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ALGAE FROM THE LOWER PALAEOZOIC STRATA OF NORTH GREENLAND

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May 1989

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Algae from the Lower Palaeozoic strata of North Greenland

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Taxonomic disclaimer: This report is not deemed to be valid for taxonomic/ nomenclatural purposes.

ABSTRACT

The present report gives an overview of algae which have been recorded in the Lower Palaeozoic strata of North Greenland and draws attention to their palaeobiological and palaeogeographic significance by correlation with their Recent relatives.

The algae are only well preserved in carbonate rocks which have been examined in thin section. The following have been recorded: *Renalcis, Gordonophyton, Wetheredella, Girvanella, Obruchevella, Sphaerocodium, Hyella, Gloeocapsa, Pleurocopsa,* Solenoporaceae, *Palaeoporella, Dimorphosiphon*, Dasycladaceae.

Most of these are regarded as benthic shallow-water organisms and are typical indicators of a subtropical to tropical climate at the time of deposition.

INTRODUCTION

The study of fossil algae are important for petroleum geological studies in that they are virtually the only marine organisms capable of producing energy-rich, complex carbon compounds from carbondioxide using light as energy source (photosynthesis). The photosynthesising organisms (primary producers) are subsequently food for heterotrophic organisms laying the foundations to nearly all animal life.

Preservation of these complex carbon-compounds from degradation into CO_2 during the early stages of sedimentation would cause accumulation of carbohydrates, which eventually could transform into petroleum during thermal diagenesis. According to Tissot & Welte (1984) less than 4% (usually <0.1%) of the produced organic carbon is preserved. The greater part of this organic carbon in the biosphere is immediately recirculated.

Another aspect of the geologically relevant activity of the algae is their ability to accumulate $CaCO_3$ in or on their cell walls (= calcareous algae).

Calcareous blue-green algae are common microfossils in shelf deposits from the latest Precambrian up to Cretaceous (or Jurassic) times but despite the fact that blue-green algae have existed since the early Precambrian in almost unaltered forms, calcareous blue-green algae are mainly known from Palaeozoic and Mesozoic time. This phenomenon can possibly be explained as a result of changes in ocean chemistry (Riding, 1982).

Calcareous red algae are known from at least Cambrian to Recent time, where they are found in tropical to arctic waters. Recent calcareous red algae are especially common on reefs.

Calcareous green algae are known from (pre-)Cambrian time and are still common. Throughout geological time calcareous green algae have been of great importance as sediment producers. Today marine calcareous green algae (especially dasycladaceans) characteristically occur in shallow water lagoons in tropical and subtropical regions.

"Non-calcareous algae" contribute to sedimentation as sediment-trapping and binding organisms.

Some algae also act as sediment decomposers especially in carbonates. Many small algae especially blue-green and green-algae live as endoliths by boring holes or cavities in solid carbonate as for example ooliths, mollusc shells or limestone. By destroying solid carbonate the boring algae plays an important role in the formation of micrite and micritic envelopes (Bathurst, 1966; Flügel, 1978).

METHODS

More than 400 samples were examined in thin sections. The slides were stained with Alizarin Red S and potassium ferricyanide (Adams *et al.*, 1984) and sprayed with 'Merckoglas'. Some additional unstained slides with coverslide mounted in Canada-balsam were made to improve the quality of observation. In some few cases phosphatized algal remains have been prepared out of limestone by use of 10% acetic acid, and subsequently studied with a Cambridge Scanning Electron Microscope.

CLASSIFICATION AND OCCURRENCE

Renalcis Vologdin

These relatively small fossils occur in aggregates of rounded hollow chambers with a dark, diffuse microcrystalline 'wall'. The chambers range in size from approximately 40 µm to 400 µm and aggregates may be up to 2 - 3 mm wide. Occasionally the chambers are connected in a branched pattern (figs 2 and 3) and sometimes the chambers are almost single (fig. 1).

The biological affinity of *Renalcis* is not clear. Riding & Brasier (1975) interpreted *Renalcis* as the earliest calcareous foraminifer, whereas Hofmann (1975) proposed that *Renalcis* was the remains of chroococcalean blue-green algae with irregularly arranged colonies, where the gelatinous colony 'walls' were cemented by carbonate. Poncet (1976) suggested affinity to the Rivulariaceae. Wray (1977) placed *Renalcis* among 'problematical blue-green algae', and Pratt (1984) proposed a model showing how *Renalcis* and related structures could become 'diagenetic microfossils from calcification of coccoid blue-green algae'. Chuvasov & Riding (1984) mentioned *Renalcis* among 'possible cyanophytes'.

The geological range of *Renalcis* (and *Renalcis*-like fossils) is from Cambrian to Devonian (Carboniferous?). According to Riding & Watts (1983) the only reports of Silurian *Renalcis* are from Gotland (Sweden) and Kazakhstan.

In North Greenland *Renalcis* is very common in samples from the Silurian Lafayette Bugt Formation and Thors Fjord Member, but is also found in carbonate clasts in the Cambrian - Lower Silurian trough sequence.

Possible *Renalcis* (and *Epiphyton*) structures have been proposed in the Cambrian RG2 Formation (Brønlund Fjord Group) by Ineson & Peel (1987 fig. 6) but thin sections of the illustrated sample did not provide evidence of either *Renalcis* or any other algae.

Gordonophyton Korde

This genus occurs as rather large, dendritic, 'bushy' fossils up to several millimetres in size with segmented, dense usually dichotomously branching with microcrystalline walls.

Korde (1973) distinguished *Gordonophyton* by its segmented thallus from the genus *Epiphyton*. One species, *Gordonophyton grande* (Gordon) Korde, was described by Gordon (1920) from Antarctica as *Epiphyton grande*. In the description of *E. grande,* Gordon compared this species to two other *Epiphyton* species using characters like size, diameter of tubules, and distance between branching. Gordon did not mention the criteria that the thallus should be segmented, although his plate 1 fig. 5 may indicate segmentation. James (1981) considered *Gordonophyton* as a form of *Epiphyton*. Pratt (1984) proposed that both *Epiphyton* and *Gordonophyton* are 'diagenetic microfossils' formed by pseudofilamentous growth of coccoid blue-green algae. The precipitation of micritic calcite took place either in the gelatinous sheath (*Gordonophyton*), giving a chambered or septate appearance, or throughout the colony resulting in a solid appearance (*Epiphyton*).

Korde (1973) regarded *Gordonophyton* as belonging to the red algae establishing a new order Epiphytales, and a new class Protofloridomorphophyceae. Wray (1977) did not mention *Gordonophyton* but regarded *Epiphyton* as a problematic blue-green algae. Also Roux (1985) classified *Epiphyton* as 'Incertae Algae' but he did not consider *Gordonophyton*.

Gordonophyton seems to be a rather rare fossil with scattered distribution, reported only from Siberia (e.g. Korde, 1973), Newfoundland (James, 1981) and Antarctica (Gordon, 1920).

Gordonophyton (figs 4 and 5) is found in one sample (GGU 319 511), collected east of J. P. Koch Fjord, from the Cambrian - Lower Silurian outer shelf and slope sequence (Davis & Higgins, 1987) where it occurs in carbonate clasts, often in close connection with *Girvanella* (fig. 4). The North Greenland example resembles the occurrence from the Cow Head Group (Cambrian-Ordovician) in western Newfoundland reported by James (1981).

Wetheredella Wood

Wood (1948) described *Wetheredella* as a tubular foraminifer with 'tubes' of varying diameter, from approximately 10 µm to approximately 1000 µm. It is questionable whether it really forms tubes or if it defines more or less irregular pillows. Wood (1948) mentioned perforations in the 'wall' whereas Copper (1976) pointed out that the Ordovician *Wetheredella* material from

Anticosti Island exhibits no such apertures. In some cases (figs 7 and 8) the material from Greenland shows fine dots (tangential section) or fine lines (transversal sections) indicating perforations of the 'wall'.

The systematic position is not obvious. As mentioned above Wood (1948) interpreted it as a foraminifer, Copper (1976) classified it as a blue-green alga, and Roux (1985) included *Wetheredella* in *Chlorophycophyta?*. Maybe *Wetheredella* is the calcified inner part of a *Rivularia* or *Gloeotrichia*-like organism with thin hairs projecting out from the apertures.

It is characteristic that *Wetheredella* is generally closely associated with *Sphaerocodium* (figs 6 and 8), and it cannot be excluded that these two fossils may represent different parts of the same organism. The geological range is restricted to the Early Palaeozoic with a cosmopolitic distribution. *Wetheredella* has been reported from the Silurian Odins Fjord Formation in Peary Land (Hurst, 1984). In central North Greenland it is found in samples from the Lafayette Bugt Formation and the Thors Fjord Member, both of Silurian age.

Girvanella Nicholson & Etheridge

This fossil consists of more or less flexuous tubular, unsegmented filaments with allmost uniform diameter and practically no branching. The 'wall' is usually rather thick and distinct but structureless. The external diameter varies from less than 10 µm to about 100 µm, mainly between 10 and 30 µm. Occasionally the filaments occur separately, but usually they are found in lumps, varying from almost parallel filaments to strongly twisted tubules. Comprehensive studies of *Girvanella* were presented by Danielli (1981) and Edhorn (1979).

Girvanella was described by Nicholson & Etheridge in 1878 as a foraminifer, Seward (1898) regarded it as a blue-green alga, and Johnson & Høeg (1961) placed *Girvanella* among the blue-green algae or the siphonous green algae. Subsequently it was again considered as a blue-green alga (e.g. Riding, 1972), and finally Riding (1977) suggested that Recent *Plectonema gloeophilum* is one of a number of extant filamentous blue-greens whose calcified sheaths are referable to *Girvanella*.

Girvanella is a rather common cosmopolitic fossil with records from the Late Proterozoic to mid-Cretaceous (Danielli, 1981) which restricts its stratigraphical and palaeogeographical value.

In the material from North Greenland *Girvanella* was recorded in one Cambrian sample from the uppermost part of the Henson Gletscher Formation in Peary Land. This sample (GGU 271 718) contains numerous forms of microfossils including several types of *Girvanella* (figs 9 and 10). The *Girvanella* filaments vary in thickness and configuration. Often they form 'algal mats' and it is likely that they have formed large sediment trapping carpets on the sea-bottom that served as nourishment for the many invertebrates now found fossilized together with the algae. A second possibly Cambrian occurrence of *Girvanella* in North Greenland is from the outer shelf and slope sequence where it is found in close association with *Gordonophyton* (fig. 4).

From the Ordovician succession there is only one record of *Girvanella* from the Cape Calhoun Formation in contrast to the the Silurian succession where *Girvanella* is a very common fossil in the calcarenites of the Thors Fjord Member (figs 11 and 12) and the Lafayette Bugt Formation. Hurst (1984) reported *Girvanella* from the Silurian of Peary Land.

Obruchevella Reitlinger

Obruchevella occurs as small isodiametric filaments in rather regular helical coils (fig. 14). Originally, Reitliger (1948) described it as a foraminifer, but later it was transferred to the blue-green algae. Chuvasov & Riding (1984) placed it in the *Girvanella* group with 'probable filamentous cyanophyte'-affinity. A comparison between the morphology of *Obruchevella* and the recent blue-green alga *Spirulina* is obvious but based on rather dubious superficial similarities. *Obruchevella* is known from Precambrian to Ordovician? times, apparently with the highest abundance at the Precambrian-Cambrian transition.

Obruchevella was reported from Siberia and Mongolia by Riding & Voronova (1984), from China by Song Xueliang (1984), and from North Africa by Cloud *et al.* (1978). It was preliminary reported from the Portfjeld Formation in Peary Land (Peel, 1980) and from the lower part of the Cambrian - Lower Silurian slope sequence in northern Nyeboe Land (Higgins & Soper, 1985).

Sphaerocodium Rothpletz

Sphaerocodium (= *Rothpletzella*) consists of tubular filaments which are dichotomously branched in one plane. This characteristic type of branching is shown in fig. 13. The dimensions of filaments are commonly 30-50 µm in height and 40-100 µm in width (Wray, 1977). *Sphaerocodium* is well known from Silurian reef carbonates in Gotland (Rothpletz, 1908, 1913).

Sphaerocodium is often regarded as a blue-green alga or green alga, but the affinity is not obvious (Chuvasov & Riding, 1984).

Sphaerocodium is restricted to Palaeozoic sediments but according to Wray (1977) similar forms existed in Triassic time.

In North Greenland, it is a rather common fossil in samples of resedimented calcarenites from the Silurian Lafayette Bugt Formation and Thors Fjord Member. *Sphaerocodium* was reported from the Odins Fjord and the Samuelsen Høj Formations, both of Silurian age, from Peary Land (Hurst, 1984). The material from North Greenland seems to include at least two types, one type with rather fine filaments (fig. 15), a second with somewhat larger filaments (fig. 16).

1) *Hyella* Bornet & Flahault, 2) *Gloeocapsa* Kützing and 3) *Pleurocapsa* Thuret in Hauck.

Hyella is an extant genus of blue-green algae belonging to the order Pleurocapsales. The genus occurs as boring endolithic organisms mainly in carbonate shells but also in solid limestone and ooliths. The genus *Hyella* is the the most differentiated types of coccoid blue-green algae (LeCampion-Alsumard & Golubic, 1985).

Hyella has different developmental stages. The *Hyella* stage consists of more or less branched filaments penetrating into a substratum, mainly calcium carbonate. Filaments developed from a rather undifferentiated upper, older part of the alga, closest to the substrate surface. From the undifferentiated cells many small baeocytes (endospores) are released to the water masses. When, or if a baeocyte is sedimented onto a suitable carbonate substrate it penetrates the substrate and starts cell divisions growing into a new 'mature' alga.

In the development, depending on ecological factors, there exists some morphological stages of *Hyella*. These resemble other blue-green algae like *Chrooccocus, Gloeocapsa* and *Pleurocapsa* in such detail that only culture experiments can reveal the connection to *Hyella* (Nielsen, 1973; LeCampion-Alsumard, 1978; LeCampion-Alsumard & Golubic, 1985). At present four species of marine *Hyella* are known: *H. balani, H. caespitosa, H. gigas* and *H. pyxis* (Lukas & Hoffman, 1984). *Hyella balani* Bornet & Flahault branches close to the substrate surface, and the branching pattern may be difficult to observe due to the undifferentiated cells. Filament cells are rounded, but with an elongated terminal cell.

Hyella gigas Lukas & Golubic has generally larger dimensions. The branching occurs slightly deeper within the substrate, so that branching pattern becomes a little more visible. Filament cells are rounded with an almost isodiametric terminal cell.

Hyella caespitosa Bornet & Flahault has very long filaments with elongated cells. It is sparsely branced and has almost parallel filaments.

Hyella pyxis Lukas & Hoffman is comparable to *H. caespitosa* but generally exhibits shorter and more branched filaments. The cells are elongated. Branching filaments are generally not parallel, but define angles up to approx. 90^{o}.

Cambrian fossils from North Greenland with remarkable resemblance to the living blue-green algae *Hyella, Gloeocapsa* and *Pleurocapsa* were preliminary reported by Larsen (1985). They were found in only one sample (GGU 271 718) from the uppermost part of the Cambrian Henson Gletscher Formation in Peary Land near Hans Tavsens Iskappe. The excellent preservation by phosphatization is unique. In thin section, the fossils are dark to light brown and apparently with almost intact cell remains.

Hyella-like borings in silicified Riphean/Vendian ooids from East Greenland were reported by Campbell (1982) and according to LeCampion-Alsumard & Golubic (1985) there is a record of similar fossils from mid-Precambrian stromatolites from China.

Figs 23 and 24 show a fossil endolith comparable to the Recent *Hyella gigas*. The filaments are often branched, relatively thick and have almost isodiametric terminal cells.

Fig. 20 show the fossil *Hyella* with more slender filaments. Filament cells are rounded with exception of the terminal cell which is elongated. The fossil resembles the Recent *Hyella balani.*

Figs 17 and 18 show recrystallized ooids with endolithic organisms comparable to to the Recent *Hyella pyxis,* with rather long slender filaments with branching almost perpendicular to each other.

Figs 25 to 28 show algae with close resemblance to the extant genus of blue-green algae *Gloeocapsa*. Recent *Gloeocapsa* can not be distinguished from the gloeocapsoid stage of *Hyella,* therefore it cannot be excluded that the fossil *Gloeocapsa* from these sample are developing stages of fossil *Hyella*.

Figs 29 and 30 show fossils which may be compared to the Recent genus *Pleurocapsa*.

Both *Gloeocapsa* and *Pleurocapsa* are stratigraphically and environmentally widely distributed so their fossil possible ancestors are of no stratigraphical or environmental value. The Ordovician *Gloeocapsomorpha* Zalessky (= *Gloeocapsa* ??) has been suggested as the source for Ordovician petroleum occurrences (e.g. Reed *et al*., 1986).

Solenoporaceae Pia

This family of extinct organisms is usually referred to the red algae although they were considered as tabulate corals by Wray (1977). The species of this family are characterized by incrusting forms with nodular or pillow-like morphology. The size ranges from some millimetres to a few centimetres. Solenoporacean algae consist of radial rows of calcified cells forming a fountain pattern. The cells may be circular (fig. 34) or polygonal (fig. 33) in cross section. Reproductive structures are not known (Wray, 1977). The family Solenoporaceae is apparently closely related to the extant family Corallinaceae.

Solenoporacean algae are known from the Cambrian to the Tertiary. They are usually considered to be characteristic indicators of reef-facies due to the close relationship to the Recent reef-building Corallinaceae (Wray, 1977).

Solenoporacean algae occur in the Silurian Odins Fjord Formation in Peary Land (Hurst, 1984) (fig. 34). In central North Greenland they were found in the Ordovician Troedsson Cliff Formation and the Silurian Lafayette Bugt Formation and Thors Fjord Member. Some few strongly recrystallized algal fragments from the Silurian Wulff Land Formation may perhaps be referred to the Solenoporaceae.

Palaeoporella? Stolley

The fossil in fig. 38 is tentatively referred to the genus *Palaeoporella*. The preservation is poor and only the illustrated specimen from the Ordovician Aleqatsiaq Fjord Formation in central Nyeboe Land was found. The genus *Palaeoporella* is characterized by having longitudinally arranged threads in the centre of the thallus parallel to the growth axis with more or less perpendicular branches extending to the cortex.

Palaeoporella is usually referred to the extant family *Codiaceae* (Wray, 1977), but other affinities have been proposed (Roux, 1985). However there is general agreement about the position among the siphonous green-algae.

The geological range of *Palaeoporella* is from the Late Cambrian to the Early Devonian? with reported examples from USSR, the Baltic areas, Norway and North America (Johnson & Høeg, 1961; Roux, 1985).

Dimorphosiphon Høeg

The genus *Dimorphosiphon* includes fossils of strongly calcified cylindrical bundles of parallel filaments, which branch and rebranch into smaller and smaller tubes, the outermost of which form a cortical layer (Johnson &

Høeg, 1961). *Dimorphosiphon* is referred to the extant family Codiaceae and has a strong anatomical resemblance to the Recent *Halimeda*.

The geological range of *Dimorphosiphon* is from the Ordovician to the Silurian with records from Kazakhstan, Canada (Poncet, 1986), Norway (Høeg, 1927, 1932), and Scotland (Elliot, 1972).

The North Greenland material consists of two fragments of questionable origin. The specimen shown in fig. 37 exhibits the central filament bundle very well, but there are only few and weak traces of branching. The affinity to *Dimorphosiphon* is not certain but fairly reliable. The two fragments are from Upper Ordovician/Lower Silurian in Nyeboe Land (Store Canyon, Unit 13A (Dawes & Peel, 1984)) and from the Silurian Lafayette Bugt Formation.

Dasycladacean Algae

Fossil algae referred to the family Dasycladaceae Kürtzing or closely related taxonomic groups with extant species, are common in a number of Ordovician units from North Greenland. The Dasycladacean algae are probably the best described fossil algae.

The size of the algae ranges from about 1 mm to several centimetres. The thallus is generally cylindrical and consists of an unbranched or weakly branched main axis with many side branches. All extant and the majority of fossil dasycladaceans display verticillate branching but with non-verticillate branching in the oldest types (Herak *et al.*, 1977). The North Grenland fossils belong to the nonverticillate Dasycladaceae.

Arcticella was reported from Arctic Canada (Poncet, 1986), *Intermurella* from Scotland (Elliott, 1972) and Arctic Canada (Poncet, 1986); all records of Ordovician age. *Vermiporella* ranges from the Ordovician to the Pennsylvanian, and possibly to the Permian (Johnson & Høeg, 1961). Ordovician *Vermiporella* is known from U.S.A. (Johnson & Høeg, 1961; Johnson & Sheehan, 1985), Canada (Poncet, 1986), Scotland (Elliott, 1972), and Baltic (Johnson & Høeg, 1961; Kozlowski & Kazimierczak, 1968).

In North Greenland dasycladacean algae were recorded from the Ordovician Gonioceras Bay, Troedsson Cliff, Cape Calhoun and lower part of Aleqatsiaq Fjord Formations. The preservation is variably ranging from strongly recrystallized fragments to excellently preserved specimens. The most abundant occurrence is from the Ordovician part of the Aleqatsiaq Fjord Formation, where dasycladacean packstone occurs. Dasycladacean algae were also reported from the Turesø Formation in Peary Land (Hurst, 1984).

Fig. 36 shows a fossil referable to the genus *Arcticella* Poncet established from material of Ordovician age in Arctic Canada (Poncet, 1986). Fig 39 shows an alga with branching main axis, probably a species of *Vermiporella* Stolley. Figs 40, 41, and 42 show algae which may be referred to the genus *Intermurella* Elliott.

PALAEOENVIRONMENT

Fossil algae may indicate both depth, facies and palaeoclimate. Recent marine algal macrophytes live from the upper limit of seawater influence to depths of approximately 260-270 m where crustose coralline algae have been found at the Bahamas (Littler *et al.*, 1985). According to Riding (1975) *Nostoc* a blue-green alga has been reported in the Indian Ocean from depths below 1000 m.

An unidentified fossil alga is only a general indicator of water depth, and even when identified, it must be referred to an extant taxon with well known biology before it is applicable as a more specific indicator. Riding (1975) discussed the problem of algae as depth indicators, and suggested that the benthic algae may be regarded as indicators of the euphotic zone, ranging from 0 - max. 150 m.

Renalcis, Gordonophyton (Epiphyton), Wetheredella, Girvanella and *Sphaerocodium* may be regarded as benthic blue-green algae, indicating a water depth of less than 150 m.

The Recent endolithic genus *Hyella* and its depth distribution has been intensely studied in different marine areas. Budd & Perkins (1980) in a study on microborings in Puerto Rican shelf and slope sediments reported that *Hyella* spp. was recorded from the intertidal zone to a depth of approximately 35 m, but that the *Hyella* spp. characterized the upper photic zone (intertidal to approximately 20 m). Records from the Scottish continental shelf have shown same tendency, but with a much lower maximum of depth, of approximately 17 m (Akpan & Farrow, 1984). In the Mediterranean *Hyella balani* has been reported from intertidal zone to 25 m (LeCampion-Alsumard, 1978). Similar depths are given from the Bahamas (Lukas & Golubic, 1983). In eastern Florida *Hyella pyxis* is found to maximum depths of 50 m and *Hyella caespitosa* to 100 m.

Assuming the comparison of fossil *Hyella* with the extant species is correct, it seems probable that the studied examples were deposited at subtidal conditions apparently at a depth of less than 20 m.

Hyella balani is regionally recorded from e.g. Denmark, Scotland, Florida, Puerto Rico, New Zealand and the Mediterranean Sea indicating distribution from tropical to temperate waters. *Hyella gigas* is reported from the Florida continental margin (Lukas & Golubic, 1983) and New Zealand (Nielsen, 1987) indicating subtropical distribution. *Hyella pyxis* has only been recorded from Florida and Bermuda (Lukas & Hoffman, 1984). Findings of similar forms in Lower Cambrian rocks strongly indicate that they were deposited under tropical or subtropical conditions.

The Solenoporacean algae are rather poor indicators of depth and geographical range. As previously mentioned the extant crustose corallinaceae are known from polar to tropical waters with a depth range from intertidal to more than 250 m.

The extant calcareous members of Codiaceae and Dasycladaceae are typical benthic algae characteristic of subtropical and especially tropical lagoons. The fossil codiacean and dasycladacean algae may be interpretated as indicators of: 1) shallow water, 2) tropical to subtropical climate, and 3) low energy environment.

This interpretation of a tropical to subtropical climate in North Greenland in the Early Palaeozoic time is in accordance with palaeogeographical reconstructions for this time interval (Smith *et al.*, 1981).

PRODUCTIVITY

Most of the algae discussed in the previous sections are benthic organisms. In Recent seas the primary production of benthic plants is approximately a factor 2500 smaller than the primary production of phytoplankton (Tissot & Welte, 1984). However, the primary production of phyto-benthos may obviously be of great local importance.

Primary production in tropical oligotrophic (nutrient poor) oceans has long been considered to be low (Tissot & Welte, 1984). New research may modify this point of view. Adey & Goertemiller (1987) mentioned, in a study on the oligotrophic sea of the Bahamas that coral reef algal turfs are master producers in nutrient poor seas. It is important to note that these results are obtained from water depths between 0.15-12 m.

Concerning the phytoplankton of tropical seas Kerr (1983) suggested that conventional ^{14}C-measurements of ocean primary production underestimate the production by a factor 5 to 10.

The most important primary producers of Recent seas are diatoms and dinoflagellates, but these groups of organisms were not evolved in Early Palaeozoic time (Tappan, 1980). Consequently the most appropriate primary producing organisms of Palaeozoic time are achritarchs, blue-green algae and perhaps prasinophycean algae. The systematical position of achritarchs is still debated, but general agreement on some algal affinity has been achieved. The prasinophycean algae, represented by the phycoma-stages =tasmanids) and leiosphaerids were evolved during Precambrian and still exist, but with limited importance as primary producers. Neither achritarchs nor tasmanids and leiosphaerids occur frequently in the Lower Palaeozoic sediments of North Greenland.

Recent years of research on picoplankton has drawn attention to the blue-green algae as being important primary producers. Picoplankton is plankton which ranges in size between 0.2 and 2.0 µm (Sieburth, 1979). Johnson & Sieburth (1979) found chroococcoid blue-green algae from the North Atlantic Ocean in concentrations of 10^3-10^4 cells per ml and El Hag & Fogg (1986) found concentrations of up to 1.5 x 10^5 cells per ml in samples from the Irish Sea. Platt *et al.* (1983) noted that picoplankton from the tropical North Atlantic Ocean contains a significant, metabolically-active, autotrophic component, capable of supplying about 60 % of the total primary production in an open-ocean ecosystem. The autotrophic component referred to, was the blue-green algal genus *Synechococcus*.

It seems likely that these tiny and primitive blue-green algae were much more important as primary producers in the Early Palaeozoic when competition with larger planktonic autotrophs did not exist. The small size and the lack of a resistant cell-wall give a reliable explanation to the fact that they are almost impossible to detect in sediments. Examples of some small fossils probably belonging to the blue-green algae are shown in fig. 31 (Microcystis?) and fig. 32 (Synechococcus?).

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FIGURE CAPTIONS

Fig. 1 *Renalcis* with almost free chambers. Wulff Land Formation, Thors Fjord Member, Hendrik Ø. GGU 83 487. Scale bar: 250 µm.

Fig. 2 *Renalcis* with branching connected chambers. Cambrian-Silurian slope sequence. Northern Nyeboe Land. GGU 313 071. Scale bar: 250 µm.

Fig. 3 *Renalcis* with some chambers totally fused and showing branching. Cambrian-Silurian starved basin sequence. Northern Nyeboe Land. GGU 313 071. Scale bar: 250 µm.

Fig. 4 *Gordonophyton* and *Girvanella*. Cambrian-Lower Silurian outer shelf sequence, east of J. P. Koch Fjord. GGU 319 511. Scale bar: 250 µm.

Fig. 5 *Gordonophyton*. Same sample as above. Scale bar: 250 µm.

Fig. 6 *Wetheredella* and *Sphaerocodium*. Freja Fjord Member, Peary Land. GGU 270 754. Scale bar: 250 µm.

Fig. 7 *Wetheredella* exhibiting 'apertures' seen as fine lines in transversal sections or fine dots in tangential sections. Stained thin section. Freja Fjord Member, Peary Land. GGU 270 754. Scale bar: 250 µm.

Fig. 8 *Wetheredella* interwowen with *Sphaerocodium*. From clasts in Freja Fjord Member, Odins Fjord Formation. The specimen exhibits some radiating structure. GGU 270 760. (Same specimen as shown in Hurst, 1984). Scale bar: 250 µm.

Fig. 9 *Girvanella*. SEM of specimen prepared out of the sample by acetic acid digestion. Uppermost Henson Gletscher Formation, Peary Land, near Hans Tavsens Iskappe. GGU 271 718. Scale bar: 100 µm.

Fig. 10 *Girvanella* sp. Thin section slide of same sample as above. Scale bar: 25 µm.

Fig. 11 *Girvanella* sp. ball-shaped. Wulff Land Formation, Thors Fjord Member Hendrik Ø. GGU 83 487. Scale bar: 100 μm.

Fig. 12 *Girvanella* sp. forming algal mat. Same sample as above. Scale bar: 100 μm.

Fig. 13 *Sphaerocodium* sp. exhibiting the characteristic branching pattern. From clasts in Freja Fjord Member, Peary Land. GGU 270 762. Scale bar: 100 μm.

Fig. 14 *Obruchevella* sp. from the Cambrian-Silurian slope sequence in Northern Nyeboe Land. GGU 319 748. Scale bar: 10 μm.

Fig. 15 *Sphaerocodium* sp. from the Lafayette Bugt Formation in Warming Land. GGU 324 114. Scale bar: 250 μm.

Fig. 16 *Sphaerocodium* sp. Same sample as above. Scale bar: 100 μm.

Fig. 17 Ooids with boring alga referred to the extant species *Hyella pyxis*. Uppermost Henson Gletscher Formation, near Hans Tavsens Iskappe, Peary Land. GGU 271 718. Scale bar: 250 μm.

Fig. 18 Same as previous, but with crossed nicols to show the recrystallization of ooids.

Fig. 19 Same specimen as 17. Branching almost perpendicular to the main axis of filament. Scale bar: 100 μm.

Fig. 20 Boring alga referred to the extant species *Hyella balani*. The filament cells are rounded except the terminal cell which is elongated. Same specimen as 17. Scale bar: 10 μm.

Fig. 21 Phosphatic mould of fossil *Hyella* prepared out of the carbonate by acetic acid digestion. SEM. sample as 17. Magnification approximately 300 x.

Fig. 22 Detail showing thin fungal hypha around algal filament. In recent *Hyella*-borings fungal hyphae are common in the space between alga and substrate (e.g. Lukas & Golubic, 1983 fig. 4). Sample as 17. Magnification approx. 2000x.

Fig. 23 Boring alga referred to the extant species *Hyella gigas*. Filament cells, including the terminal cells are rounded. Sample as 17. Scale bar: 25 µm.

Fig. 24 Detail of 23. Scale bar: 10 µm.

Fig. 25 *Gloeocapsa*-like alga. Sample as 17. Scale bar: 25 µm.

Fig. 26 *Gloeocapsa*-like alga. Sample as 17. Scale bar: 25 µm.

Fig. 27 *Gloeocapsa*-like alga. Sample as 17. Scale bar: 25 µm.

Fig. 28 *Gloeocapsa*-like alga. Sample as 17. Scale bar: 25 µm.

Fig. 29 *Gloeocapsa/Pleurocapsa*-like alga with filamentous shape. Sample as 17. Scale bar: 25 µm.

Fig. 30 *Pleurocapsa*-like alga. Sample as 17. Scale bar: 10 µm.

Fig. 31 *Microcystis*-like colony. Sample as 17. Scale bar: 25 µm.

Fig. 32 Single small algal? cell. Sample as 17. Scale bar: 10 µm.

Fig. 33 Solenoporacean alga and *Girvanella*. Wulff Land Formation. Thors Fjord Member. Hendrik Ø. GGU 83 487. Scale bar: 250 µm.

Fig. 34 Solenoporacean alga from Odins Fjord Formation, clast in Freja Fjord Member, Peary Land. Same specimen as shown by Hurst 1984. GGU 270 756. Scale bar: 250 µm.

Fig. 35 Solenoporacean alga from Odins Fjord Formation, clast in Freja Fjord Member, Peary Land. GGU 270 754. Scale bar: 250 µm.

Fig. 36 Dasycladacean alga referred to the genus *Arcticella*. Aleqatsiaq Fjord Formation, Nyeboe Land. GGU 301 997. Scale bar: 250 µm.

Fig. 37 Fossil with probable affinity to *Dimorphosiphon*. A central bundle of tubes is clearly visible. Kap Ammen unit 1A (Dawes & Peel, 1984). Hall Land. GGU 82 408. Scale bar: 250 µm.

Fig. 38 Fossil with possible affinity to *Palaeoporella*. Aleqatsiaq Fjord Formation. Store Canyon, Nyeboe Land. GGU 82 148. Scale bar: 250 µm.

Fig. 39 *Vermiporella* with branching thallus. Kap Ammen unit 1A (Dawes & Peel, 1984), Hall Land. GGU 82 408. Scale bar: 250 µm.

Fig. 40 Cf. *Intermurella*. Aleqatsiaq Fjord Formation, Nyeboe Land. GGU 82 148.
Scale bar: 250 µm.

Fig. 41 As fig. 40.

Fig. 42 Cf. *Intermurella*. Aleqatsiaq Fjord Formation, Nyeboe Land. GGU 301 997. Scale bar: 250 µm.

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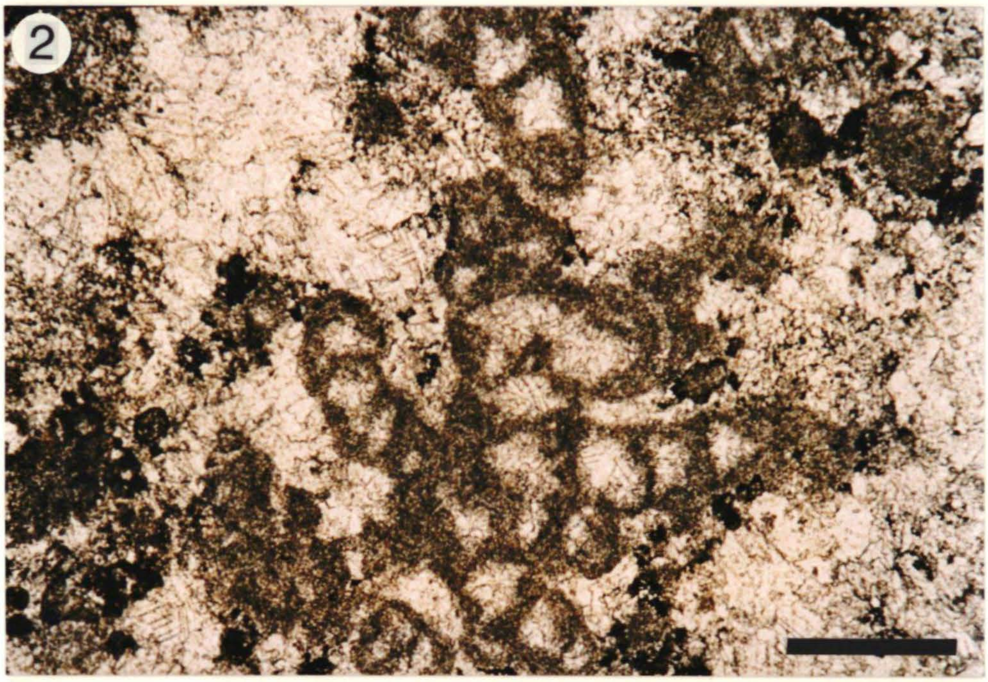

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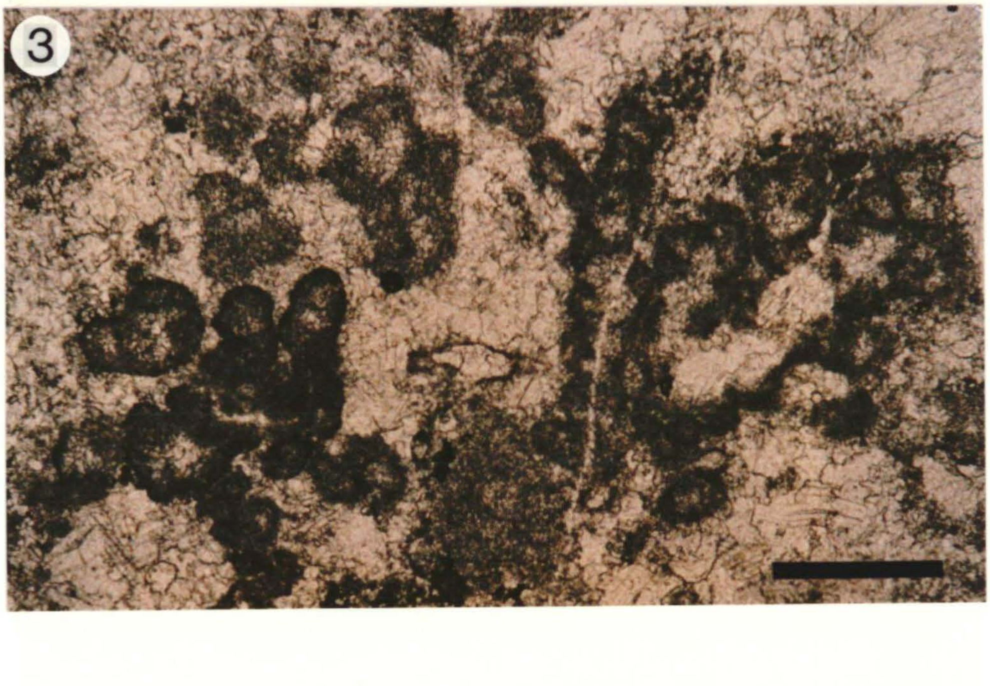

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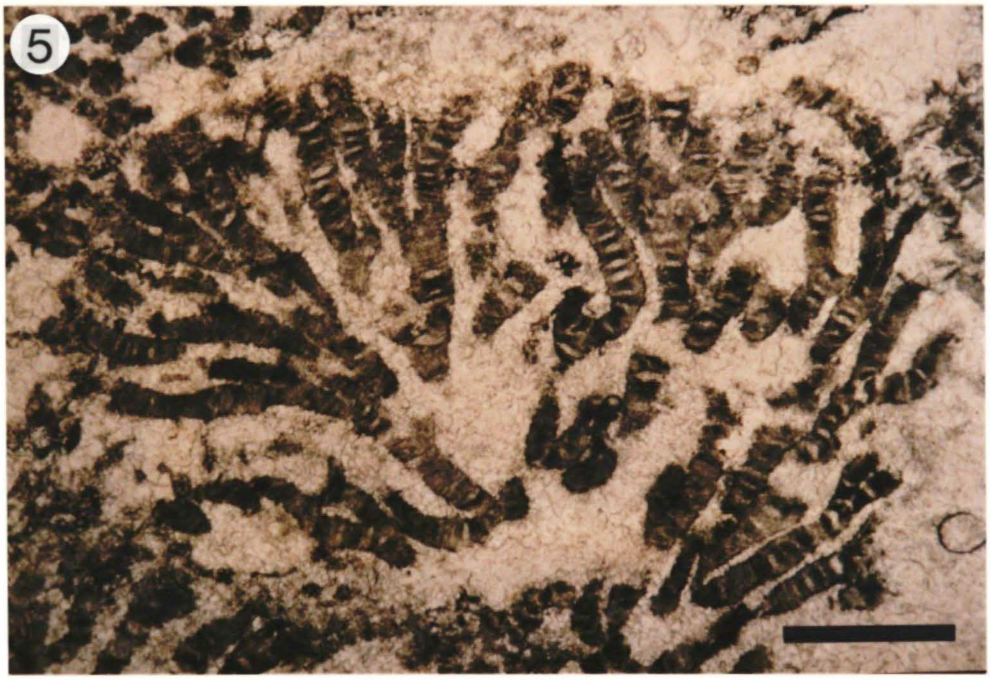

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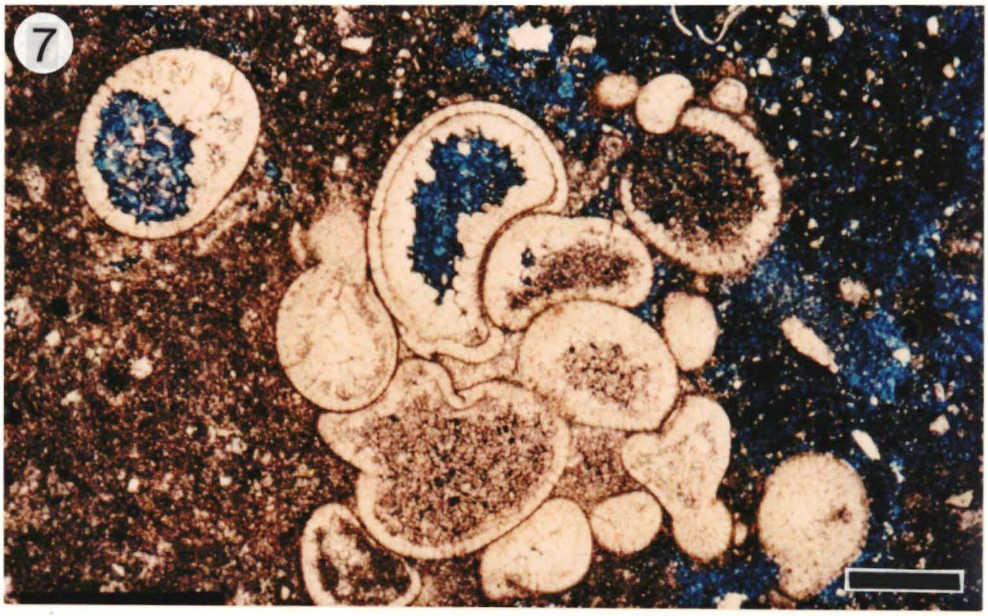

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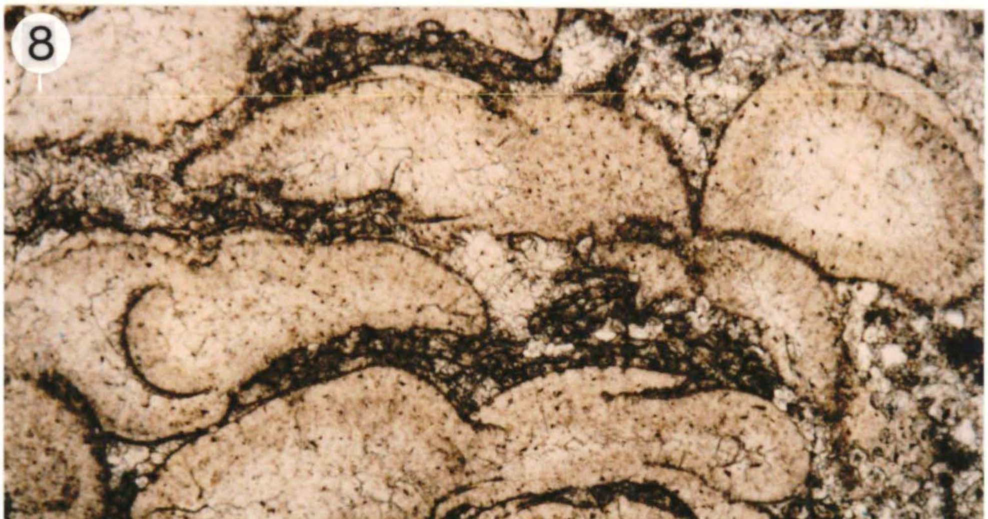

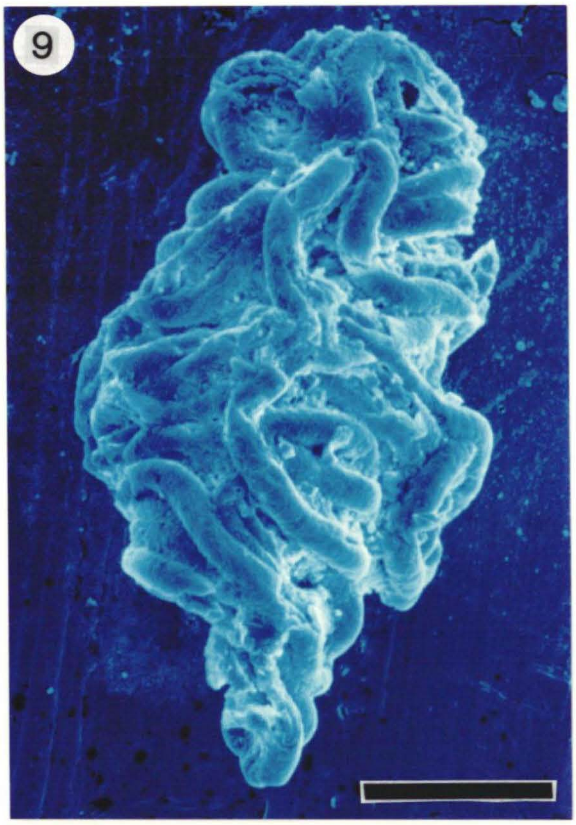
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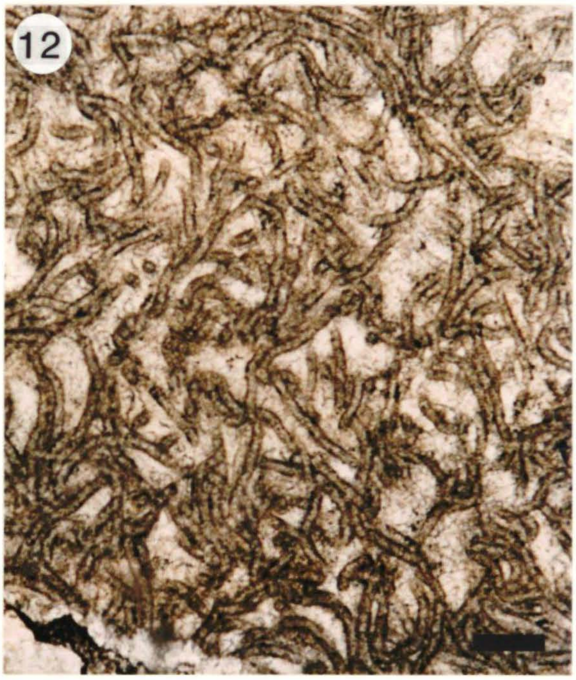
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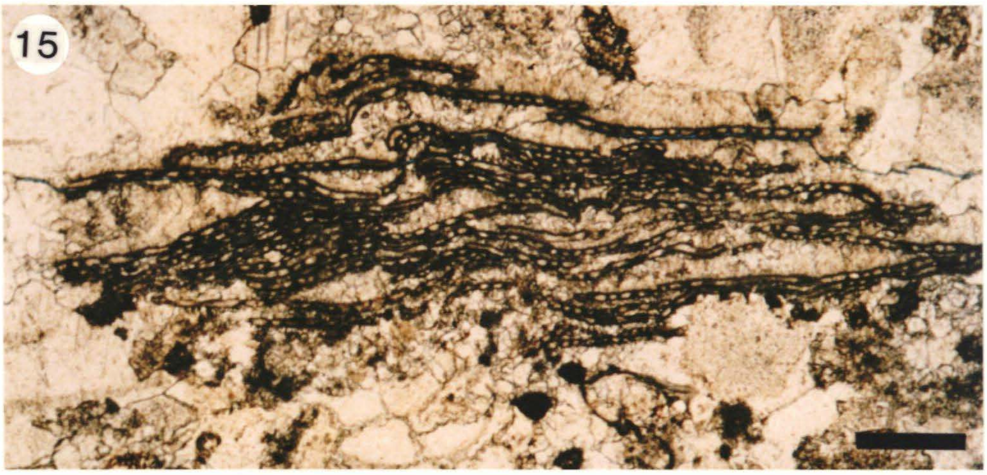

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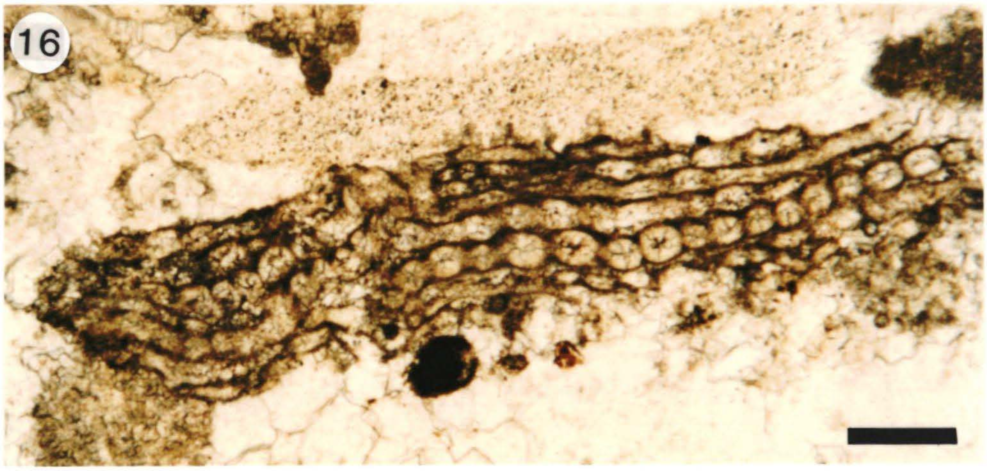


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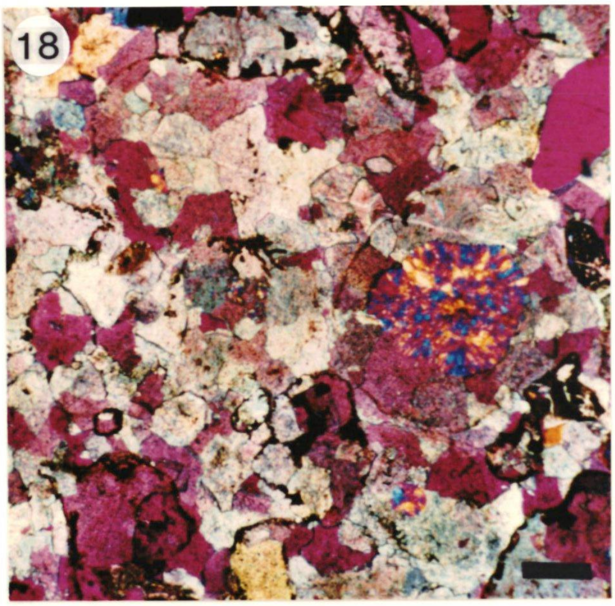
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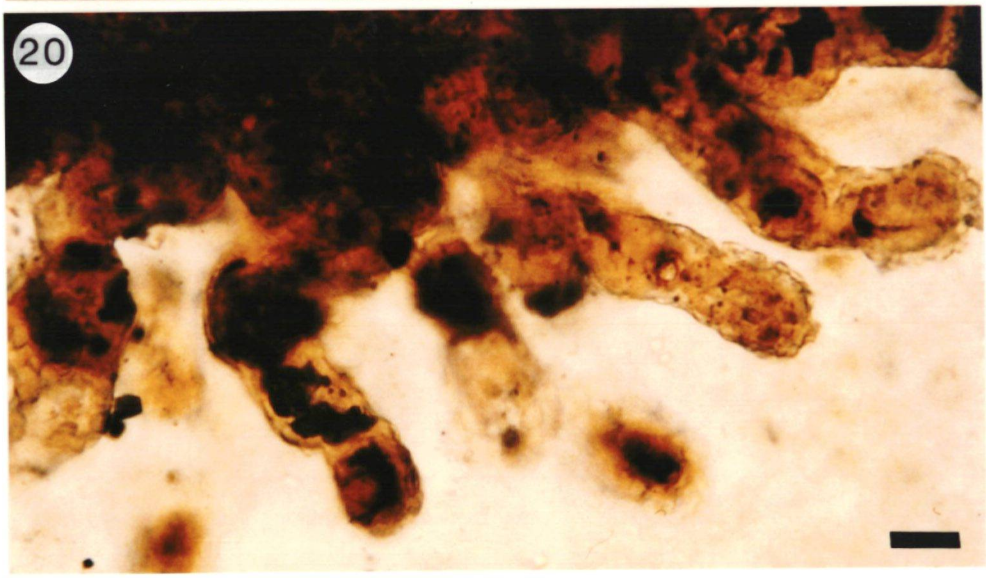
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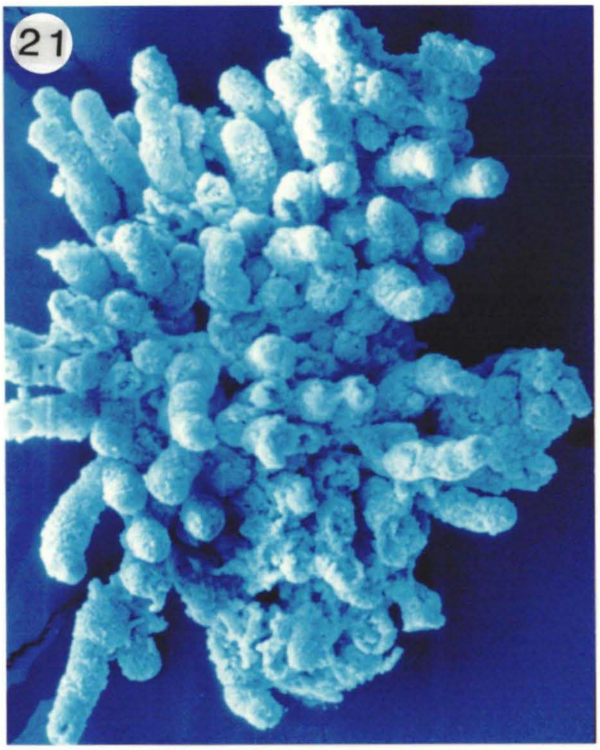
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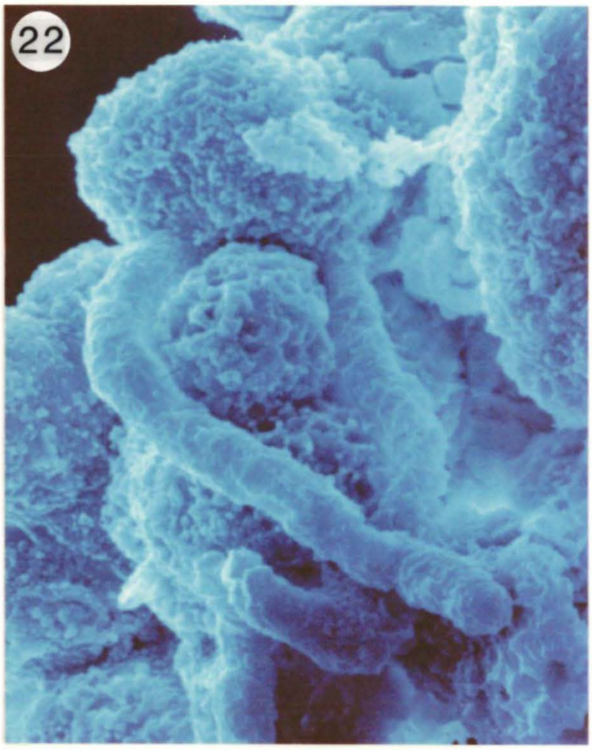
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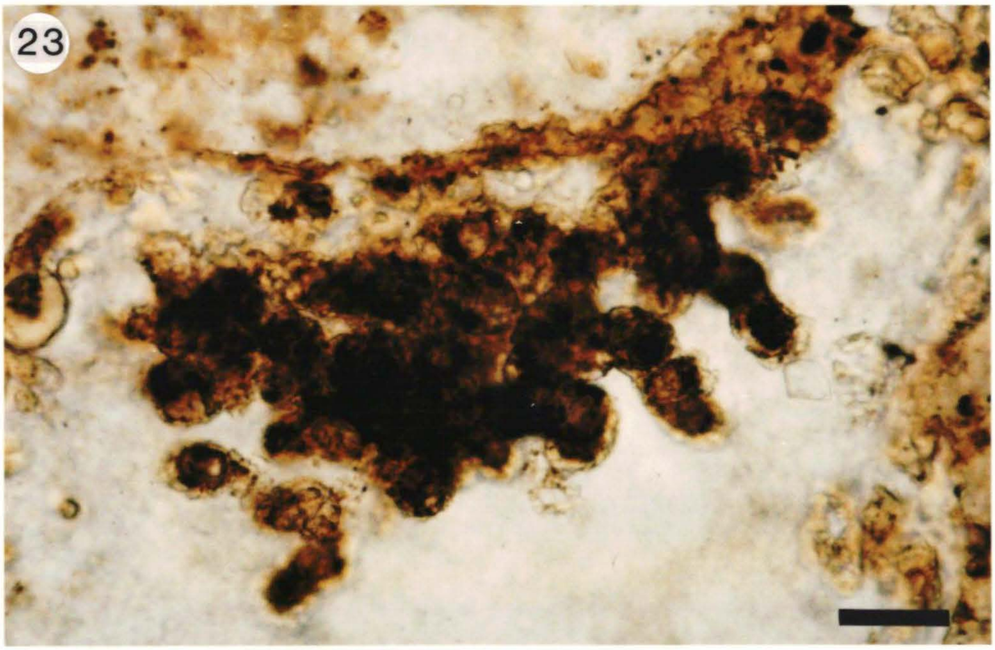
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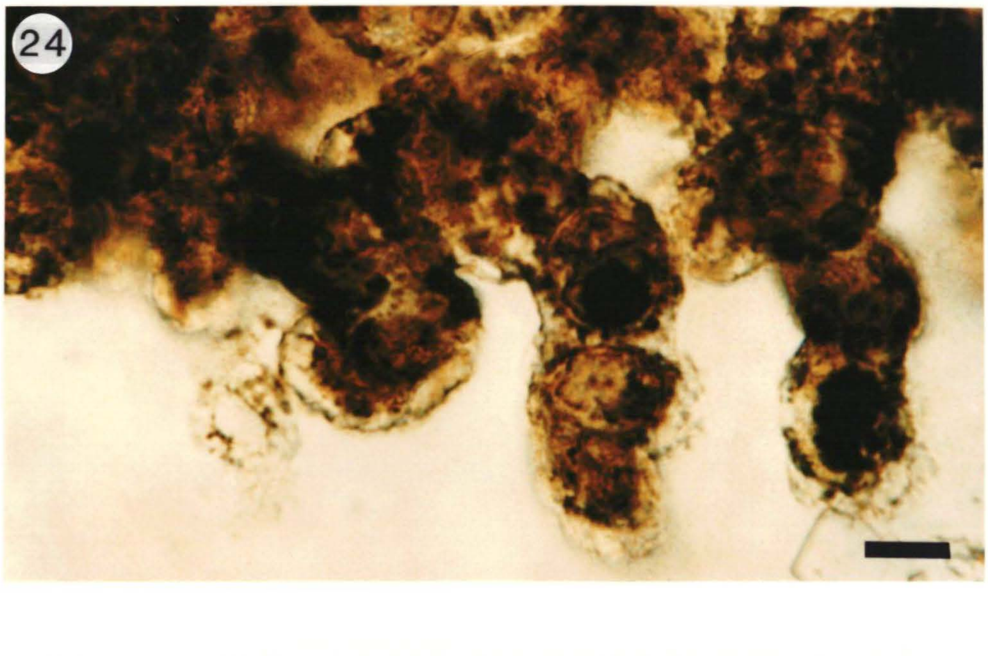
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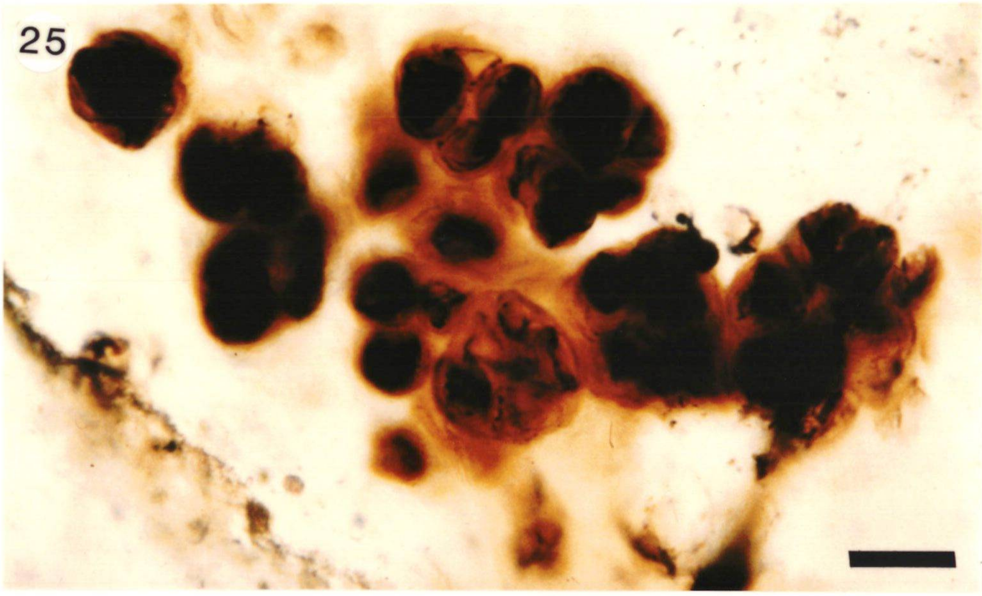

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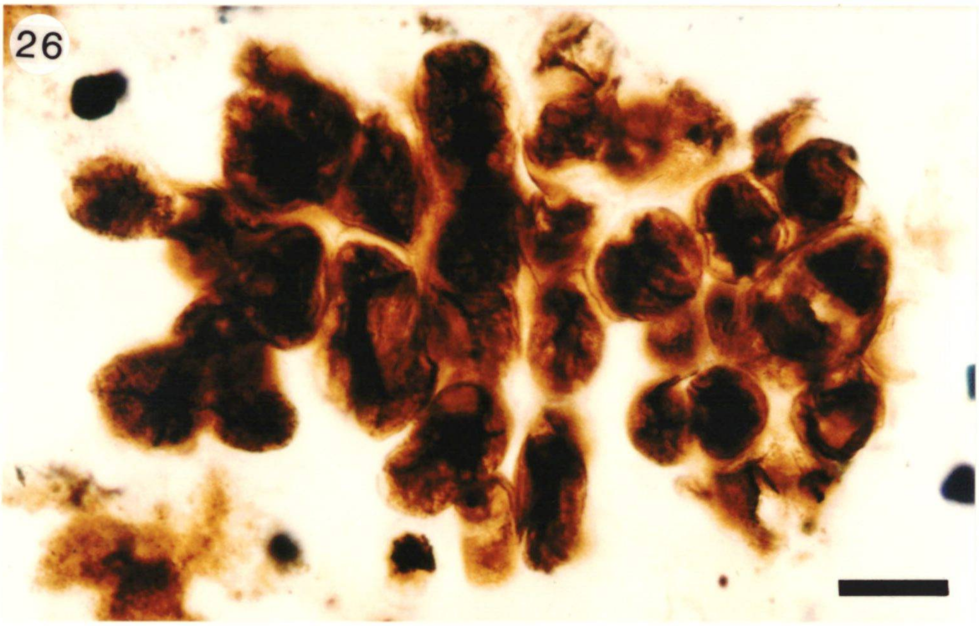

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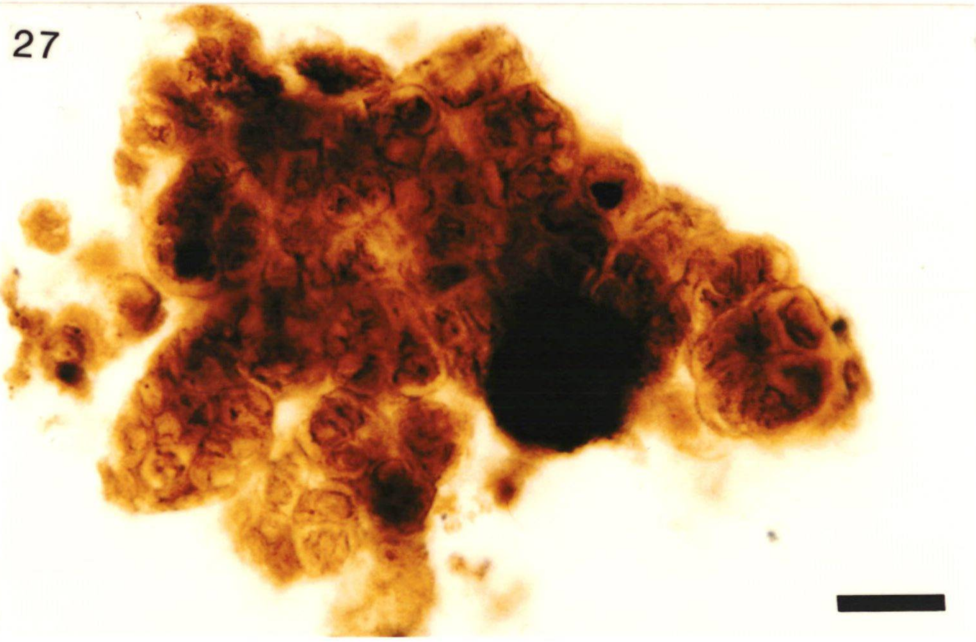

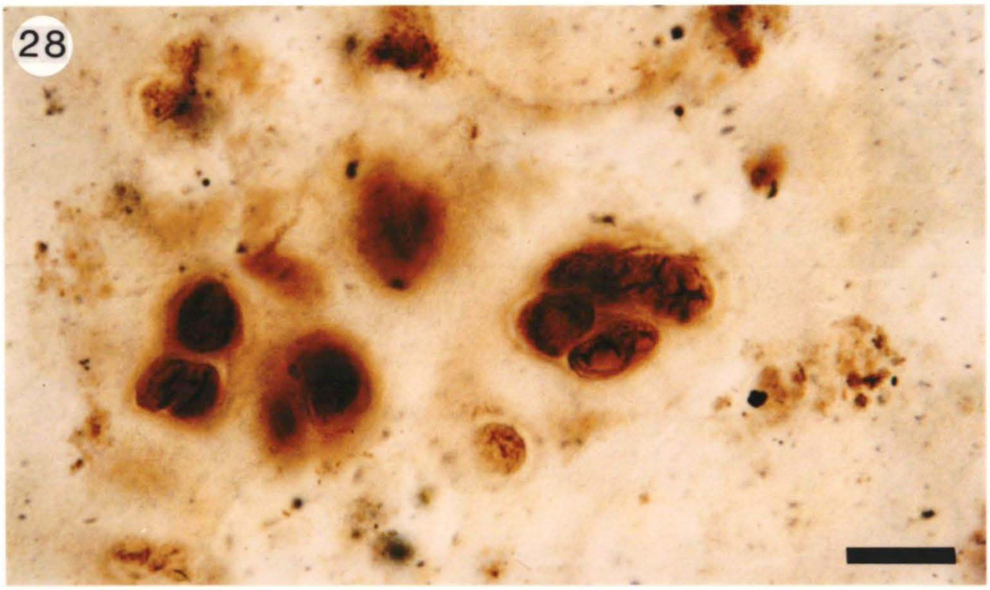
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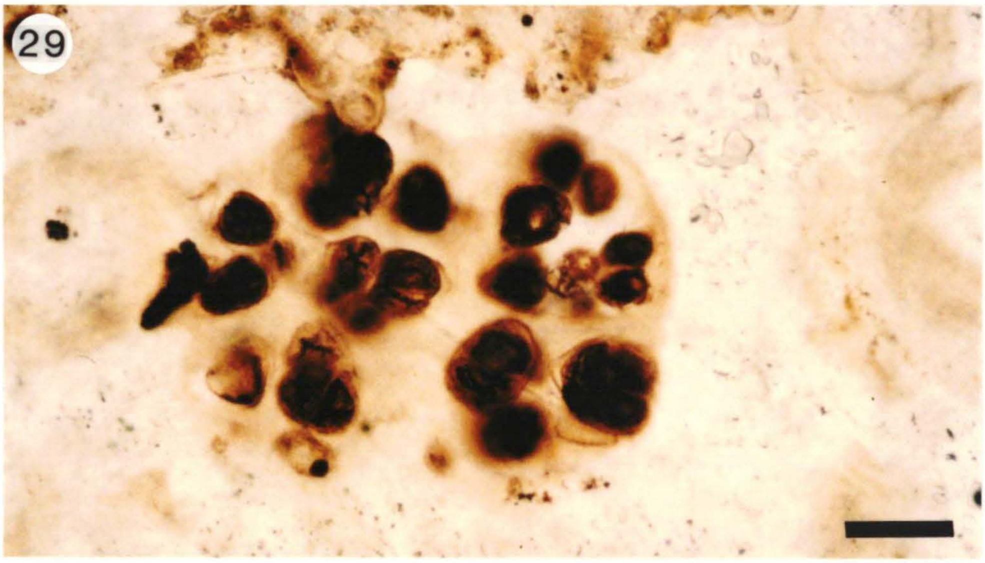
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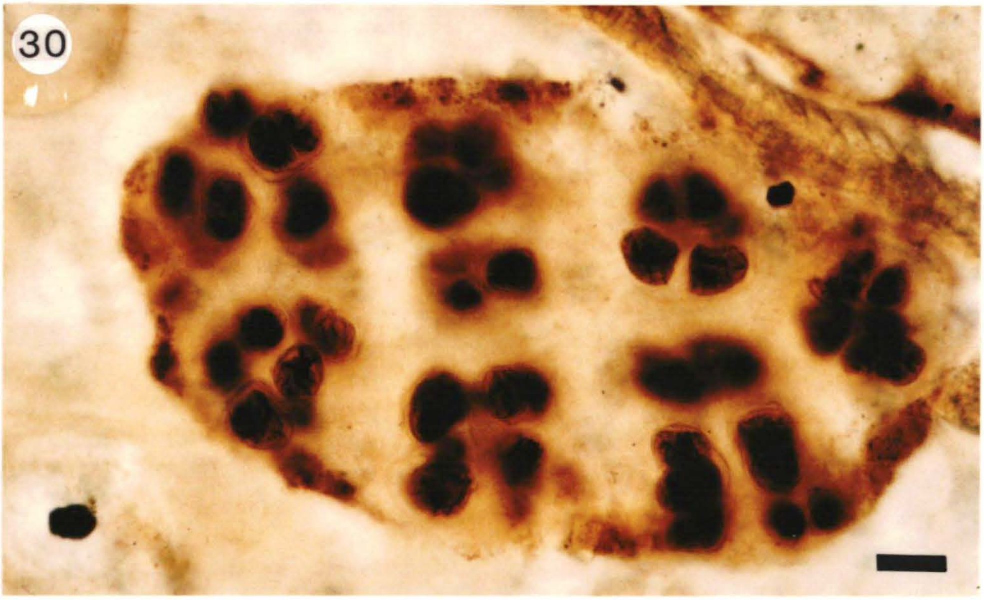
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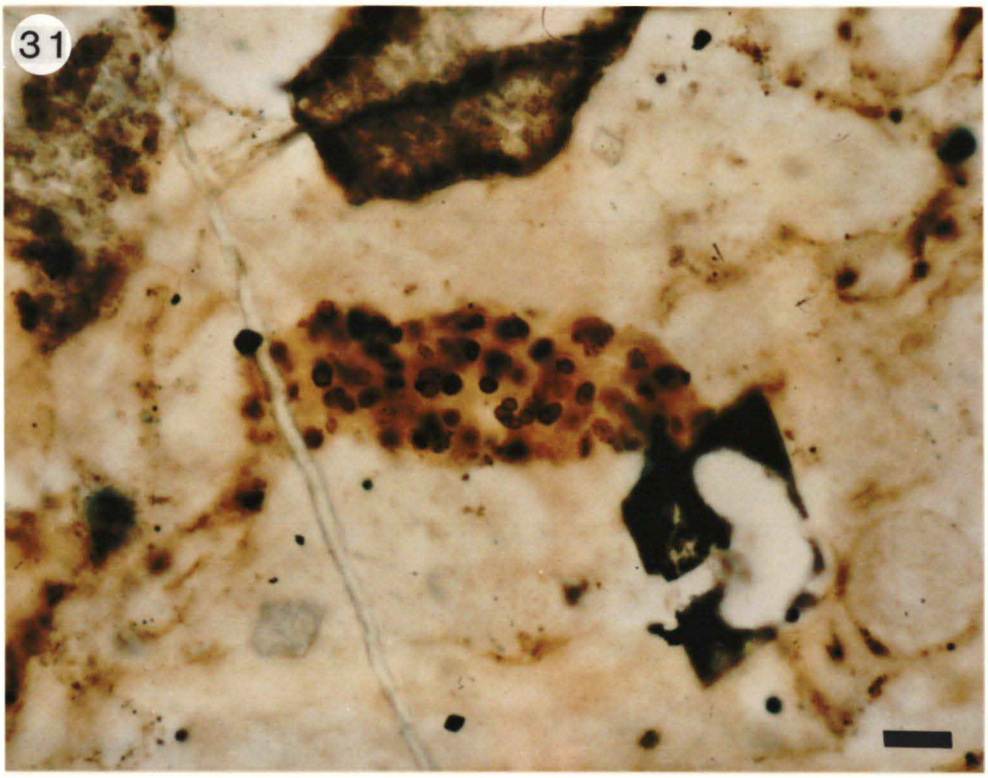

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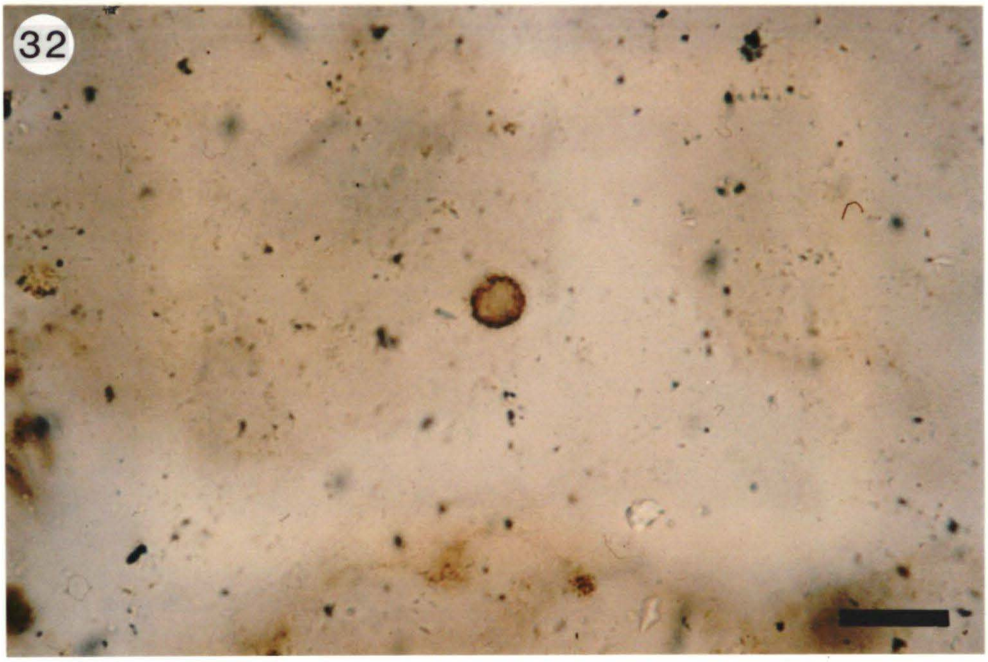

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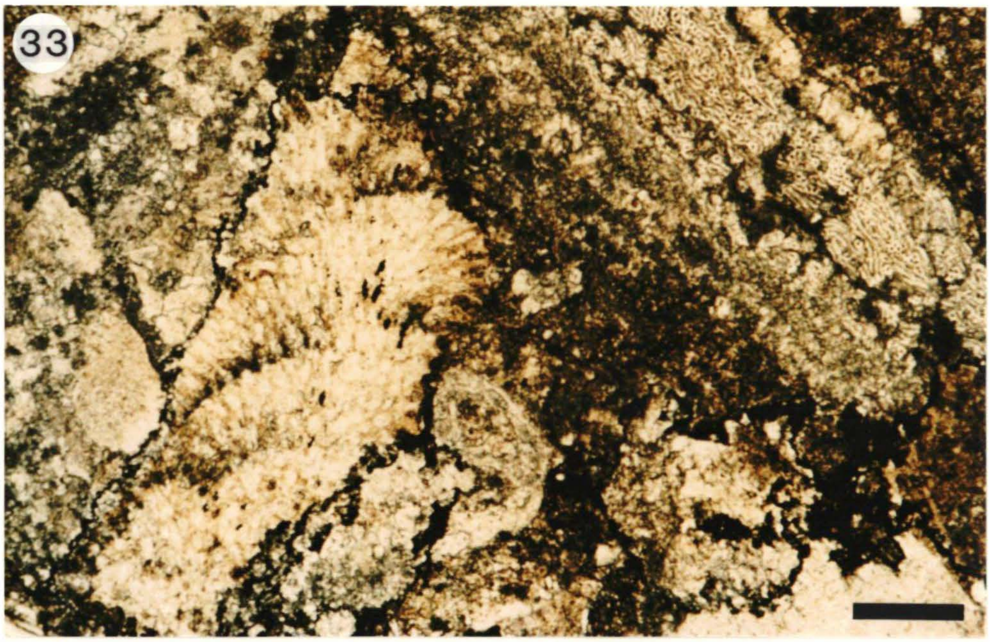

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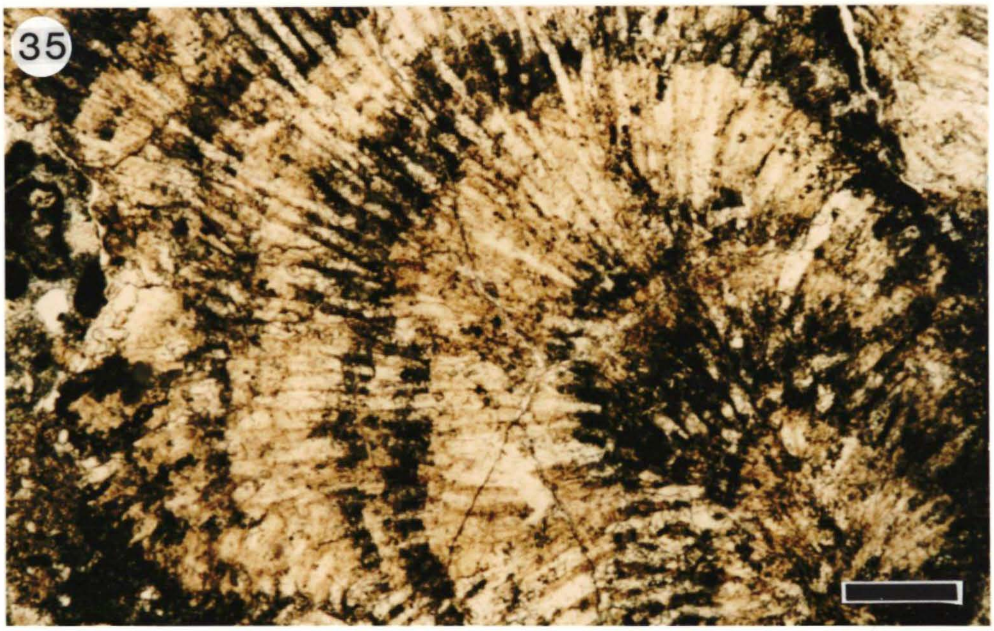

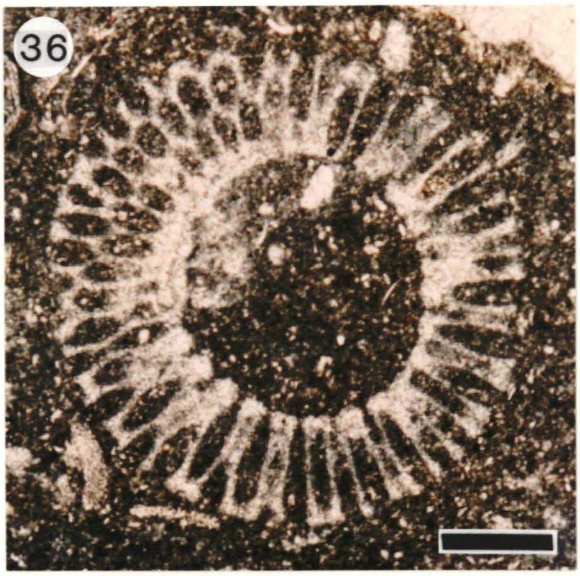
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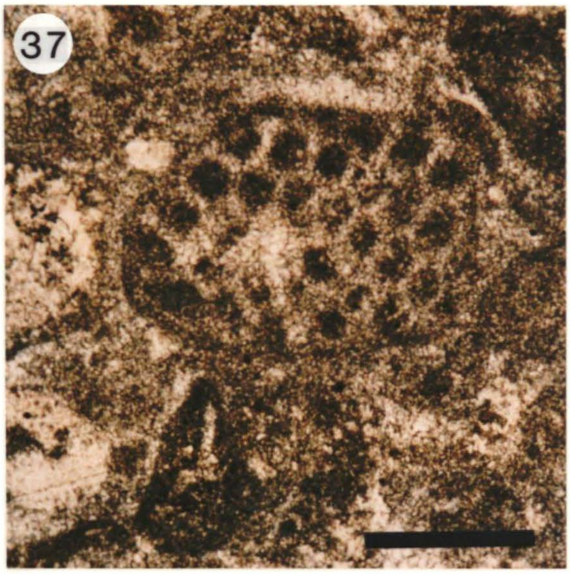
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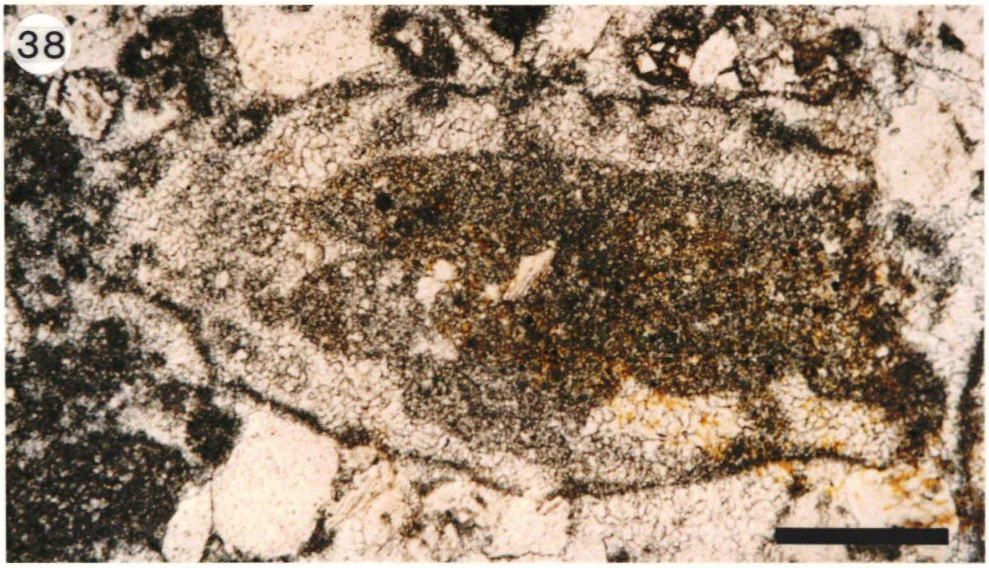
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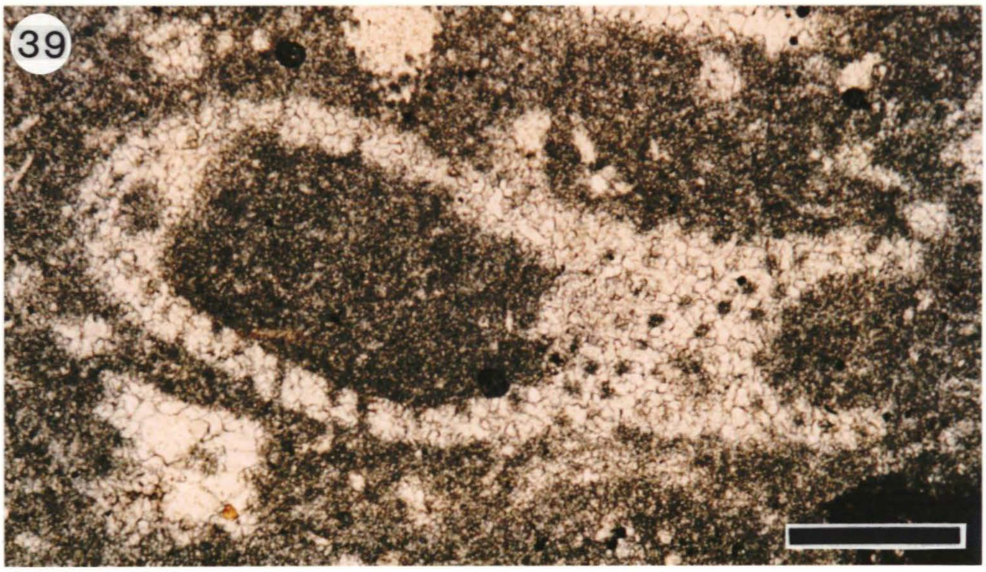
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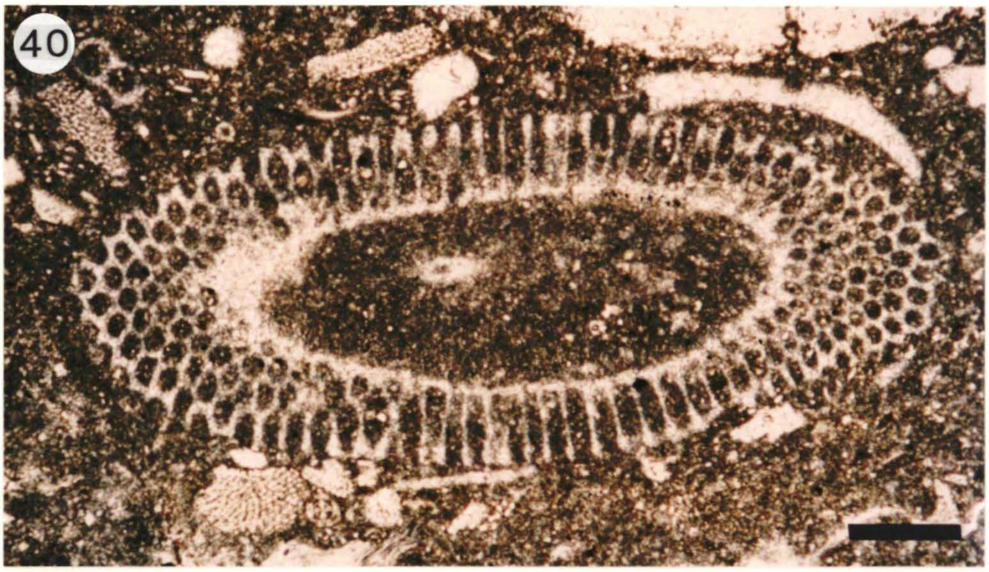

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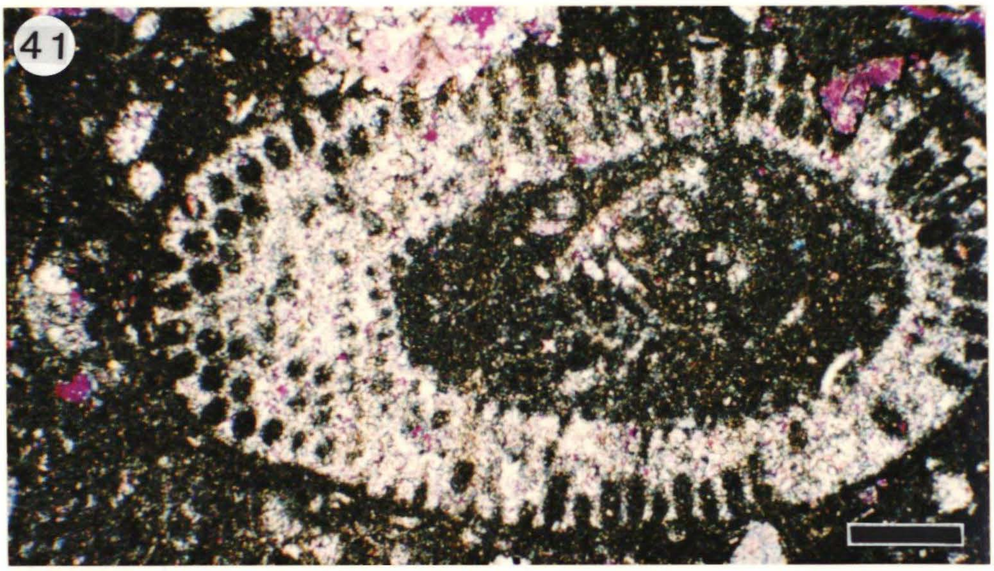

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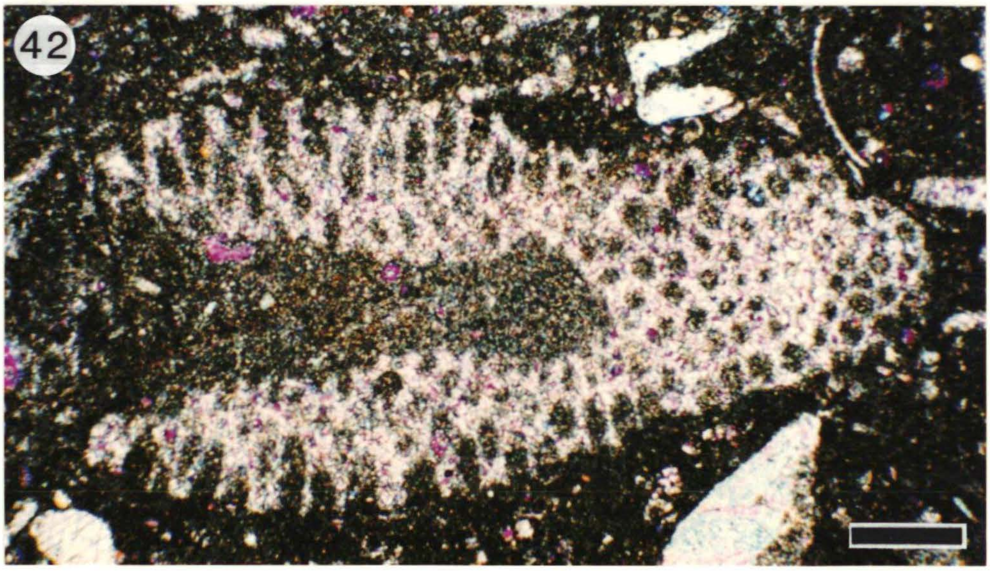

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