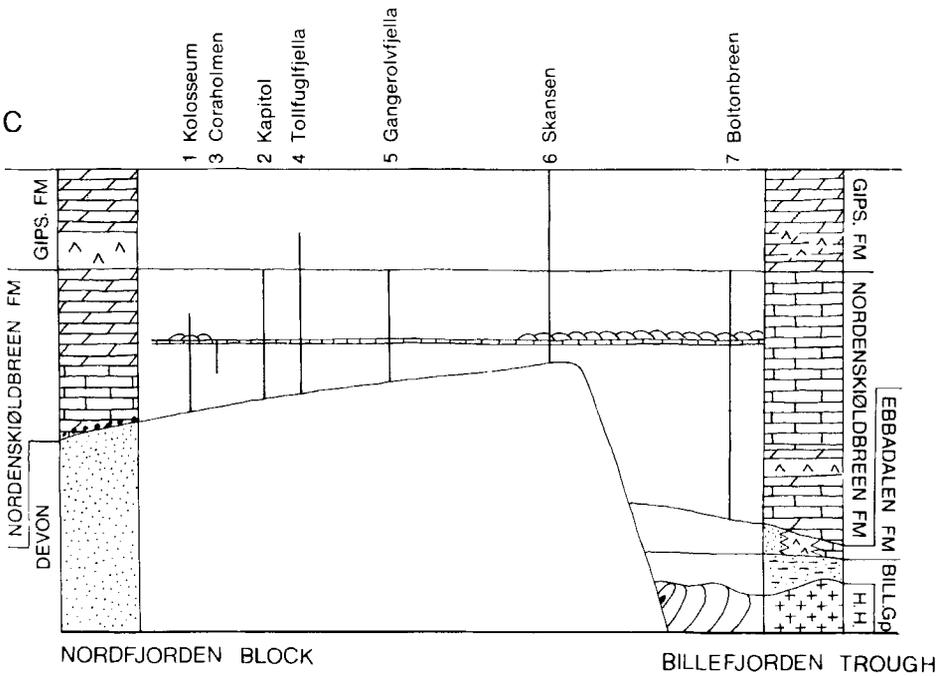


Fig. 1.

- a) Location map illustrating the Nordfjorden block and Billefjorden trough in Central Spitsbergen.
- b) Investigated area with sections measured.
- c) The block trough situation illustrated with stratigraphical columns on either side of the Billefjorden fault zone. Palaeoaplysinid bioherms marked as separate horizon.

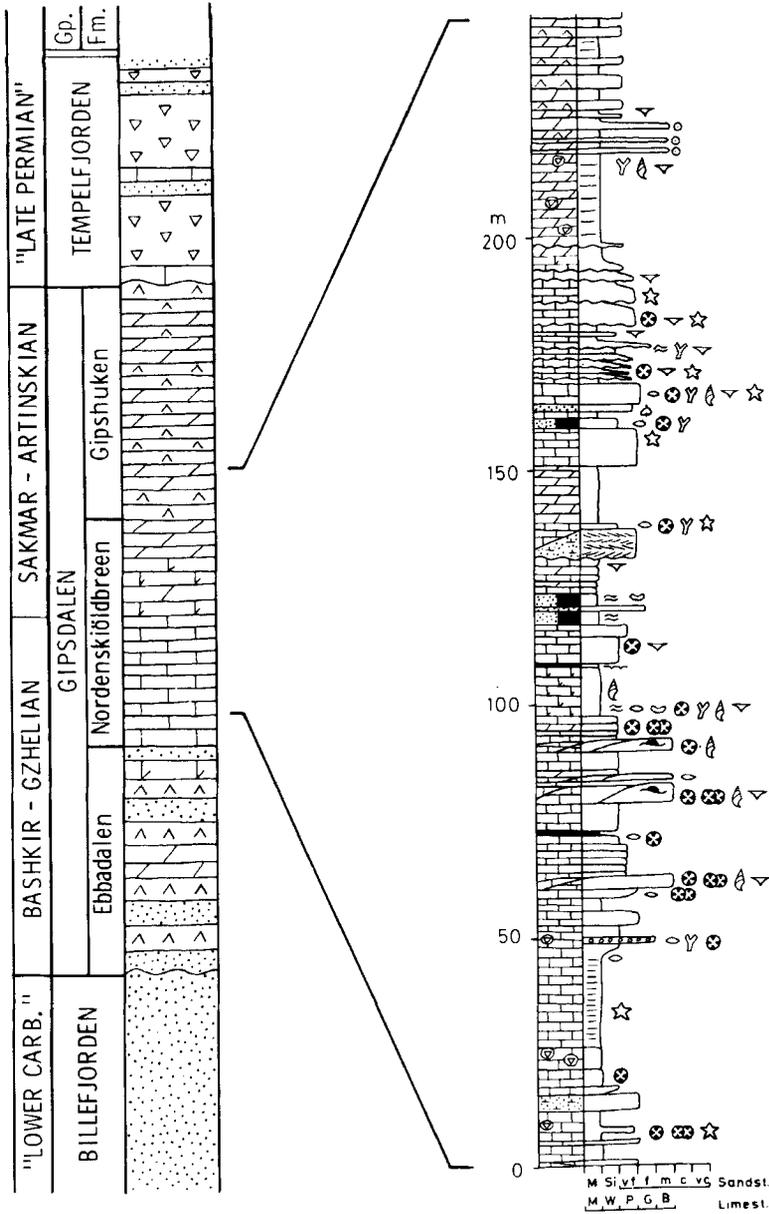
A noteworthy feature of these structures is the abundance of the ?hydrozoan *Palaeoaplysina*. This fossil has previously been reported as an important constituent of carbonate buildups spanning the Carboniferous-Permian boundary along the western margins of the Soviet Urals (ELIAS 1959, TCHUVASCHOV 1973), on Ellesmere Island (NASSICHUK 1972, DAVIES and NASSICHUK 1973), in the Yukon territory (DAVIES 1971), and in Idaho (BREUNINGER 1969, 1976).

Palaeoaplysina has also been reported from older strata, for example from the Lower Moscovian of British Columbia (MACQUEEN and BAMBER 1977). However, in such older occurrences the taxon is a minor component and apparently does not form buildups. Most workers assign *Palaeoaplysina* to the phylum Hydrozoa. There are still, however, diverging opinions on the functional morphology, mode of life and biological affinities of the taxon. Our finds provide an interesting link between known occurrences of *Palaeoaplysina* in the Soviet Union and northern America and we will herein briefly describe the development of palaeoaplysiniid buildups in the Norwegian arctic areas. Our brief account suggests that the structures can be termed bioherms in the sense of NELSON et al. (1962), i.e. they are reeflike bodies which can neither be proved or disproved to have had primary topography or potential for wave resistance.

Stratigraphical framework

The Carboniferous and Permian succession of Svalbard was deposited on an epicontinental platform dissected by a series of NNW-SSE trending fault lineaments. The resultant graben and horst development had a complex, but still poorly understood, control on the region's depositional history during these periods. Palaeoaplysiniid bioherms are developed over the major Billefjorden lineament of central Spitsbergen (see Fig. 1 and HARLAND et al. 1974), extending both on to the eastern margins of the Nordfjorden block to the west, and into the Billefjorden trough to the east of this fault zone.

The bioherms occur in the Nordenskiöldbreen Formation of the Gipsdalen Group; units assigned to this group clearly exhibit the interplay between regional transgressive/regressive episodes and local tectonic events. The group's tripartite development in the Billefjorden trough (Fig. 2) suggests continuous deposition from the Bashkirian to the Artinskian. The lowermost Ebbadalen Formation shows that fault movements which were initiated in the Bashkirian produced erosion of the Nordfjorden block. The erosional products were deposited on alluvial fans along the block's eastern margins (GJELBERG and STEEL 1979). The entire



LITHOLOGY	SED. STRUC.	FOSSILS	
Bioherm		Algal lam.	Bryozoans, <i>Fenestella</i>
Chert nod.		Plant remains	Brachiopods
Chert		Calcareous algae	Brachiopod spicules
Limest.		Fusulinids	Bivalves
Dolomite		Foram	Gastropods
Gyp./anhydrite		Foram encrust.	Ostracods
Dol. limest.		Sponges	Trilobites
Sandst.		Sponge spicules	Crinoids
Shale/siltst.		Corals, solitary	Bioturbation
Intrafm. congl.		Corals, colonial	Horizontal traces
		<i>Palaeoaplysina</i>	<i>Microcodium</i>
		Bryozoans	Fossil, unspec.

Fig. 2. Stratigraphical column of the Carboniferous/Permian strata of central Spitsbergen, with a detailed section through parts of the Nordenskiöldbreen and Gipshuken formations in the Billefjorden trough.

area was also affected by a regional transgression at that time and these fans' coarse clastic deposits pass laterally into sabkha and marginal marine sediments. Ongoing transgression and decreasing tectonic activity resulted in the deposition of the restricted to open marine carbonates of the Nordenskiöldbreen Formation. Sequences assigned to this formation in the Billefjorden trough suggest continuous deposition from the Moscovian to the Sakmarian. In contrast, the Nordfjorden block was first transgressed in the late Carboniferous. The Tyrrellfjellet Member, uppermost in the Nordenskiöldbreen Formation, is developed both on the block and in the trough east of the Billefjorden lineament. Thicknesses and facies developments are similar in both areas, indicating tectonic stability over the lineament in the early Permian.

Palaeoaplysiniid bioherms occur near the Carboniferous/Permian boundary at the base of the Tyrrellfjellet Member on the Nordfjorden block and in the Billefjorden trough. Buildups have also been observed during helicopter surveys up to 20km east of the Billefjorden lineament, and detailed studies have been made in Gipsdalen 12 km east of this structure. In contrast, bioherms on the Nordfjorden block appear to be restricted to the structure's easterly margins. Palaeoaplysiniid remains are found further west on the block, but these either form a minor component of normally bedded limestones, or occur in biostromes. Occurrences of palaeoaplysiniid bioherms both in the block and trough sequences mark the beginning of a regressive episode in the early Permian which culminated in the development of dolomites and sabkha evaporites (LAURITZEN 1981) assigned to the Gipshuken Formation.

On Bjørnøya, the Kapp Hanna and Kapp Duner Formations of Gzhelian to Asselian age show a transition from synsedimentary fault-controlled clastic deposition to stable carbonate platform environments. These carbonates contain various types of biohermal structures; interbedded units were deposited both in open marine and restricted lagoonal environments (AGDESTEN 1980). The most important framework builder of the biohermal structures is reminiscent of *Palaeoaplysina*. However, eogenetic dolomitization of these structures has almost totally destroyed primary features, leaving only obscure ghosts of the original framework.

Bioherm development

The bioherms on both sides of the Billefjorden lineament appear to have essentially similar developments, and our description of their sedimentology and biota is based on all structures examined. In many areas, however, studies are hampered by extensive scree cover and/or

inaccessible steep cliffs; exposures on Pyefjellet adjacent to Boltonbreen (see Fig. 1) were therefore chosen for detailed lithofacies studies because of both good vertical sections and the possibility for lateral control.

Two to three horizons with bioherms are usually found in any single section within a 15 to 30 m thick interval. Interbedded rocks mainly consist of dark bituminous fusulinid-rich wackestones and packstones which correspond to the 'Fusulina Limestone' of early workers; this unit was redefined as the Brucebyen Beds by CUTBILL and CHALLINOR (1965). Other interbeds consist of light grey limestones with diverse faunas or light grey dolomites. Minor amounts of gypsum/anhydrite are also found as veins, nodules and vug infills within this lithofacies association. Bioherms occur as

- small isolated domed structures (up to 6 m high),
- apparently tabular units with planar bases and tops, several tens of metres long and up to 15 m high,
- offlapping sequences with one bioherm laterally draping over the adjacent one; individual bioherms are about 10 m high (Fig. 3).

Their basal surfaces are sharp and usually planar to slightly undulatory. Most tops are also sharply defined but some do show gradational contacts to overlying bedded carbonates. Even where bioherms pinch out laterally there is no evidence of talus deposits in the adjacent strata. Vertical cliff exposures may represent sections parallel to the long axes of elongated bioherms: however, more studies are necessary to elucidate the three-dimensional form of all these structures.

Bioherms

Palaeoaplysina is the dominant faunal component of these bioherms. Sub-parallel to undulating plates may be closely packed (Fig. 4a), or enclose pockets of mudstone/wackestone, or float in a mudstone/wackestone matrix. Other faunal elements within the resultant bindstone are forams, molluscs, corals, echinoderms, bryozoans and the rhynchonellid brachiopod *Septacamera*. Possible algal contribution to the development of the structures is still uncertain.

The following notes on the development of the *Palaeoaplysina* are based on field observations and on studies of thin sections, the terminology used follows that of DAVIES (1971). Individual plates of *Palaeoaplysina* are 1-5 mm thick and up to 40 cm long. Their undersurfaces are clearly defined and smooth (Fig. 4b). Internal canals are filled by mixtures of mud (often pelloidal), finely comminuted skeletal debris and carbonate cement. There is no evidence of cellular tissue between the canals; this is

assumed to be a result of diagenetic replacement of original textures.

The internal canals open to the upper surface of the plate through a series of pores with diameters of 100 to 150 μ . Some specimens display regular dome-like protuberances rising up to 1.5 mm above the surrounding plate surface. These may represent sections through the 'mamelon-like oval protuberances' noted by BREUNINGER (1969). Weathered upper plate surfaces show a sub-parallel to parallel fabric of ridges representing internal canal fills; the original wall structure between the canals has been dissolved during diagenesis.

The mode of life of *Palaeoaplysina* is still uncertain, and the genetic interpretation of the bioherms depends upon whether their constituent limestone should be regarded as bafflestone, bindstone or framestone (EMBRY and KLOVAN 1971). Earlier workers have suggested a growth form for *Palaeoaplysina* either as an undulose laterally-expanding encrustation (BREUNINGER 1969, 1976; DAVIES 1971) or as an erect body (DAVIES and NASSICHUK 1973). We propose that the most common development of closely packed horizontal plates (Fig. 4a) and the large dimensions of the individual plates (up to 40 cm across) are both significant features; these indicate that *Palaeoaplysina* grew horizontally, binding the bioclastic sediments. The organism must therefore be regarded as a binder rather than a frame builder or a baffler.

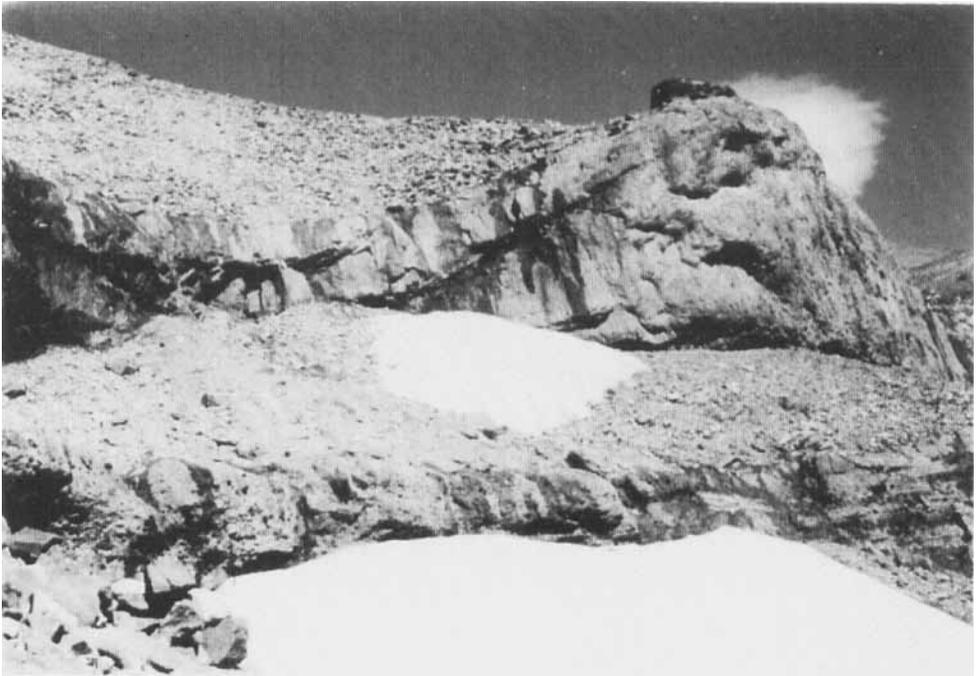


Fig. 3. *Palaeoaplysina* bioherm exposed in Gipsdalen (Billefjorden trough). Maximum thickness 6 metres.

Associated lithofacies

Our notes are based on field work and on studies of thin sections and polished slabs. We recognize seven different microfacies associations, which are briefly described and discussed below; many of these can be referred to Standard Microfacies (SMF) defined by WILSON (1975).

The sequence studied on Pyefjellet lies between two marker horizons representing a transgressive event at the base of the sequence and a period of subaerial exposure at its top. The basal unit is an intraformational conglomerate up to 15 cm thick with a matrix of bioclasts, quartz grains and detrital *Microcodium* grains; some intraclasts have been bored. This unit probably represents the base of the Tyrrellfjellet Member of CUTBILL and CHALLINOR (1965). The top of the sequence is marked by a bedding plane with desiccation cracks in a sandy bioclastic dolomite. The bioclasts are often well rounded, with a micritic or oncolitic coating. Plant remains and scattered *Microcodium* grains are also seen. This horizon is thought to represent local subaerial exposure of the top of a bioclastic barrier bar sequence (microfacies D, see below).

The sedimentary sequence between these two horizons contains the following microfacies associations:

Fusulinid wackestone/packstone (A) (Pl. 1-1)

Matrix consists of micrite or dolomicrosparite while benthic forams (mainly fusulinids) dominate the fauna. High organic content (mean value 6% T.O.C.). Occasional intraclasts and micritized bioclasts, abundant microstylolites.

Compares well with SMF 9 and 10 of WILSON (1975).

Palaeoaplysiniid bindstone (B)

Major binder is ?hydrozoan *Palaeoaplysina*. Matrix is a wackestone/packstone often with a clotted appearance. *Palaeoaplysina* may be encrusted by bryozoans or tubular forams; borings are also seen. Most bioherms have a matrix/binder ratio of 1:1 to 2:1.

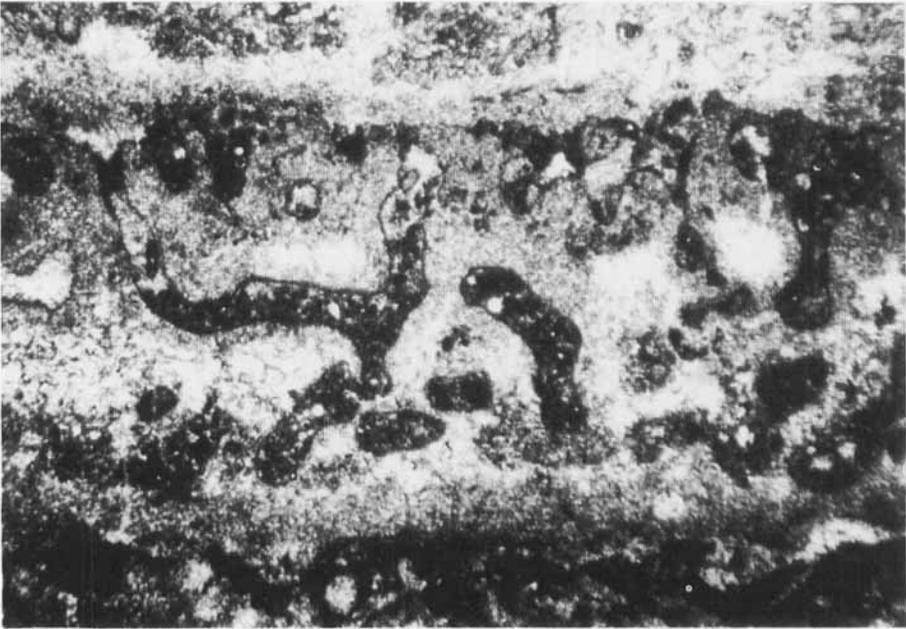
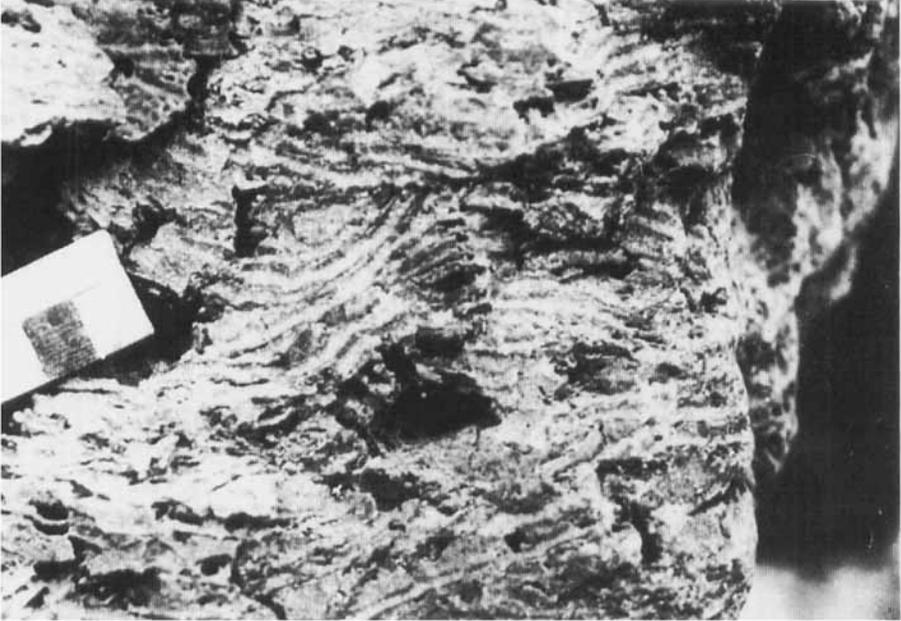


Fig. 4.

- A. Detail from a bioherm showing closely packed palaeoaplysiniid plates.
- B. Thin section through an individual plate.

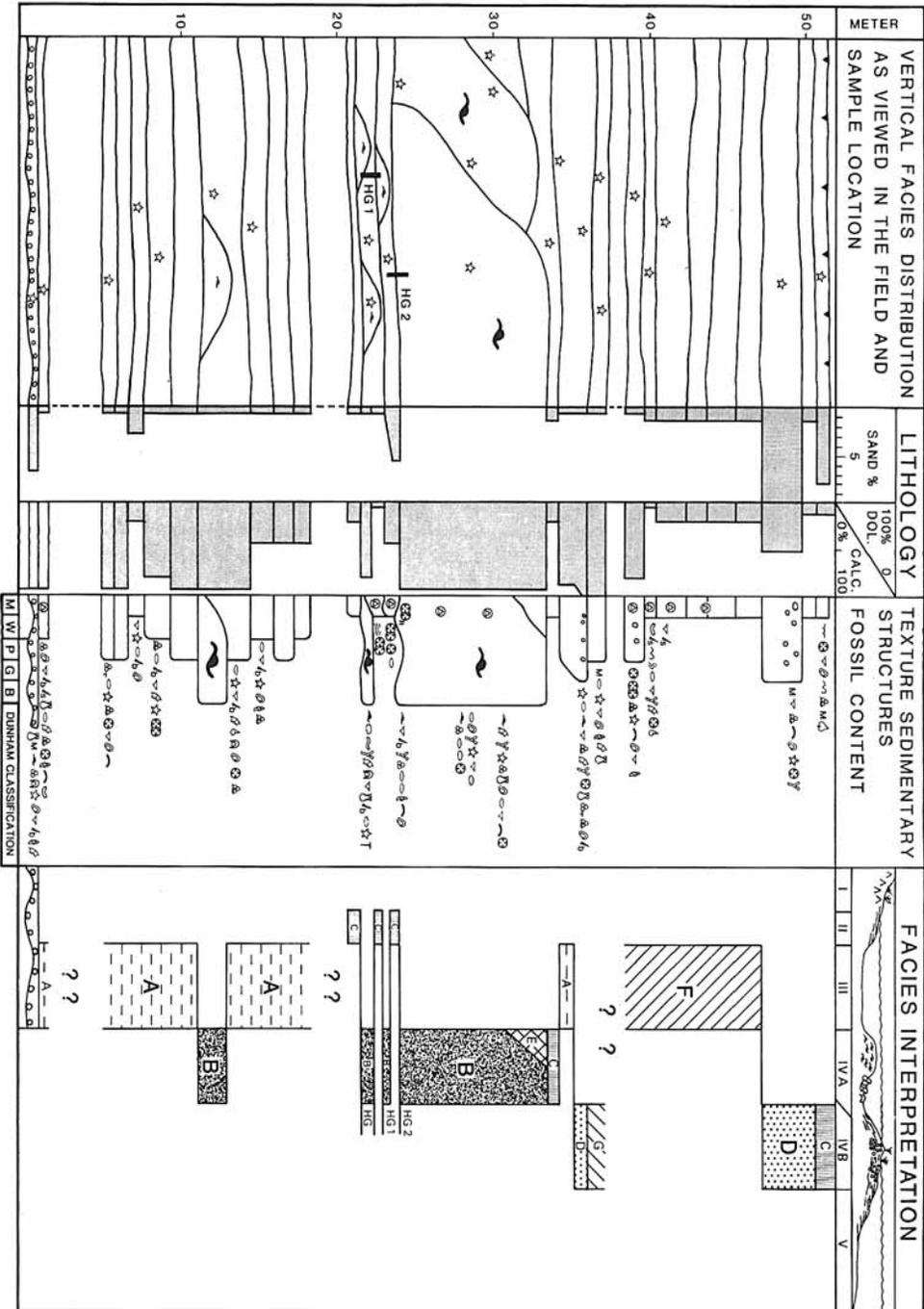


Fig. 5. Facies interpretation based on thin section studies, textures, sedimentary structures and palaeontological evidence, as they appear in Pyefjellet, north of Bolton-breen.

?Algal laminated dolomitized mudstone/wackestone (C)
(Pl. 1-2, 3)

Laminated dolomicrosparites and dolomicrites with sparse bioclastic content. Pseudomorphs after ?evaporite crystals sometimes filled by length-slow chalcedony (see Pl. 1-3), calcite or dolomite rhombs.

Resembles SMF 20 and 23.

Bioclastic grainstone/packstone (D)
(Pl. 1-4)

Abraded crinoid fragments dominate, with sparry calcite cement. Some intraclasts of wackestone and of micritized fossils occur. Contains disaggregated (detrital) *Microcodium* grains.

Compares well with SMF 11.

Bioclastic floatstone (E)

There is a predominance of wackestone/packstone matrix over bioclasts, bioclasts are mainly fragmented palaeoaplysiniid plates with some fusulinids. Sparry calcite filled cavities give the rock a brecciated appearance. This sediment flanks the bioherms.

Compares well with SMF 5.

Dolomitized spiculitic wackestone/packstone (F)
(Pl. 1-5)

Microbioclastic wackestone/packstone. Contains abundant silica sponge spicules and whole sponges. Matrix is a dolomicrosparite, often with clotted appearance. High kerogen content. Nodules of length-slow chalcedony.

Close resemblance to SMF 1 and 2.

Wackestone/packstone with in situ Microcodium (G)
(Pl. 1-6)

Microcodium aggregates in wackestone/packstone with a marine fauna, mostly fusulinids. *Microcodium* content ranges from virtually absent to rock forming, and appears in rosettes and as 'corn on the cob'. *Microcodium* is frequently seen truncating the bioclasts in the host rock.

Our interpretation of the depositional environments represented by these microfacies associations is shown in Fig. 5. Following a transgressive episode marking the base of the studied section, a shelf lagoon environment developed. This was laterally protected by palaeoaplysiniid bioherms which formed an effective barrier to open marine conditions. The biota, texture and organic content of the sediments in this lagoon indicate a low energy and slightly anoxic environment. Regression or barrier migration caused the repeated rhythmic development of microfacies B and C, with hardground formation at the top of each rhythm representing periods of nondeposition within a lagoonal environment (see Fig. 5). The uppermost hardground (HG 2) shows signs of freshwater leaching and cementation: this surface marks the base of the major biohermal development in the Pyefjellet section. The planar top of the bioherm may represent an erosion surface; this is overlain by a unit assigned to microfacies C. The flanking beds of microfacies E indicate moderate to low energy conditions on the lee side of the structure.

Two shallowing upward sequences make up the rest of the studied section; the lowermost rhythm consists of microfacies A, D, and G, where A is interpreted as a lagoonal sediment, D as a bioclastic barrier bar, and G as the bar's exposed surface. *Microcodium* aggregates, the major constituent of microfacies G, are thought to represent calcification structures along terrestrial plant rootlets in association with fungi; they thus indicate the presence of a paleosol (KLAPPA 1978). Terrestrial plants may have grown in a supratidal or more probably an intertidal 'sea grass' environment as suggested by the biota of the associated host sediment.

The uppermost sequence contains units assigned to microfacies F, D, and C; these form a rhythm which essentially follows the same development pattern. The sediments of microfacies F are admittedly similar to those of SMF 1 and 2 which WILSON (1975) places in a 'basin to open shelf' environment; however, we suggest that both juxtaposition with adjacent units and textural and mineralogical features rather suggest deposition in a slightly restricted hypersaline lagoon. Comparable near-shore siliceous sponge spicule packstones have been reported from Pennsylvanian limestone deposits of the Stanton Formation (LANE 1981).

The whole sequence studied thus represents a series of small-scale regressive sequences reflecting the lagoonwards migration of both biohermal and bioclastic barrier sequences. A notable feature of the development of the bioherms is their repeated establishment on hardground surfaces, marking transgressive pulses between these rhythms. The development of these hardgrounds is briefly discussed below.

Hardgrounds at bioherm bases

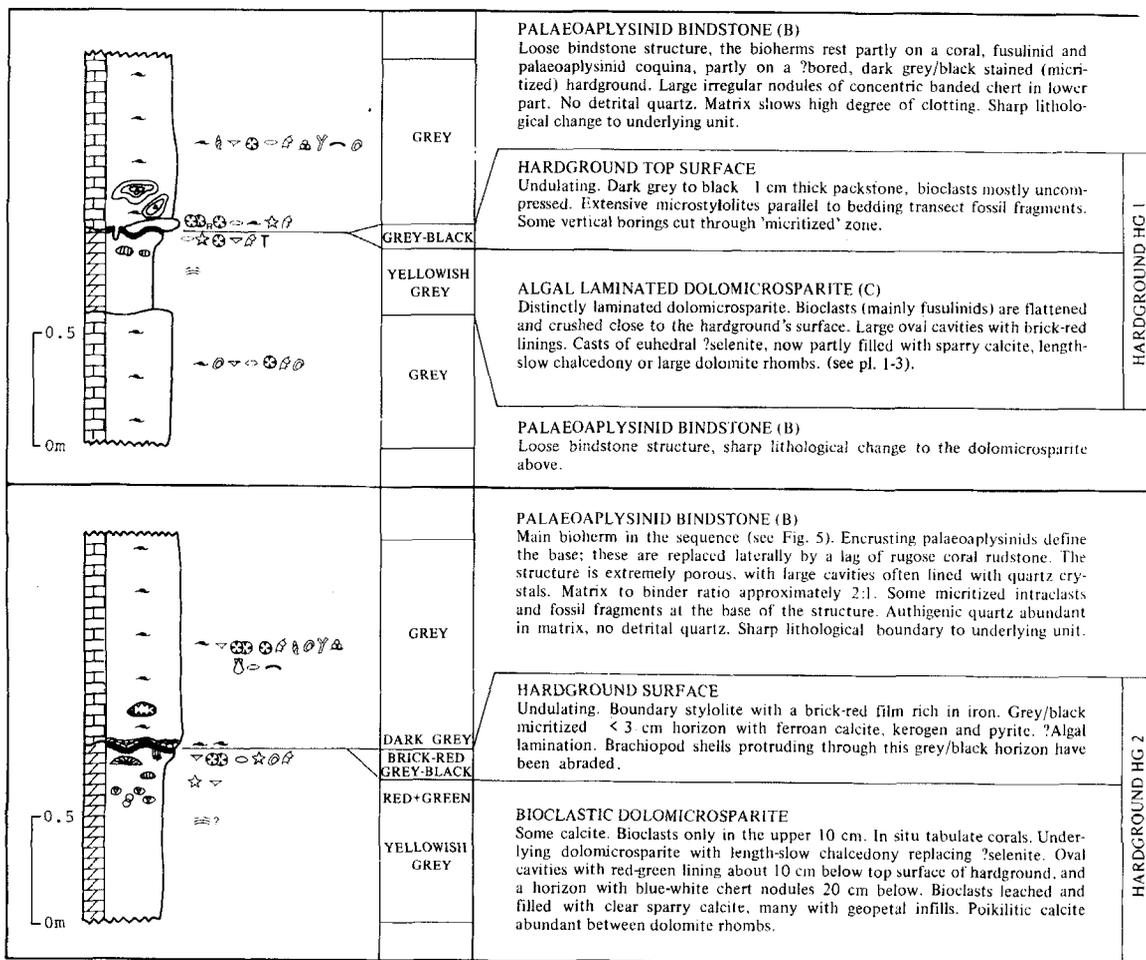
We have noted that the basal surfaces of the bioherms are sharply defined and we suggest that these represent hardgrounds. The three hardground horizons noted in Fig. 5 (HG, HG 1, and HG 2) are easily identified in the field and can be followed laterally along the whole length of the exposure (approximately 200 m, Fig. 6). We base this interpretation on the following criteria (see Fig. 7):

- sharply defined undulating boundary between the hardgrounds and the encrusting palaeoaplysiniid bioherms,
- dark stained 'micritized' zone, approximately 1 cm thick, in the surface of the hardground, with kerogen and pyrite concentration,
- abrupt change in the weathering colour, reflecting change in lithology,
- eroded upper surface of HG 2 and ? bored surface of HG 1,
- ferroan calcite crust and brick red/green stained boundary films,
- oval cavities with Fe-linings and/or chert nodules typically 10-20 cm below hardgrounds,
- zone with compressed/crushed bioclastic material (especially fusulinids) below the hardground.



Fig. 6. Hardground 2 (H) as it appears in the section investigated in Pyefjellet, north of Boltonbreen.

These features are all typical of hardgrounds. The dark stained 'micritized' zone consists of organic material derived mainly from decaying microfilamentous algae, the pyrite content suggesting anoxic conditions during decay. Many of the other criteria listed here are also described by ROSE (1970) and BATHURST (1975: 395, 1980), while SARKAR et al. (1980) have demonstrated the presence of deformed allochems in the proximity of hardgrounds. No clasts derived from the underlying hardground units have been identified. This would not necessarily be expected as the bioherms appear to have migrated across a low energy inter/subtidal environment represented by microfacies C and A. Rugose colonial corals are observed attached in life position to HG 1, and as a coarse coquina lag on top of HG 2 where they act as a substrate for later *Palaeoaplysina* bioherm growth. A rhynchonellid brachiopod protruding through HG 2 displays an abraded umbo, suggesting early cementation and subsequent erosion of the HG 2 surface prior to *Palaeoaplysina* bioherm development. Ferruginous crusts and Fe-calcite in the uppermost part of HG 2 may either indicate a period of non-deposition and accumulation of Fe-salts (BATHURST 1975: 396) or may be the result of pressure solution processes along the observed boundary stylolites.



It is often difficult to decide whether a hardground has been cemented in a subaerial or submarine environment (see BATHURST 1980), and such is also the case here. The hardgrounds admittedly lack any positive evidence of subaerial exposure and their stratigraphic position clearly indicates the development of submarine environments both prior and subsequent to hardground formation. On the other hand, the development of microfacies C suggests an intertidal depositional environment for the sediments cemented by hardground formation. There is evidence of meteoric cementation processes in one of the hardgrounds, suggested by clear calcite cement filling cavities after dissolved crinoids and other bioclasts, and with a geopetal lag of 'caved in' dolomicrosparite (see HG 2 in Fig. 7 and Plate I-2). We believe that these and other apparently contradictory observations are best explained by a complex eogenetical cementation process: initial submarine cementation was followed by subaerial exposure of the partially lithified crust. Meteoric leaching and calcite cementation took place as a minor event, possibly associated with a seaward migrating freshwater lens following the retreating sea (see BATHURST 1980); this occurred prior to the next transgression and renewed bioherm growth.

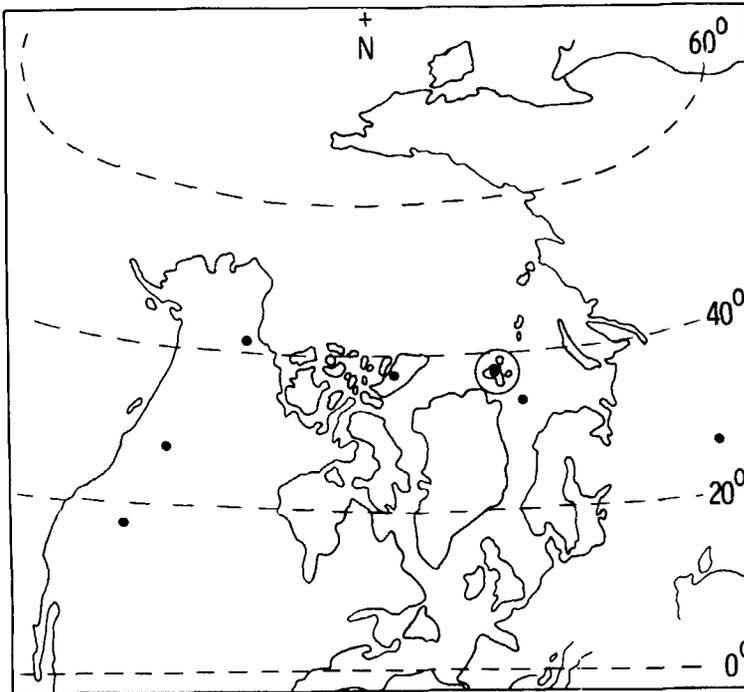


Fig. 8. Permian-Carboniferous palaeocontinental reconstruction showing known occurrences of palaeoaplysiniid buildups.

Fig. 7. Lithology and details immediately adjacent to the hardgrounds.



Discussion

The structures described here link previously noted occurrences of palaeoaplysiniid buildups in north America and the USSR. Indeed the presence of such buildups in Svalbard could almost have been predicted in view of a similar circumpolar distribution of many associated faunal elements. Finds of palaeoaplysiniid buildups to date are plotted on a palaeontinental reconstruction of BRIDEN et al. (1974) showing that most formed between 20° and 40°N of the early Permian equator (Fig. 8). Evaporites associated with the carbonate sequences containing these structures suggest warm and arid climates in these regions at that time.

The penecontemporaneous buildups previously described have been assigned to differing depositional settings such as 'broad shelves' (Yukon territory), 'barrier complexes' (Soviet Urals) or 'basinal margins' (Sverdrup Basin). The bioherms found on Spitsbergen occur on a broad shelf, but drape over a temporarily quiescent lineament; they are restricted to the margins of the block to the west of this lineament, but extend an appreciable distance into the trough to the east. The occurrence of similar structures on Bjørnøya is interesting in this respect as this island is also believed to have been the site of a similar block/trough marginal lineament. This lineament was also temporarily stable at the time of biohermal development and the structures are found on the troughward side of the lineament.

Although on a small scale, we also believe that the bioherms created effective barrier systems, leading to the development of lagoonal environments behind their structures. The bioherms studied in detail here occur in small regressive rhythms but whether this is a local or general feature is not certain. The bioherms in central Spitsbergen show little evidence of internal organization or of ecological succession, although succession has been reported from Bjørnøya by AGDESTAIN (1980). Studies there suggest increasing binder density upwards in the structures, bioherm tops being marked by the dominance of large and presumably wave resistant coral colonies.

Biohermal development by encrustation of hardground surfaces has not been reported previously. The occurrence of hardgrounds and regressive rhythms suggests an interesting interplay of small-scale transgressive and regressive events within a larger generally regressive development. This culminated in the deposition of sabkha evaporites in the Artinskian.

In view of the proved reservoir properties of the petroleum producing buildups in the Soviet Union, the association of the Spitsbergen

bioherms with bituminous interbeds is of special interest. Both potential source and reservoir units are admittedly thin in present exposure areas on Spitsbergen and Bjørnøya. However, the exposed lineamental system extends eastwards and southwards onto adjacent shelf areas. Given (as yet poorly defined) acceptable growth conditions and a favourable diagenetic history, similar or larger structures may prove to have some economic interest in these shelf areas.

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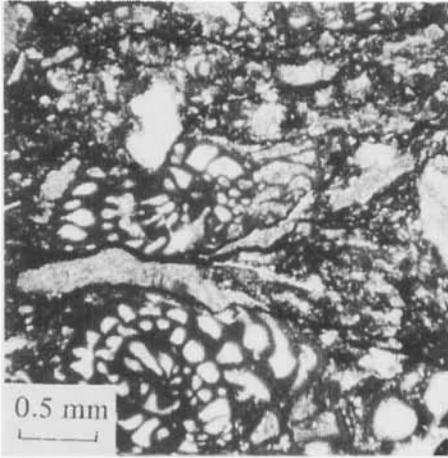
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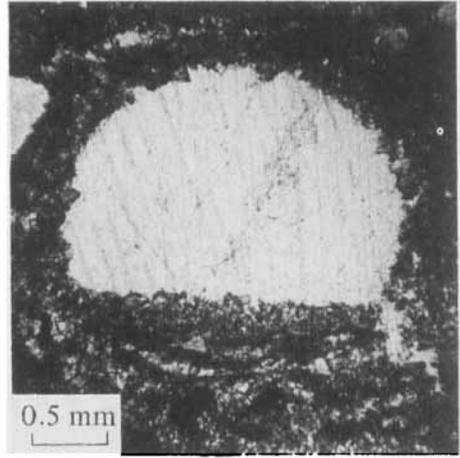
PLATE 1

1. Fusulinids truncated by microstylolites (Microfacies A).
2. Leached crinoid fragment with geopetal dolomicrosparite lag. Cavity filled with clear calcite (Microfacies C).
3. Pseudomorph after ?evaporite crystals partly replaced by length-slow chalc-dony and dolomite crystals (Microfacies C). X-nicols.
4. Bioclastic grainstone/packstone with detrital *Microcodium* grains (M). (Microfacies D).
5. Silica sponge spicules (S) in a dolomicrosparite (Microfacies F).
6. In situ *Microcodium* (M) truncating fusulinid (f). (Microfacies G.).

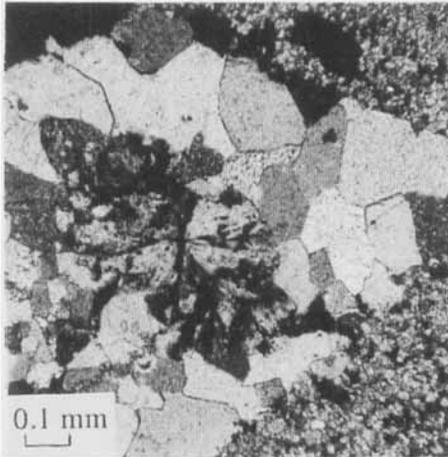




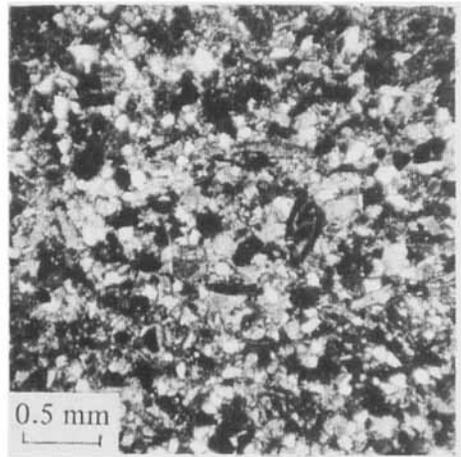
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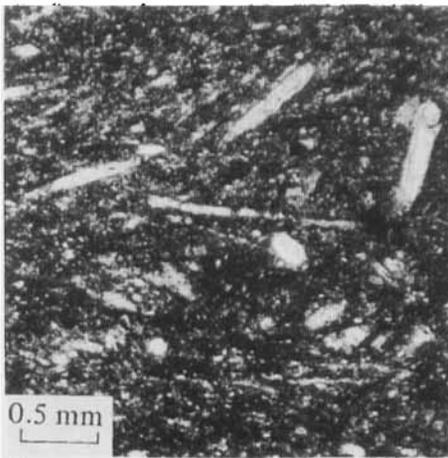
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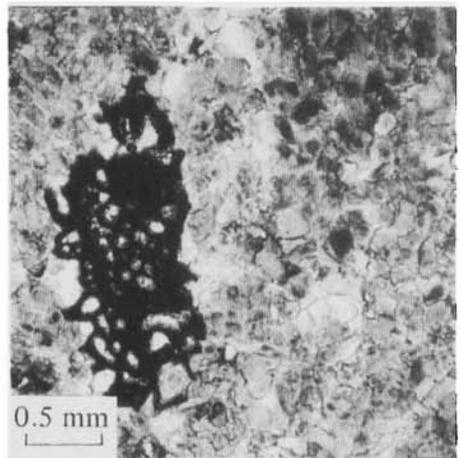
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6

