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With 22 plates and 6 range-charts

Vignette:
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Contents

Abstract

A detailed study of the palynology and palynofacies of the Fjerritslev Formation (Lower Jurassic – basal Middle Jurassic) has resulted in the definition of four spore/pollen zones and four dinoflagellate cyst zones. The spore/pollen zones are the *Corollina – Ricciisporites* Zone (Late Rhaetian), the *Cerebropollenites macroverrucosus* Zone (Sinemurian – Pliensbachian), the *Spheripollenites – Leptolepidites* Zone (Toarcian), and the *Perinopollenites elatoides* Zone (Middle Jurassic). The dinoflagellate cyst zones are the *Rhaetogonyaulax rhaetica* Zone (Rhaetian), the *Dapcodinium priscum* Zone (latest Rhaetian – earliest Sinemurian), the *Liasidium variabile* Zone (Sinemurian), and the *Nannoceratopsis gracilis* Zone (Late Pliensbachian – ?Bajocian/Bathonian). These zones, and the *Pinuspollenites – Trachysporites* Zone Lund 1977 (Hettangian), are proposed for use in the Danish Subbasin. The combined spore/pollen and dinoflagellate cyst zonation has resulted in a detailed biostratigraphical subdivision of the sequences studied.

A new combination, *Manumia delcourtii* (Pocock 1970) nov. comb. et emend., is proposed here, and the species description emended.

New photographs of the holotypes of some of the species erected by Nilsson (1958) are included in the plates.

The kerogen assemblages recorded from the Fjerritslev Formation, indicate a marine depositional environment, with a high but variable influence of terrestrially-derived organic particles. Stratigraphic variation in the kerogen assemblages generally correlate with the lithostratigraphical subdivision, and support previous environmental interpretations of the Fjerritslev Formation. Indications of strongly reducing conditions in the bottom waters were found in the Stenlille-2 borehole, in samples here referred to the Early Toarcian. The variations in the kerogen assemblages in the sequence investigated from the Gassum-1 borehole are not correlatable with the other boreholes, but seem primarily to reflect a distinct decrease in bioturbation in the Late Sinemurian.

The Fjerritslev Formation does not generally represent a potential source rock for oil. Some levels (parts of the F-III member) show, however, the characteristics of a fair to good source rock. The organic matter is generally immature or only at the earliest stage of maturity.

Introduction

Few palynological investigations have been made of the Lower Jurassic deposits in the Danish Subbasin (Evitt 1961a, 1961b, Bertelsen 1978, 1979, Dybkjær 1988); none of these have included palynofacies observations. This study concentrates on the Lower Jurassic to basal Middle Jurassic Fjerritslev Formation in the Danish Subbasin (eastern Norwegian – Danish Basin; see figs 1 and 2). The study was based on the Fjerritslev-2, Frederikshavn-2, Stenlille-2, and Gassum-1 boreholes.

The objectives of the study were:

1) To produce a palynological zonation and dating of each of the investigated sequences, utilising a combination of miospores (microspores and pollen) and dinoflagellate cysts.
2) To erect a palynological zonation for the Fjerritslev Formation, for use within the Danish Subbasin, based on the results from the individual wells, together with results from earlier investigations.
3) To carry out a detailed palynofacies investigation of the Fjerritslev Formation, and to compare the results with previous lithological and palaeo-ecological investigations.

The four borehole sections

The locations of the four boreholes are shown in figs 1 and 2, and the lithology and stratigraphy of the total well sections are shown in fig. 3.

Fjerritslev-2

The Fjerritslev-2 borehole was drilled in the spring of 1958 by DAPCo (the Danish American Prospecting Company). It is located adjacent to the Fjerritslev Fault, and is on the flank of a salt pillow. This borehole contains the type section of the Fjerritslev Formation (Larsen 1966, Michelsen 1978). The objectives of the borehole were both to establish the stratigraphy and to test the hydrocarbon potential of the Rhaetian-Jurassic strata. The borehole reached a depth of 2345m below rotary table (b.r.t.) and terminated in Keuper shales (Sorgenfrei & Buch 1964). No traces of hydrocarbons were encountered (Well Data Summary Sheet, 1981).

Frederikshavn-2

The Frederikshavn-2 borehole was drilled in the spring of 1952 by DAPCo. The drilling was part of a programme, including the wells Frederikshavn-1, -2 and -3, to test the structural situation and the origin of the natural gas in the area. The borehole reached a depth of 1079m b.r.t. in (presumed) Triassic arkose (Sorgenfrei & Buch 1964). No traces of hydrocarbons were encountered (Well Data Summary Sheet, 1981).

Stenlille-2

The Stenlille-2 borehole was drilled by Dansk Olie & Gasproduktion A/S (DOPAS) during the summer of 1987. The borehole is located centrally on a saltdome structure and is part of a series of closely-spaced boreholes designed to test the possibility of using the domal structure as an underground store for natural gas. It is planned that the sandy Gassum Formation (Rhaetian) should function as the store, and the overlaying Fjerritslev Formation as the seal. The borehole reached a depth of 1662m b.r.t., terminating in Upper Triassic sandstone (the Vinding Formation) (Frandsen 1988).

Gassum-1

The Gassum-1 borehole was drilled by DAPCo between March 1948 and March 1951 (the operation was suspended from February 1949 to November 1950). The borehole is located on the flank of a salt pillow, and contains the type section of the Gassum Formation (Larsen 1966, Bertelsen 1978). The objective was to test the Rhaetian-Jurassic-Lower Cretaceous interval. The boring reached a depth of 3462m b.r.t., terminating in (presumed) Permian sediments (Sorgenfrei & Buch 1964).

The Fjerritslev Formation

Lithology and lithostratigraphy

The first lithological and lithostratigraphical observations from the Gassum-1 borehole were presented by Norwood, Nørvang and von Elm (1951) and by Gre-

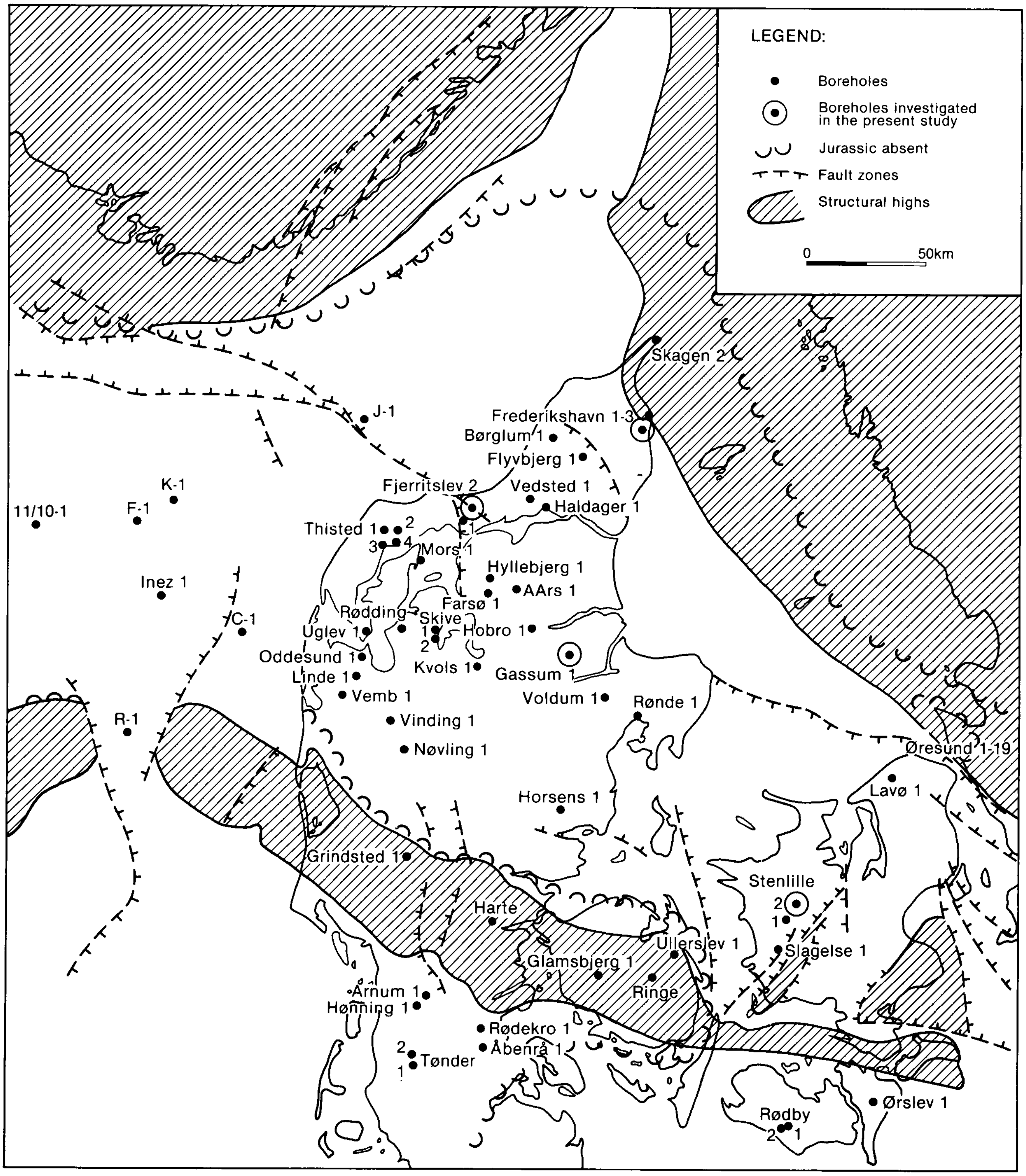


Fig. 1. The main Jurassic structural elements in the Danish area, simplified from Michelsen (1978). The boreholes shown form the regional subsurface database (see Fig. 2); this study focusses on the encircled wells.

gersen and Sorgenfrei (1951). Sorgenfrei and Buch (1964) described the lithological sequences from several Danish boreholes, including the Lower Jurassic in the Fjerritslev-2, Frederikshavn-2, and Gassum-1 boreholes.

A lithostratigraphical subdivision of the Jurassic deposits in the Danish Subbasin was presented by Larsen (1966). Michelsen (1976, 1978, 1989) revised this scheme, mainly on the basis of petrophysical logs; he amended several of the formations, and subdivided further into members.

Pedersen (1983, 1985, 1986) studied the lithology, trace- and body fossils, and sedimentary structures within the Fjerritslev Formation. The studies were based on cores from several Danish boreholes, including Gassum-1, and resulted in detailed interpretations of the depositional environment.

Frandsen (1988) described the Stenlille-2 borehole;

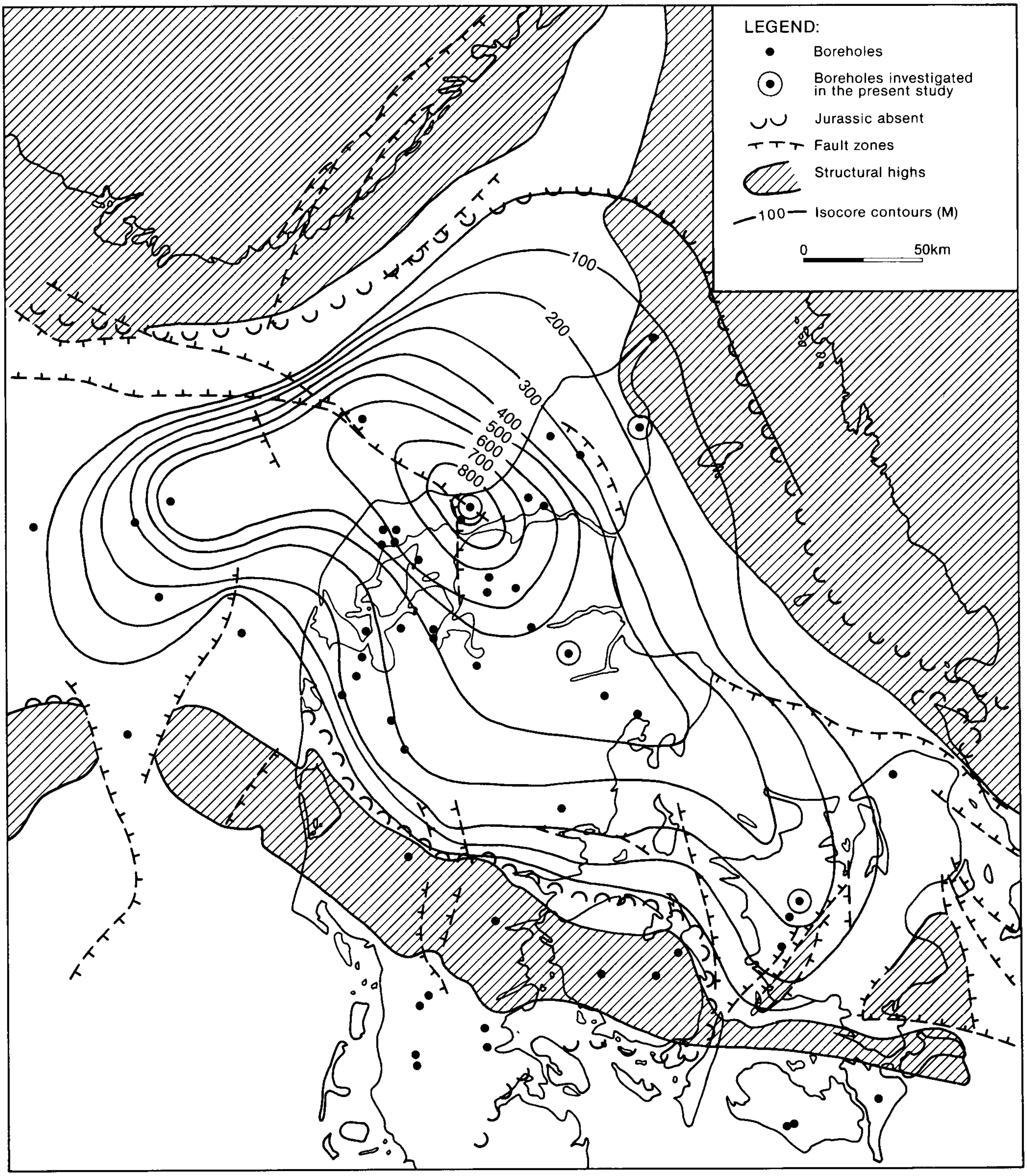


Fig. 2. Isocore contours of the Lower Jurassic Fjerritslev Formation. After Michelsen (1978), modified on the basis of new borehole data.

the lithological description and lithostratigraphical subdivision of the sequence used here (figs 3 and 9) are based on that account.

The lithological descriptions and lithostratigraphical subdivisions of the Fjerritslev-2, Frederikshavn-2, and Gassum-1 boreholes used here (figs 3, 7, 8 and 10) are based on the work of Sorgenfrei and Buch (1964), Michelsen (1978) and Pedersen (1986). The validity of the subdivision of the Lower Jurassic sequence in the Gassum-1 borehole presented by Pedersen (1986) is questionable. The subdivision was indicated on a figure (fig. 6), and was not discussed further. It has, however, been used here to permit detailed comparison with the other sequences investigated.

The Fjerritslev Formation was defined in the Fjerritslev-2 borehole by Larsen (1966). Michelsen (1978) amended the formation, subdivided it into four informal lithostratigraphical units (members F-I to F-

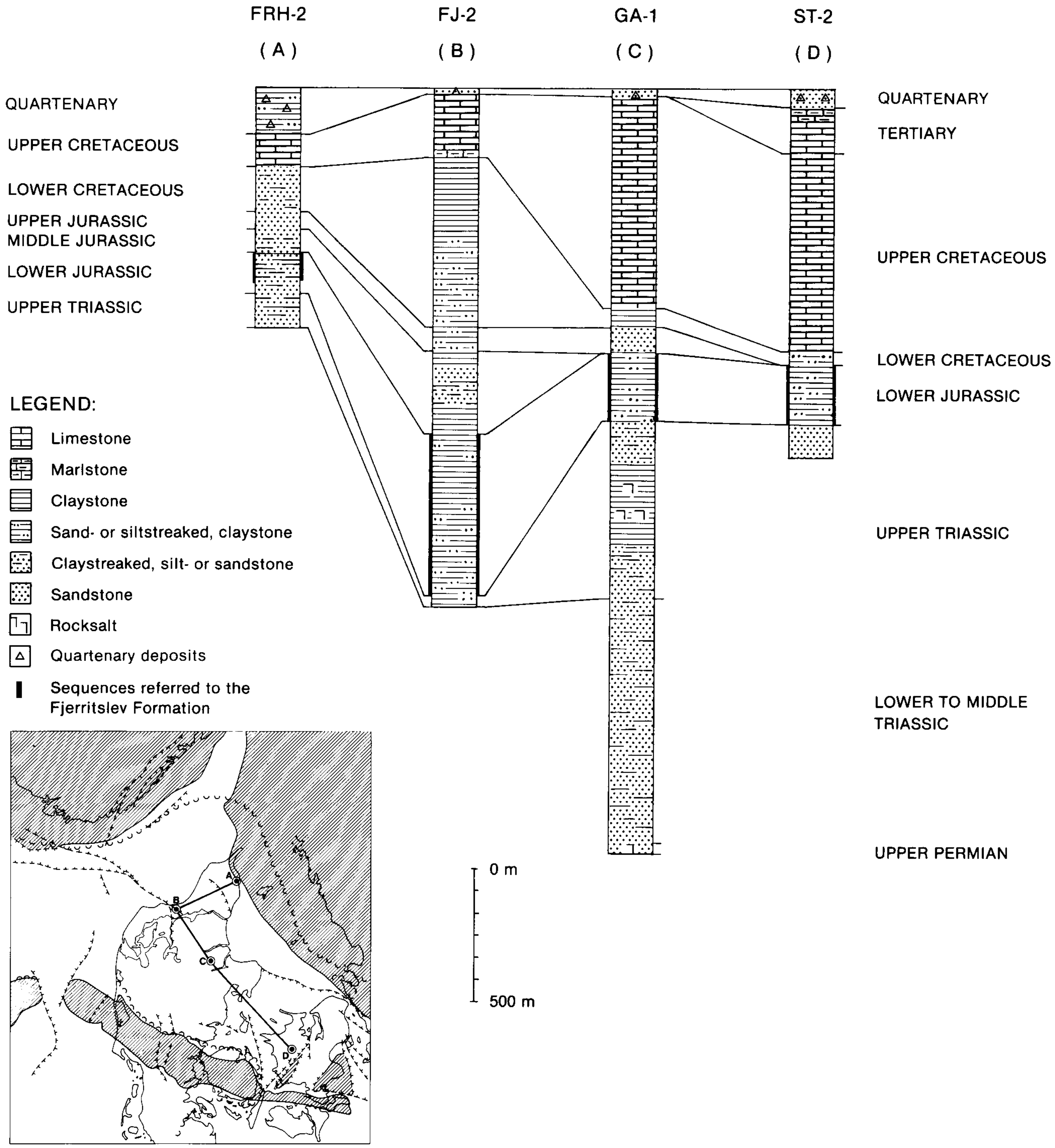


Fig. 3. The sequence in the four investigated boreholes, after Larsen (1966), Well Data Summary Sheets (1981), and Frandsen (1988). The extent of the Fjerritslev Formation in the individual boreholes is emphasized. The chronostratigraphy shown is based on Sorgenfrei & Buch (1964), Michelsen (1975), and this study.

IV), and further subdivided the F-I member into two subunits, F-Ia and F-Ib, based on petrophysical logs. Michelsen (1989) subsequently elevated these two subunits to the rank of members, and redescribed the resultant five (informal) members of the Fjerritslev Formation, adopting the Hyllebjerg-1 borehole as a reference section.

The formation comprises marine sediments dominated by dark greyish mudstone and silt-streaked mudstone. Intercalated coarse grained siltstone and fine-grained sandstone are present, and sideritic clay-ironstone concretions are common (Michelsen 1978, 1989, Pedersen 1983, 1985, 1986).

The five members of the Fjerritslev Formation are distinguished by their log signature, their lithology, and sedimentary structures (see further discussion on p. 11–12).

The Fjerritslev Formation is widely distributed in the Danish Subbasin. In the Danish Central Trough it is found only in the Salt Dome Province. Clay sequences of equivalent age in the Norwegian sector of the North Sea have also been assigned to the Fjerritslev Formation (Vollset & Doré 1984). Lower Jurassic deposits of comparable lithology are found farther north in the Norwegian and British sectors (Dunlin Group, Vollset & Doré 1984), in the southern part of the British sector (Lias Group, Rhys 1974) and in the Dutch sector (Aalburg Shale Formation, Posidonia Shale Member, NAM & RGD 1980) (Michelsen, Frandsen, Holm, Jensen, Møller & Vejbæk 1987). The maximum thickness of the Fjerritslev Formation observed in borings (911m) occurs in the type section, the Fjerritslev-2 borehole. The formation is much thinner in the marginal parts of the basin, e.g. 173m in the Frederikshavn-2 borehole (see figs 2 and 3).

In the Danish Subbasin, the Fjerritslev Formation overlies a deltaic to littoral succession, the Gassum Formation (defined in the Gassum-1 borehole by Larsen (1966), amended by Bertelsen (1978)). In northern and western parts of the Subbasin the Fjerritslev Formation is overlain unconformably by the deltaic Haldager Sand Formation (Michelsen 1989), and in the southeast (e.g. in the Stenlille-2 and Slagelse-1 boreholes) by the Lower Cretaceous Vedsted and Rødby Formations respectively (Michelsen 1978, Frandsen 1988).

Bio- and chronostratigraphy

Nørvang (1957) investigated the foraminiferal faunas in the Lower Jurassic sequences of 9 Danish boreholes, including Frederikshavn-2 and Gassum-1.

Sorgenfrei and Buch (1964) presented a chronostratigraphical subdivision of 31 Danish boreholes, including Fjerritslev-2, Frederikshavn-2, and Gassum-1, based on palaeontological, lithological, and geophysical studies by Frebold (1948), Norwood et al. (1951), Gregersen & Sorgenfrei (1951), and the study by Nørvang (1957).

Michelsen (1975) studied the ostracod faunas in the Lower Jurassic sequences of 36 Danish boreholes, (including the three mentioned above). He presented a biostratigraphical zonation of the investigated sequences and proposed a chronostratigraphical subdivision by correlation with ostracod-zoned and ammonite-dated sequences from northern Germany. The chronostratigraphical subdivisions of the Fjerritslev-2, Frederikshavn-2, and Gassum-1 boreholes shown in figs 3, 7, 8 and 10 are based on the work of Sorgenfrei and Buch (1964) and Michelsen (1975). The ostracod zonation proposed by Michelsen (1975) is shown in fig. 6.

The subdivision of the Jurassic used in this paper follows that of Harland et al. (1989). This subdivision differs from that adopted by Michelsen (1975, 1978) in two ways: 1) Michelsen referred the Aalenian to the Early Jurassic, whereas Harland et al. refer it to the Middle Jurassic. 2) Michelsen used the ammonite zone *Caenisites turneri* to define the earliest part of the Late Sinemurian, whereas this zone was used by Harland et al. (1989) to define the latest Early Sinemurian.

The subdivision by Michelsen (1975) of the sequence from the FJERRITSLEV-2 BOREHOLE (fig.7) was based partly on lithology and partly on a relatively poor ostracod fauna. The Triassic-Jurassic boundary was placed, entirely on lithological evidence, at 2300m b.r.t. The Lower-Upper Sinemurian boundary was placed, on the basis of ostracods, between 2084m and 2004m b.r.t. The Lower-Upper Pliensbachian boundary was placed at 1793m b.r.t. on the basis of the presence of the ostracod species *Ogmoconchella danica* at this level. The core from 1564m to 1561m b.r.t. was referred to the Upper Pliensbachian. No ostracods were recorded above this level. However, lithological correlation with the Vedsted-1 borehole (where ostracods were recorded from the uppermost part of the Fjerritslev Formation) points to an Early or earliest Middle Jurassic (Aalenian) age for the uppermost part of the formation.

Michelsen's (1975, 1978) subdivision of the Lower Jurassic sequence in the FREDERIKSHAVN-2 BOREHOLE (fig. 8) was based partly on a relatively poor ostracod fauna and partly on lithology. The location of the Triassic-Jurassic boundary at about 883m b.r.t. (Michelsen 1975, text fig. 3) is probably erroneous. This level is the boundary between the Gassum and Fjerritslev Formations, which does not coincide with the Triassic-Jurassic boundary in the Frederikshavn-2 borehole. The Triassic-Jurassic boundary should probably be located within the Gassum Formation, in accordance with observations from the Flyvbjerg-1 borehole (Olaf Michelsen, pers. comm. 1989).

The position of the Upper Sinemurian-Lower Pliensbachian boundary is based on ostracods and located in a gap in core coverage between 879m and 855m b.r.t. (see fig. 8). The Lower-Upper Pliensbachian boundary is located at 783m b.r.t. on the basis of the ostracod fauna. The boundary between the Lower and Middle Jurassic was placed at 731m b.r.t. As Michelsen (1975) included Aalenian in the Early Jurassic Epoch, the uppermost part of the sequence referred to the Early Jurassic could be of Aalenian (earliest Middle Jurassic) age.

The chronostratigraphic subdivision of the Fjerritslev-2 and Frederikshavn-2 boreholes, presented by Sorgenfrei and Buch (1964) is less detailed than, but comparable with, Michelsen's (1975) subdivision.

The chronostratigraphical subdivision of the STENLILLE-2 BOREHOLE (fig. 9) is based on unpublished preliminary results from ostracod and palynomorph investigations of the Stenlille-1 borehole (Michelsen 1980, Hansen 1981), correlated to Stenlille-2 using petrophysical logs (Frandsen 1988).

The positioning of the chronostratigraphic boundaries in the GASSUM-1 Lower Jurassic sequence (Sorgenfrei & Buch 1964, Michelsen 1975) was discussed by Dybkjær (1988, p. 8) and is shown in fig. 10.

The Upper Triassic to Lower Jurassic sequence in the Gassum-1 borehole has been the object of earlier palynological studies, probably because of the atypically close coring. Bertelsen (1978) dated the uppermost part of the Gassum Formation and the lowermost part of the Fjerritslev Formation as Rhaetian to Hettangian. Dybkjær (1988) defined and dated three spore/pollen zones in the uppermost Triassic to Lower Jurassic sequence in Gassum-1: Zone A (1538m to 1533m b.r.t.), Rhaetian; Zone B (1515m to 1463m), Hettangian; and Zone C (1454m to 1209m), Early Sinemurian to ?Pliensbachian/Toarcian.

Michelsen (1973, 1975, 1978) demonstrated that the boundary between the Gassum and Fjerritslev Formations is diachronous. According to Michelsen (1975) this lithostratigraphic boundary coincides with the Triassic-Jurassic boundary in the central and southern part of the basin but in the northern and eastern parts of the basin it is of Late Sinemurian age.

The age of the members of the Fjerritslev Formation, according to Michelsen (1978, fig. 3), are as follows:

F-Ia member:	Hettangian to Early Sinemurian
F-Ib member:	Late Sinemurian to earliest Early Pliensbachian
F-II member:	Early Pliensbachian to middle Late Pliensbachian
F-III member:	middle Late Pliensbachian to Toarcian
F-IV member:	(?latest Toarcian to) Aalenian

The early Middle Jurassic Mid-Kimmerian tectonic phase has important implications for the correlation of the Lower Jurassic sequences in the Danish Subbasin. During this tectonic episode the Ringkøbing-Fyn High was uplifted, resulting in the absence of Upper Triassic to lowermost Upper Jurassic strata on the high and along its margins (Michelsen 1978, Michelsen & Bertelsen 1979, Ziegler 1982). In combination with local salt-movements, this uplift may have produced the uppermost Lower Jurassic to lowermost Upper Jurassic hiatus in the Gassum-1 borehole (Sorgenfrei & Buch 1964, Larsen 1966). According to Frandsen (1988), an even longer hiatus, from the Lower Jurassic to Lower Cretaceous, is present in the Stenlille-2 borehole. No significant hiati were recorded from the Lower Jurassic in the Fjerritslev-2, and Frederikshavn-2 boreholes (Michelsen 1978).

Depositional environment

The Danish Subbasin existed as a major area of deposition and subsidence from the Late Permian to the Late Cretaceous. It is bordered to the north and east by the Fennoscandian Shield, and to the south it is separated from the North German Basin by the Ringkøbing-Fyn High (figs 1 and 2).

The distribution of sedimentary facies within the Jurassic was controlled primarily by eustatic changes in sea-level and fault-controlled subsidence (Hallam 1978, 1981, Hallam & Bradshaw 1979, Rolle, Koch, Frandsen & Surlyk 1979, Surlyk, Clemmesen & Larsen 1981).

The fine-grained clastic shelf sediments of the Fjerritslev Formation were derived from the Fennoscandian Shield, and probably transported into the basin by numerous small rivers (Larsen 1966).

Deposition of the Fjerritslev Formation started in the southern and central parts of the Danish Subbasin as the result of a global rise in sea level during Rhaetian to Hettangian times. Deltaic and littoral conditions prevailed to the northeast, in northern Jutland, and to the southeast, in the Danish-Polish Trough, until Late Sinemurian times when the Fjerritslev Formation succeeded the Gassum Formation in those areas. During deposition of the Fjerritslev Formation, the depocentre shifted eastwards from northwest Jutland to east of the Fjerritslev Fault (Michelsen 1975, 1978).

A warm and humid climate is indicated by the dominance of kaolinite in the clay minerals of the Fjerritslev Formation (Schmidt 1985a). According to Hallam (1985) the Early Jurassic climate in the region was subtropical to warm temperate, and “seasonally wet”.

Environmental interpretation of the Gassum-1 section

The depositional environment of the Fjerritslev Formation has been determined from detailed lithological, palaeontological and palynological investigations (Michelsen 1975, Pedersen 1986, Dybkjær 1988).

Michelsen (1975) studied the diversity and density of the Lower Jurassic ostracod faunas in the Gassum-1 borehole. The results are shown here in fig. 18.

The effects of the major “pulses” of sea-level rise during the Early Jurassic transgression have been studied by Pedersen (1986) and Dybkjær (1988). According to Hallam (1981) major “pulses” in sea-level rise occurred in the earliest Hettangian, the Early Sinemurian, the Late Sinemurian to Early Pliensbachian, the Late Pliensbachian and the Early Toarcian (see fig. 19). These regional, eustatic phases of sea level rise are recognizable both in the sedimentary sequences along the margin of the Danish Subbasin, and as minor lithological changes in the central parts of the basin (Bertelsen 1978, Michelsen 1978, Pedersen 1983, 1986). According to Pedersen (1986) an additional mid to late Sinemurian deepening event is recognizable in the Danish Subbasin.

Pedersen (1986) studied variations in the bivalve assemblages through the Fjerritslev Formation in Gassum-1 and compared the results with those from earlier studies of benthic foraminifera (Nørvang 1957) and ostracods (Michelsen 1975). The bivalve assemblages generally indicate an outer shelf depositional environment with normal salinities and normal to reduced levels of dissolved oxygen in the bottom waters.

A general upward decrease in the number of bivalve species, and a corresponding increase in the number of benthic foraminifera species (fig. 18; see also fig. 6, Pedersen 1986), were interpreted as indicating an increase in water depth related to the Early Jurassic transgression.

A distinct change in the bivalve assemblages from a "normal shale facies fauna" to a "restricted shale facies fauna" (Morris 1979, Pedersen 1986) was recorded in the Upper Sinemurian sequence (middle part of the F-Ib Member) (Pedersen 1986). The less diverse fauna is recorded throughout the Pliensbachian. The change was interpreted as a response to a reduction in the levels of dissolved oxygen in the bottom waters, probably related to the Late Sinemurian-Early Pliensbachian eustatic sea-level rise (Pedersen 1986). This change in the bivalve assemblages, close to the Sinemurian-Pliensbachian boundary, is contemporaneous with a distinct drop in the number of ostracod species and specimens, and a less pronounced decrease in the number of benthic foraminifera species (fig. 18; see also fig. 6, Pedersen 1986).

In the uppermost sample from the Fjerritslev Formation of Late Pliensbachian age, bivalves are totally lacking; the number of ostracod species decreases abruptly, but the number of benthic foraminifera species is relatively high. On the basis of the sparse benthic fauna and the occurrence of pyrite crystals on rare ostracod shells, Michelsen (1975) suggested that the environment was more reducing in nature. Pedersen (1986) related these observations to the initiation of the Early Toarcian deepening event. The observed faunal changes are not reflected by a significant lithological change.

Dybkjær (1988) interpreted the depositional environment of the Fjerritslev Formation in Gassum-1 on the basis of variations in the palynomorph assemblage. A dominance of terrestrial palynomorphs over marine palynomorphs throughout the formation confirmed earlier interpretations of a shelf environment. Minor variations between the main morphological groups of palynomorphs were recorded. Assumed minima of freshwater influence, recorded as maxima percentages of marine palynomorphs together with maxima of saccate pollen and minima of trilete spores, were recorded at four levels: 1) uppermost Rhaetian to lowermost Hettangian, 2) Lower Sinemurian, 3) the sequence from 1402m to 1341m b.r.t., referable, according to Sorgenfrei & Buch (1964), to the Upper Sinemurian, 4) the sequence 1341m to 1280m b.r.t., referable, according to Sorgenfrei & Buch (1964), to the Lower to Upper Pliensbachian. These levels were regarded as reflecting the earliest four phases of eustatic sea-level rise in the Early Jurassic, as recognized by Hallam (1981). Furthermore, a less pronounced increase in the relative abundance of marine palynomorphs was recognized in the uppermost sample of the Fjerritslev Formation in the Gassum-1 sequence, immediately below the latest Pliensbachian-Late Jurassic hiatus. This increase was interpreted as reflecting the start of the Early Toarcian rise in sea-level.

Depositional environment of the five members

The depositional environment of the five members of the Fjerritslev Formation is discussed below. The account is based on earlier studies by Michelsen (1975, 1978, 1989), Pedersen (1983, 1985, 1986), and Thomsen, Damtoft & Andersen (1987). The environmental interpretations are shown in fig. 19. The stratigraphical and geographical distribution of each member is shown in Michelsen (1978, figs 12,13, 1989, figs 4,5) and Pedersen (1983, figs 21, 22, 23; 1986, fig. 7).

F-Ia member:

The transition from the relatively coarse-grained Gassum Formation to the black silty claystones of the Fjerritslev Formation occurs within a very narrow interval in the cores from the Stenlille-1 and -2 boreholes, and is also evident on the petrophysical logs from several other boreholes. This transition is believed to correspond to the basal Hettangian transgression, probably caused by eustatic sea-level rise.

The F-Ia member is characterized by the greatest lithological variation encountered within the Fjerritslev Formation. The dominant lithologies are mudstone and silt-streaked mudstone interbedded with siltstone and limestone. The ostracod fauna shows increasing faunal density and diversity upwards, and the shells are well preserved. The depositional environment has been interpreted as shallow-water, well-oxidized, and with varying energy levels (Michelsen 1978).

F-Ib member:

This member comprises a relatively homogeneous dark grey mudstone. The ostracod faunal diversity and density are low, and the shells are poorly preserved. The member was probably deposited at greater depth, and farther offshore, than the F-Ia member; according to Michelsen (1975), reducing conditions prevailed.

The area of marine sedimentation expanded in the Late Sinemurian. During this time, the F-Ib member rapidly overstepped the Gassum Formation in the area north of the Fjerritslev Fault. According to Michelsen (1975, 1978) the Fjerritslev Formation did not overstep the Gassum Formation in the northernmost parts of the Danish Subbasin until the latest Sinemurian. This event which occurs during deposition of the middle part of F-Ib member, seems time-equivalent with the Late Sinemurian-Early Pliensbachian phase of eustatic sea-level rise.

F-II member:

The member consists of a laminated claystone with a relatively high sand and silt content. Numerous current and wave-generated structures are present. These suggest higher energy environments and shallower water depths than those of either F-Ib member or F-III member. The ostracod fauna is diverse and indicates a well oxygenated environment. The member has been recorded throughout the Danish Subbasin.

Petrophysical logs can be used to subdivide the member into three subunits which can be distinguished in several wells. This subdivision indicates that parts of the member (often the upper part) are locally missing. In the southern parts of the basin the top of the member is eroded and overlain unconformably by Middle- and Upper Jurassic formations.

F-III member:

This member is characterized by mudstone, in places slightly silty, and showing only minor bioturbation, indicating deposition in a generally deeper and lower energy environment than the F-II member. Due to erosion in the eastern and southern parts of the Danish Subbasin, the member is now restricted to the central and northern parts.

The lower part of the F-III member is characterized by a relatively high ostracod faunal diversity and density, indicating a well-oxygenated sea-floor. However, the upper part of the sequence is barren of benthonic fossils, indicating increasingly reduced conditions in the bottom waters.

The reducing conditions in the upper part of F-III member could be a reflection of the Early Toarcian sea-level rise, as recognized by Hallam (1963, 1967, 1981, 1987) and Vail & Todd (1981). This sea-level rise was accompanied by widespread deposition of anoxic shale facies throughout northwestern Europe, including the German Posidonia Shale (e.g. Seilacher 1982, Wille 1982, Riegel, Loh, Maul & Prauss 1986) and the Jet Rock of the British Jurassic (Hallam 1967, 1978, Morris 1980).

F-IV member:

This unit is generally coarser-grained than the F-III member. It is dominated by mudstone but includes siltstone and sandstone laminae, locally carbonate-cemented.

Based on the ostracod fauna, Michelsen (1978) interpreted the depositional environment as lagoonal, with strongly reducing conditions in the bottom waters. In the cores studied by Pedersen (1983), however, there is no direct evidence in either the trace fossil assemblage or the sedimentary facies for either a lagoonal environment or reducing conditions. A core referred to the F-IV member from the Farsø-1 borehole contains numerous burrows that are indistinguishable from trace fossils observed in the other fully marine members of the Fjerritslev Formation.

Organic matter

The amount, type and maturity of organic matter in the Fjerritslev Formation have been investigated by Lindgren & Thomsen (1982), Thomsen, Lindgren & Wrang (1983), Schmidt (1985b), Thomsen et al. (1987), and Damtoft, Andersen & Thomsen (1987).

The Total Organic Carbon content (T.O.C.) of this formation generally lies between 0.9 and 1.6% in the Danish Subbasin (Schmidt 1985b, Thomsen et al. 1987), but the open-marine shales of the Fjerritslev Formation in the Salt Dome Province of the Danish Central Trough contain an average of 2.1% T.O.C. (Damtoft et al. 1987).

The organic material is generally dominated by terrestrially-derived particles (Lindgren & Thomsen 1982, Schmidt 1985b), but significant variations have been recorded from borehole to borehole (Thomsen et al. 1987). The F-Ia, F-Ib and F-II members of the Fjerritslev Formation were deposited under generally oxic conditions and are dominated by highly oxidized gas-prone Type III kerogen (see definition of kerogen types in Tissot, Durand, Espitalié & Combaz (1974) and Tissot & Welte (1984)). The change towards more reducing conditions during deposition of the F-III and F-IV members is reflected by the presence of significant amounts of Type II-III and Type II kerogens. Significant variations in the quality of the hydrocarbon source-rock have, however, been recorded from borehole to borehole. These lateral variations were thought to reflect local facies control, which could have been caused by salt-induced movements producing local basin and swell topography. Anoxic conditions could thus have developed locally in rim-synclines (Thomsen et al. 1987).

The organic matter from the Fjerritslev Formation is generally immature with respect to hydrocarbon generation (Schmidt 1985b, Thomsen et al. 1983, 1987). According to Thomsen et al. (1983), the Thermal Alteration Index (T.A.I.) for the Rhaetian-Jurassic-Early Cretaceous deposits in the Danish Subbasin ranges between 1 and 2+ (using a modified version of the scales published by Staplin (1969) and Burgess (1974), with a scale ranging from 1 to 5, corresponding to the one used in the present study). Thomsen et al. (1983) observed an increase in maturity of the organic matter towards the centre of the Subbasin, reflecting increasing depth of burial. The lowest maturity values, indicating shallow burial, were encountered towards the Fennoscandian Border Zone and the Ringkøbing-Fyn High.

Materials and methods

Sampling

The study was based on 120 conventional core samples, 16 sidewall core samples, and 84 cuttings samples. The material from the Fjerritslev-2, Frederikshavn-2, and Gassum-1 boreholes was made available by the Geological Survey of Denmark, and that from the Stenlille-2 borehole was provided by Dansk Olie & Gasproduktion A/S. Regularly spaced samples were taken from the cored intervals, or selected from sidewall cores or cuttings where conventional cores were not available. All significant lithological variations observed in the cores were sampled; representative cuttings material was selected on the basis of size and coherency.

Palynological preparation

The technique adopted was that used in the preparation of material from the Gassum-1 borehole (Dybkjær 1988).

About 4g of material were processed from each of the core and sidewall core samples. 2–4g samples were taken from cuttings material, depending on the availability of suitable fragments. In order to remove surficial drilling mud contamination, cuttings were carefully washed with distilled water. All samples were subsequently processed using an identical procedure: 10% HCl (30 min to 24 hours), 40% HF (100°C, 2×2 hours), 10% HCl (100°C, 30 min), followed by washing in distilled water.

Prior to further treatment (including oxidation or sieving) one or two slides of the total assemblage of organic matter ("kerogen") in each sample were made.

The remaining residue was subsequently sieved through a 10 micron mesh nylon filter and temporary water-suspended mounts examined under the microscope. All samples were then treated with nitric acid (HNO3) (65%) for one minute in order to remove concentrations of pyrite (especially common within the sacci of bisaccate pollen grains). The samples were then washed with distilled water on a 10 micron mesh filter.

Heavy liquid separation was found to be necessary because of the amount of mineral matter that had survived HCl and HF treatment. Zinc chloride (specific gravity 1.9g/cm^3) was added to the residue, which was then thoroughly stirred and centrifuged. The supernatant portion containing the organic matter was decanted, and fresh $ZnCl_2$ added to the remaining portion which was re-stirred and re-centrifuged. This procedure proved very effective. The $ZnCl_2$ containing the heavy fraction was examined prior to disposal to check for any potential loss of organic material. The residues were finally washed with distilled water on a 10 micron mesh filter to remove any traces of chemicals. Two to four glycerine-mounted slides were prepared for each sample.

Total organic carbon (T.O.C.) measurements

The total content of organic carbon (weight percent) of all core samples and sidewall core samples was measured at the Geological Survey of Denmark.

A minimum of 1g of material from each sample was crushed to a maximum grain-size of 250 microns; 200 mg (+/− 0.5%) of the pulverized sample was placed in a crucible. A few drops of ethanol were added, followed by ten drops of concentrated hydrochloric acid (HCl), and the compound was heated to about 120°C for 30 minutes. After cooling, the HCl treatment was repeated twice to ensure removal of carbon bonded as carbonate. The sample was placed overnight in an oven at a temperature of 120°C. The organic carbon content was then measured in a LECO oven (IR-212 carbon 784–400 System). The crucible containing the dry, acid-treated sample was placed in the oven which was heated to 2000°C; oxygen was added to ensure complete combustion of the organic material. Evolved CO_2 was measured and converted into weight percent organic carbon. The results are presented in appendix A to E, and in figs 12, 14, 16 and 18.

Thermal Alteration Index (T.A.I.)

The colour of organic material changes from bright yellow to brown and black with increasing thermal alteration (e.g. Schopf 1948, Correia 1967, Burgess 1974, Combaz 1975, Staplin 1969, 1977). Several indices and scales for thermal alteration of organic sedimentary particles have been presented, e.g. Staplin (1969), Burgess (1974), Dow (1977), and Batten (1980, 1981, 1982).

Response to thermal alteration varies with the type of kerogen particles. Generally the colours of spores and pollen, particularly unornamented species, are considered to be the most sensitive and reliable indicators of maturity, especially at the immature end of the thermal scale; dinoflagellate cysts tend to be less reliable (Staplin 1969, Batten 1981, Venkatachala 1981a).

In the present study a pollen/spore colour standard card (produced by D.L. Pearson, Phillips Petroleum Company) was used. The colour scale is correlated to a T.A.I. scale with values from 1 to 5, subdivided into a total of 11 categories. The use of a standard colour scale ensured an objective and uniform T.A.I. determination throughout the study.

The T.A.I. values were determined on the basis of one specific spore species, *Deltoidospora toralis* (Leschik 1955) Lund 1977. This species is well suited for this purpose, being well-represented in nearly all studied samples, and having a relatively thin, unsculptured exine. T.A.I. values were determined for every specimen of *Deltoidospora toralis* observed during counting of palynomorphs for biostratigraphical purposes. The results are presented in fig. 21.

Microscopic examination and counting

The most suitable samples and slides were chosen for counting by examination under a Leitz Wetzlar light microscope. They were selected to provide a representative distribution of biostratigraphical and palynofacies observations, and to take into account all the major lithological variations present in the sequence. Some of the samples are barren of palynomorphs, and were thus only used for counting kerogen particles. The location of the samples chosen for counting are shown in figs. 7–10. A general lithological description of each sample is given in appendices A-D.

Biostratigraphical counting

Biostratigraphical counting was carried out in preparations from both core and cuttings samples. The counting was carried out at a magnification of x400, and at least 250 miospores were recorded for each sample (independently of the number of aquatic palynomorphs). These counts were used to determine the percentage composition of the palynomorph assemblage. The remainder of the slide (and in the case of a sparse assemblage, a second slide) was then thoroughly examined in order to assess the total diversity of the assemblage present. Additional species observed during this procedure were recorded as "< 1%" (see range-charts, tables 1–6).

Counting of kerogen particles

Counting of kerogen particles was only performed on core and sidewall core samples, as it is generally impossible to discriminate between caved and in situ kerogen particles. Furthermore, biostratigraphical evidence clearly indicated caving in several of the cuttings samples (particularly those from the Frederikshavn-2 borehole).

At least 500 particles were counted in each sample. The counting was carried out at a magnification of x250 and the results were used to determine the percentage composition of the kerogen assemblage (see table 7 for the categorization of the kerogen particles). The whole slide was scanned in order to provide a qualitative assessment of the degree of sorting and state of preservation of the palynomorphs. The results are presented in appendix A to E, and in figs 12, 14, 16 and 18.

The slides counted from the Gassum-1 borehole were those used in the earlier biostratigraphical study by Dybkjær (1988), together with a few additional slides from samples that were barren of palynomorphs.

The biostratigraphical investigation

Introduction

Although the palynology of the Early Jurassic Epoch has been studied by a number of workers, erection of a detailed spore/pollen zonation for the NW European region has not proved successful (see for example the zonations in fig. 6). The reason for this is probably that floral evolution during the Early Jurassic was slow and gradual, and that the dominant spore/pollen species ranged throughout that epoch.

A combination of a spore/pollen zonation and a dinoflagellate cyst zonation turned out to be very useful in the study reported here. The use of dinoflagellate cysts made the resulting zonation and dating more detailed than would have been possible using only the spores and pollen.

The use of dinoflagellate cysts in the zonation of Lower Jurassic sequences is a relatively new approach (Williams 1977, Morbey 1978, Woollam & Riding 1983). This fossil-group seems to have some advantages compared with the miospore-group:

1) the single species often appear in large numbers
2) they generally show limited, and well-defined ranges
3) both their first and last appearances are used as stratigraphically important events.

The only clear disadvantage is that they are essentially restricted to marine sediments.

Results of the biostratigraphical counting

The results of the biostratigraphical counting are shown in the range-charts (tables 1–6). All recorded "in situ" species are mentioned in the systematic section, including comments on some species. The studied sequences generally contained a moderately preserved and diverse assemblage of spores, pollen and aquatic palynomorphs. Evidence of reworking is only sporadic, while caving turned out to be a general feature in the cuttings samples, especially in the Frederikshavn-2 borehole. Caving in the cuttings samples from the Fjerritslev-2 and Stenlille-2 boreholes was not recorded with certainty.

Records of reworked palynomorphs

Reworked Carboniferous spores are well known from Upper Triassic and Jurassic sequences in the Danish area and adjacent regions: from the Rødby-1 borehole (Lund 1977), from several boreholes in NW Scania (Guy-Ohlson, Lindqvist & Norling 1987), and from Lower to Middle Jurassic sequences on Bornholm (Hoelstad 1985, Nielsen & Koppelhus 1991).

Presumed reworked Carboniferous spores were recorded sporadically in the present study. The recorded spores were referred to the genera *Lycospora* Schopf, Wilson & Bentall 1944 emend. Potonié & Kremp 1954, *Densosporites* Berry 1937 emend. Potonié & Kremp 1954 (several specimens), *Platyptera* Naumova 1934 ex. Naumova 1938, and *Murospora* Somers 1952. Most of the specimens are corroded, and show a darker colour than the "in situ"-palynomorphs, but others are rather well preserved.

Two reworked acritarchs were also recorded. One was referred to the species *Diexallophasis denticulata* (Stockmans & Willière 1963) Loeblich 1970 and the other to the genus *Multiplicisphaeridium* Staplin 1961 emend. Staplin, Jansonius & Pocock 1965. Both types are known from Silurian and Devonian strata in North America and Europe.

Reworking of material from other levels was not recorded with certainty.

Records of caved palynomorphs

Spores, pollen and dinoflagellate cysts assessed as caved were recorded from several cuttings samples, especially from the Frederikshavn-2 borehole.

Among the presumed caved dinoflagellate cyst species are: *Odontochitina operculata* (Wetzel 1933) Deflandre & Cookson 1955, *Sirmiodinium grossii* Alberti 1961 emend. Warren 1973, *Kleithriasphaeridium readei* (Davey & Williams 1966) Davey & Verdier 1976, *Spiniferites ramosus* (Ehrenberg 1838) Loeblich & Loeblich 1966, and *Protoellipsodinium spinosum* Davey & Verdier 1971.

Presumed caved spores and pollen include the following: *Concavissimisporites variverrucatus* (Couper 1958) Brenner 1963, *Foveosporites labiosus* Singh 1971, *Clavifera triplex* (Bolchovitina 1953) Bolchovitina 1966, *Cicatricosisporites hallei* Delcourt & Sprumont 1955, *Gleicheniidites* cf. *bulbosus* Kemp 1970, *Parvisaccites radiatus* Couper 1958, and *Contignisporites glebulentus* Dettmann 1963 emend. Filatoff & Price 1988.

Gleicheniidites senonicus Ross 1949 is very common in Lower Cretaceous strata. This species was recorded sporadically from core-samples referred to the Early and Middle Jurassic in the present study (see discussion in the systematic section). The high relative abundance of this species recorded in samples Frh-18,s and Frh-20,s, however, is probably due to caving, as high relative abundances of this species are only known from Lower Cretaceous strata.

All these spore/pollen species, except *Contignisporites glebulentus,* have been recorded from the Lower Cretaceous sequence in the Frederikshavn-1 borehole (Elly Andersen, pers. comm., 1988). Furthermore, the mentioned dinoflagellate cyst species as well as the spores and pollen, are generally known as Early Cretaceous types (see Couper 1958, Döring 1965, 1966, Kemp 1970, Dörhöfer 1977, 1979, Heilmann-Clausen 1987). If the terrestrial and marine palynomorphs are presumed to originate from the same level, their common occurrence indicates a possible age range from the Barremian to immediately above the Aptian-Albian boundary. The age is limited (downwards) by the occurrence of *Odontochitina operculata,* and (upwards) by *Sirmiodinium grossii* (see the range of these species in northwestern Europe in Heilmann-Clausen (1987, fig.4).

Systematics

All palynomorph taxa presumed to be "in situ", or to be reworked from older strata, are listed in this section. Species that are presumed to be caved (see p. 16) are not considered here, while species which may be caved, but which are known to occur sporadically in Lower Jurassic deposits, are included.

Taxonomic references to genera and higher taxa are not included but are given by Dettmann (1963). Only synonyms from the most important references are presented.

The holotypes of species marked with an asterisk have been investigated by the author. New photographs of these holotypes are presented on plates 21 and 22.

The orientation of the grains when measuring their size is in accordance with Schulz (1967, text fig. 1). The stated total dimensions include sculptural elements. Where more than one specimen has been measured, the minimum value (a), mean value (b), and maximum value (c) are stated as follows: a (b) c (n specimens).

Spores and pollen

Anteturma ***Sporites*** H. Potonié 1893
Turma ***Triletes*** (Reinsch 1881) Dettmann 1963
Subturma ***Azonotriletes*** (Luber 1937) Dettmann 1963
Infraturma ***Laevigati*** (Bennie & Kidston 1886) R. Potonié 1956

Genus *Deltoidospora* Miner 1935 emend. Danzé-Corsin & Laveine 1963

Deltoidospora toralis (Leschik) Lund
Pl.1, fig. 1

1955: *Laevigatisporites toralis* – Leschik, p.12; pl.1, figs 1, 2.
1958: *Concavisporites toralis* (Leschik 1955) – Nilsson, p.34; pl.1, figs 12, 13.
1977: *Deltoidospora auritora* (Reinhardt 1962) – Lund, p.50; pl.1, fig.5.
1977: *Deltoidospora toralis* (Leschik 1955) – Lund, p.49; pl.1, figs 2, 3.

Remarks: This species was used to estimate the "Thermal Alteration Index" (T.A.I.), see p. 14.

Deltoidospora minor (Couper) Pocock
Pl.1, fig. 2

1953: *Cyathidites minor* – Couper, p.28; pl.2, fig. 13.
1970: *Deltoidospora minor* (Couper 1953) – Pocock, p.28; pl.5, fig. 3.

Remarks: This species differs from *Deltoidospora toralis* in having no proximal kyrtome, and from *Deltoidospora australis* in having a spore-diameter < 57 microns (Couper 1953).

Deltoidospora cf. *minor* (Couper) Pocock
Pl.1, fig. 3

Description: Trilete spore with a triangular amb, straight to slightly concave or convex sides and slightly pointed angles. The trilete mark has a distinct labrum, the sutures are more or less sinuous, and extend for ¾ to ⅘ of the spore radius. The exine is laevigate, 1–2 microns thick.
Equatorial diameter: 21 (23) 25 microns (3 specimens)
Remarks: These specimens differ from *Deltoidospora minor* (Couper 1953) Pocock 1970 in having pointed angles, sinuous sutures, a slightly thicker exine, and a smaller size.

Deltoidospora australis (Couper) Pocock

1953: *Cyathidites australis* – Couper, p.27; pl.2, fig. 11.
1970: *Deltoidospora australis* (Couper 1953) – Pocock, p.27.

Genus *Cibotiumspora* Chang 1965

Cibotiumspora jurienensis (Balme) Filatoff
Pl.1, fig. 4

1957: *Concavisporites jurienensis* – Balme, p.20; pl.2, figs 30, 31.
1958: *Auritulina intrastriatus* – Nilsson, p.36; pl.1, fig. 17.
1975: *Cibotiumspora jurienensis* (Balme 1957) – Filatoff, p.61; pl.10, figs 8–13.

Genus *Tripartina* Maljavkina 1949 emend. Potonié 1960

Tripartina variabilis Maljavkina
Pl.1, fig. 5

1949: *Tripartina variabilis* – Maljavkina, p.49; pl.7, fig. 11.

Remarks: Differs from *Deltoidospora* cf. *minor* in having narrow, sinuous channels at the proximal surface, perpendicular to the rays of the trilete mark.

Genus *Intrapunctisporis* Krutzsch 1959

Intrapunctisporis toralis (Leschik) Lund
Pl.1, figs. 6, 7

1955: *Punctatisporites toralis* – Leschik, p.19; pl.2, fig. 11.
1977: *Intrapunctisporis toralis* (Leschik 1955) – Lund, p.51; pl.1, fig. 8.

Genus *Punctatisporites* Ibrahim 1933 emend. Potonié & Kremp 1954

Punctatisporites globosus (Leschik) Lund
Pl.1, fig. 8

1955: *Laevigatisporites globosus* – Leschik, p.11; pl.1, fig. 5.
1958: *Todisporites minor* – Couper, p.135; pl.16, figs 9, 10.
1977: *Punctatisporites globosus* (Leschik 1955) – Lund, p.52; pl.1, fig. 11.

Punctatisporites major (Couper) Kedves & Simoncsics

1958: *Todisporites major* – Couper, p.134; pl.16, figs 6–8.
1964: *Punctatisporites major* (Couper 1958) Kedves & Simoncsics, p.13; pl.3, figs 1, 2.

Genus *Retusotriletes* Naumova 1953

Retusotriletes mesozoicus Klaus

1960: *Retusotriletes mesozoicus* – Klaus, p.120; pl.28, fig. 6.

Retusotriletes cf. *mesozoicus* Klaus
Pl.1, fig. 9

Remarks: Only one specimen recorded. This specimen only differs from *Retusotriletes mesozoicus* Klaus 1960 in being distinctly larger. The recorded specimen is 75 microns in spore-diameter, while the size-range for *Retusotriletes mesozoicus* was given as 35–55 microns (Klaus 1960).

Genus *Calamospora* Schopf, Wilson & Bentall 1944

Calamospora tener Leschik emend. Mädler
Pl.1, fig. 10

1955: *Laevigatisporites tener* – Leschik, p.13; pl.1, fig. 20.
1964b: *Calamospora tener* Leschik 1955 emend. Mädler, p.92; pl.8, fig. 2.

Calamospora sp. 1

Remarks: Identical to *Calamospora tener* apart from a thicker exine (about 1 micron), resulting in less tendency to folding. See photograph in Dybkjær (1988, pl.1, fig. 11, *Calamospora* sp.).

Genus *Stereisporites* Pflug 1953

Stereisporites stereoides (Potonié & Venitz) Pflug
Pl.1, fig. 11

1934: *Laevigatisporites stereoides* – Potonié & Venitz, p.11; pl.1, figs 4, 5.
1953: *Stereisporites stereoides* (Potonié & Venitz 1934) – Pflug, in Thomson & Pflug (1953), p.53; pl.1, figs 64–73.

Stereisporites antiquasporites (Wilson & Webster) Dettmann
Pl.1, fig. 12

1946: *Sphagnum antiquasporites* – Wilson & Webster, p.273; fig. 2.
1963: *Stereisporites antiquasporites* (Wilson & Webster 1946) – Dettmann, p.25; pl.1, figs 20, 21.

Stereisporites punctus (Klaus) Krutzsch
Pl.1, figs 13, 14

1960: *Distalanulisporites punctus* – Klaus, p.133; pl.28, fig. 8.
1963: *Stereisporites* (*Distalanulisporites*) *punctus* (Klaus 1960) Krutzsch, p.19.

Stereisporites cicatricosus (Rogalska) Schulz

1954: *Sporites cicatricosus* – Rogalska, p.44; pl.12, fig. 11.
1967: *Stereisporites* (*Rogalskaisporites*) *cicatricosus* (Rogalska 1954) – Schulz, p.557; pl.1, figs 8, 9.

Stereisporites aulosenensis (Schulz) Schulz
Pl.2, fig. 1

1966: *Stereisporites* (*Sculptisporis*) *aulosenensis* (Schulz 1967) Schulz, p.77; pl.3, figs. 4–6.
1967: *Camarozonosporites* (*Camarozonosporites*) *aulosenensis* – Schulz, p.573; pl.7, figs 12–14.

Remarks: This species differs from *Stereisporites hauterivensis* Schulz 1966 in having a thinner exine, a larger, more rugulate sculpturing, and a larger size.

Stereisporites cf. *seebergensis* Schulz
Pl.2, fig. 2

Remarks: These specimens differ from *Stereisporites seebergensis,* originally described by Schulz (in Döring, Krutzsch, Schulz & Timmermann (1966)), in having a thinner exine, and a less distinct curvatura perfecta.

Stereisporites hauterivensis Döring
Pl.2, fig. 3

1966: *Stereisporites* (*Sculptisporis*) *hauterivensis* Döring, in Döring et al. (1966), p.77; pl.3, figs 1–3.

Infraturma ***Apiculati*** (Bennie & Kidston 1886) R. Potonié 1956

Genus *Trachysporites* Nilsson 1958

Trachysporites fuscus Nilsson
Pl.2, figs 4, 5; Pl.21, figs 1, 2, 7 (the holotype), fig. 2

1958: *Trachysporites fuscus* – Nilsson, p.38; pl.2, fig. 1 (*)
1958: *Trachysporites tuberosum* – Nilsson, p.39; pl.2, fig. 2 (*)
1958: *Trachysporites* sp.A – Nilsson, p.40; pl.2, fig. 6 (*)

Trachysporites asper Nilsson
Pl.2, fig. 6; Pl.21, fig. 3 (the holotype)

1958: *Trachysporites asper* – Nilsson, p.39, pl.2, fig. 3 (*)

Trachysporites sparsus (Bharadwaj & Singh) Lund
Pl.2, figs 7, 8

1964a: *Anemiidites spinosus* – Mädler, p.180; pl.2, fig. 11.
1977: *Conbaculatisporites spinosus* (Mädler 1964) – Lund, p.56; pl.2, figs 11a, b.

Genus *Conbaculatisporites* Klaus 1960

Conbaculatisporites mesozoicus Klaus
Pl.2, fig. 9

1960: *Conbaculatisporites mesozoicus* – Klaus, p.126; pl.29, fig. 15

Conbaculatisporites spinosus (Mädler) Lund
Pl.2, fig. 10

1964a: *Anemiidites spinosus* – Mädler, p.180; pl.2, fig. 11.
1977: *Conbaculatisporites spinosus* (Mädler 1964) – Lund, p.56; pl.2, figs 11a, b.

Conbaculatisporites sp. 1
Pl.3, fig. 7

Description: Trilete spore with a subtriangular amb, straight to slightly convex sides and rounded angles. The trilete mark is distinct; the sutures extend for ⅘ of the spore radius. The exine is 2–3 microns thick, and sculptured with scattered 3–6 microns high baculae and spinae.
Equatorial diameter: about 61 microns (1 specimen).
Remarks: Only one specimen was recorded, from sample Frh-16,c, one of the samples not counted. This specimen is therefore not mentioned in the range-chart. Because of secondary folding, the size could not be measured precisely.

Genus *Baculatisporites* Thomson & Pflug 1953 emend. Krutzsch 1967

Baculatisporites wellmanii (Couper) Krutzsch
Pl.2, figs 11, 12

1953: *Osmundacidites wellmanii* – Couper, p.20; pl.1, fig. 5.
1959: *Baculatisporites wellmanii* (Couper 1953) – Krutzsch, p.142.

Baculatisporites comaumensis (Cookson) Potonié
Pl.3, fig. 6

1953: *Triletes comaumensis* – Cookson, p.470; pl.2, figs 27, 28.
1956: *Baculatisporites* (*Triletes*) *comaumensis* (Cookson 1953) – Potonié, p.33.

Baculatisporites oppressus (Leschik) Lund
Pl.3, fig. 3

1955: *Cyclogranisporites oppressus* – Leschik, p.17; pl.1, fig. 23.
1977: *Baculatisporites oppressus* (Leschik 1955) – Lund, p.57; pl.2, figs 15a, b.

Cf. *Baculatisporites* sp.
Pl.5, fig. 8

Description: Trilete spore with a subcircular amb. The trilete mark is distinct; the sutures extend for ⅘ of the spore radius, and are bordered by a 3–4 microns wide labrum. The exine is 2–3 microns thick, and sculptured with closely spaced verrucae and baculae, ½ – 2 microns wide and 1–2 microns high.
Equatorial diameter: about 66 microns (1 specimen).
Remarks: Only one specimen was recorded from sample Fj-16,c. The exact dimensions could not be measured because of secondary folding.

Genus *Apiculatisporis* Potonié & Kremp 1956

Apiculatisporis ovalis (Nilsson) Norris
Pl.3, figs 1, 2, 4, 5; Pl.21, figs 5, 6 (the holotype), fig. 8

1958: *Acanthotriletes trigonus* – Nilsson, p.41; pl.2, fig. 7 (*)
1958: *Acanthotriletes ovalis* – Nilsson, p.40; pl.2, figs 8, 9 (*)
1965: *Apiculatisporis ovalis* (Nilsson 1958) – Norris, p.245; figs 2b, 18, 22, 23

Apiculatisporis parvispinosus (Leschik) Schulz

1955: *Apiculatisporites parvispinosus* – Leschik, p.17; pl;2, figs 1–4.
1962: *Apiculatisporis parvispinosus* (Leschik 1955) – Schulz, p.312; pl.2, figs 16–19.

Remarks: This species has a mixed trilete-monolete mark.

Genus *Anapiculatisporites* Potonié & Kremp 1954

Anapiculatisporites telephorus (Pautsch) Klaus
Pl.3, figs 8, 9

1958: *Sporites telephorus* – Pautsch, p.323; pl.1, fig. 12.
1960: *Anapiculatisporites telephorus* (Pautsch) – Klaus, p.124; pl.29, fig. 17.

Anapiculatisporites spiniger (Leschik) Reinhardt

1955: *Apiculatisporites spiniger* – Leschik, p.18; pl.2, figs 6, 7.
1962: *Anapiculatisporites spiniger* (Leschik 1955) – Reinhardt, p.707, pl.1, fig. 8.

Genus *Taurocusporites* Stover 1962

Taurocusporites verrucatus Schulz
Pl.3, figs 10, 11

1967: *Taurocusporites verrucatus* – Schulz, p.566; pl.4, figs 14–16.

Genus *Foraminisporis* Krutzsch 1959

Foraminisporis jurassicus Schulz
Pl.3, fig. 12

1967: *Foraminisporis jurassicus* – Schulz, p.564; pl.4, figs 1–3; pl.23, fig. 3.

Genus *Manumia* Pocock 1970

Manumia delcourtii Pocock comb. nov. et emend.
Pl.4, fig. 5

1967: *Trilites minutus* (Bolchovitina 1961) – Mai, in Schulz 1967, p.562; pl.3, figs 7, 8.
1970: *Concavissimisporites delcourtii* – Pocock, p.41; pl.7, fig. 9
1970: *Concavissimisporites southeyensis* – Pocock, p.41; pl.7, fig. 10
1985: *Manumia variverrucata* (Couper 1958) comb. nov. et emend. – Hoelstad, p.123; pl.2, figs 15–17

Emended diagnosis: Trilete spore with subtriangular amb, straight to slightly convex or concave sides and rounded angles. The trilete mark is distinct, bordered by a labrum, 2–4 microns thick. The trilete mark is frequently gaping. The sutures extend for about 2/3 of the spore radius. The exine is 1–2 microns thick, sculptured on the proximal as well as the distal side, with scattered, irregularly shaped verrucae and granulae, 0.5–3 microns wide, and 0.5–2 microns high. Some grains have a sculpture of verrucae of about similar size, others have a mixture of granulae and verrucae. The sculptural elements are irregularly spaced, 1–15 microns apart. The density of the elements varies from specimen to specimen, but they are not as sparse and widely scattered as on *Manumia irregularis* Pocock 1970.

Equatorial diameter (in the present study): 44 (49) 62 microns (10 specimens). The species *Manumia delcourtii* includes, however, specimens of a wide size-range, including some formerly referred to the species *Trilites minutus* (38–44 microns), and to *Concavissimisporites delcourtii* (72–75 microns).

Remarks: The genus *Manumia* Pocock 1970 comprises trilete spores with straight to slightly convex sides and a sculpturing of scattered verrucae or spines.

None of the three genera *Concavissimisporites* (Delcourt & Sprumont 1955) Delcourt, Dettmann & Hughes 1963, *Concavisporites* Pflug 1953 nor *Trilites* Cookson ex Couper 1953 seem suitable for the specimens referred to *Manumia delcourtii* in this study. According to Delcourt et al. (1963), the genus *Concavissimisporites* comprises trilete spores with concave to almost straight sides and a sculpturing of evenly distributed verrucae. The spores are generally relatively large (70–90 microns). The genus *Concavisporites* Pflug 1953 seems to be an extremely broadly defined genera. It has been used to encompass smooth as well as closely sculptured spores, generally concave, and with a wide span of size-ranges (Pflug 1953, Couper 1958, Pocock 1962). Specimens referred to the above mentioned two genera are generally recorded from Lower Cretaceous to Tertiary strata.

Hoelstad (1985) transferred the species *Concavisporites variverrucatus* Couper 1958 to the genus *Manumia* Pocock 1970, thus erecting the new combination *Manumia variverrucata.* This new combination seems inappropriate, as the species *Concavisporites variverrucatus* Couper 1958 comprises spores with distinctly concave sides and a sculpturing of relatively closely arranged, evenly spaced verrucae (see Couper 1958, Pl. 22, fig. 4 (the holotype), fig. 5). Although Couper (1958) states that the size and spacing of the verrucae on this species exhibit great variation, it is felt by the present author that it should be restricted to spores with the above mentioned main characteristics.

The genus *Trilites* Cookson ex Couper 1953 is too broadly defined to be useful. The species *Trilites minutus* (Bolchovitina 1961) Mai, in Schulz 1967, comprises relatively small specimens of the *Manumia*-type (diameter range 38–44 microns).

The three species *Trilites minutus* (Bolchovitina 1961) Mai, in Schulz 1967, *Concavissimisporites southeyensis* Pocock 1970 and *Manumia variverrucata* Hoelstad 1985 are treated as juniorsynonyms for *Manumia delcourtii* as these species fall within the variation of *Manumia delcourtii* according to the emended diagnosis.

Cf. *Manumia* sp. 1
Pl.4, fig. 6

Remarks: Only a single specimen of this type was found, in sample Fj-32,s, one of the samples not counted. It is thus not shown in the range-charts. It has a distinct proximal kyrtome, like *Deltoidospora toralis*, but, in addition, is sculptured with irregularly spaced verrucae, like the specimens referred to *Manumia.*

Genus *Uvaesporites* Döring 1965

Uvaesporites argenteaeformis (Bolchovitina) Schulz
Pl.4, figs 1–4, 7

1953: *Stenozonotriletes argenteaeformis* – Bolchovitina, p.51; pl.7, fig. 9.
1962: *Triletes reissingeri* – Reinhardt, p.707; pl.2, figs 1, 2.
1967: *Uvaesporites argenteaeformis* (Bolchovitina 1953) – Schulz, p.560; pl.2, figs 10, 11; pl.23, fig. 2.
1977: *Uvaesporites reissingeri* (Reinhardt 1962) – Lund, p.60; pl.3, fig. 14.

Genus *Polypodiisporites* Potonié & Gelletich 1933 ex Potonié 1956

Remarks: This genus comprises spores with a mixed trilete-monolete aperture.

Polypodiisporites polymicroforatus (Orlowska-Zwolinska) Lund 1977
Pl.4, figs. 8, 9

1966: *Foveosporites polymicroforatus* – Orlowska-Zwolinska, p.1011; pl.2, figs 15, 16; pl.3, fig. 19–21.
1967: *Convolutispora microrugulata* – Schulz, p.570; pl.6, figs 7–9.
1967: *Convolutispora microfoveolata* – Schulz, p.571; pl.6, figs 10, 11.
1977: *Polypodiisporites polymicroforatus* – Lund, p.32; pl.3, figs 6a, b.

Polypodiisporites polymicroforatus (Orlowska-Zwolinska) Lund 1977
Pl.4, figs 8, 9

1962: *Verrucososporites ipsviciensis* – de Jersey, p.7; pl.2, figs 8–10.
1965: *Polypodiisporites ipsviciensis* (de Jersey 1962) – Playford & Dettmann, p.150; pl.15, figs 39–40.

Genus *Leptolepidites* Couper 1953 emend. Schulz 1967

Leptolepidites major Couper
Pl.4, figs 11, 12; Pl.5, figs 1, 2

1958: *Leptolepidites major* – Couper, p.141; pl.21, figs 7–8.

Leptolepidites sp.1
Pl.5, figs 3, 4

Description: Trilete spore with a subtriangular amb, straight to slightly convex sides and rounded angles. The trilete mark is rather indistinct; the sutures extend for about ⅘ of the spore radius. Proximally the exine is

laevigate. Distally and equatorially the exine is sculptured with closely spaced verrucae, 3–6 microns wide and 1–3 microns high.
Equatorial diameter: 20 microns (1 specimen).
Remarks: Only one specimen was recorded, from sample St-16,w.

Leptolepidites sp.2
Pl.5, figs 5, 6

Description: Monolete spore with an elliptical equatorial outline. The monolete mark extends along the entire spore-length. The exine is laevigate on the proximal surface, while on the distal and equatorial surface it is sculptured with closely spaced verrucae of variable size, between 1 and 10 microns in diameter, largest in the equatorial region, and 2–3 microns high.
Dimensions: length: 26 microns; width: 21 microns (1 specimen).
Remarks: Only one specimen was recorded, in sample Frh-22,s. This specimen is referred to the Anteturma Apiculati, in spite of the monolete mark, because of its assumed relation with the genus *Leptolepidites*.

Infraturma ***Murornati*** Potonié & Kremp 1954

Genus *Lycopodiumsporites* Thiergart 1938 ex. Delcourt & Sprumont 1955

Lycopodiumsporites semimuris Danzé-Corsin & Laveine
Pl.5, figs 9, 10

1963: *Lycopodiumsporites semimuris* – Danzé-Corsin & Laveine, p.79; pl.6, figs. 15a, b, 16a, b, 17a, b, c.

Lycopodiumsporites austroclavatidites (Cookson) Potonié
Pl.5, figs 12, 13

1953: *Lycopodium austroclavatidites* – Cookson, p.269; pl.2, fig. 35.
1956: *Lycopodiumsporites* (al. *Lycopodium*) *austroclavatidites* (Cookson 1953) – Potonié, p.46.
1963: *Retitriletes austroclavatidites* (Cookson 1953) – Döring, Krutzsch, Mai & Schulz, in Krutzsch (1963, Lief.II), p.16.

Lycopodiumsporites clavatoides (Couper) pro parte emend. Tralau

1958: *Lycopodiumsporites clavatoides* – Couper, p.132; pl.15, figs 10–13.
1963: *Retitriletes clavatoides* (Couper 1958) – Döring, Krutzsch, Mai & Schulz, in Krutzsch (1963, lief.II), p.16.
1968: *Lycopodiumsporites clavatoides* (Couper 1958) pro parte emend. – Tralau, p.49; pl.1, figs 3–5.

Lycopodiumsporites gracilis Nilsson
Pl.5, figs 11, 14

1958: *Lycopodiumsporites gracilis* – Nilsson, p.46; pl.2, figs 12, 13.

Lycopodiumsporites sp.1.
Pl.6, figs 1–3

Description: Trilete spore with subtriangular to subcircular amb, and slightly convex sides. The trilete mark is distinct, bordered by a thin labrum, about 1 micron wide. The sutures extend for the entire radius of the spore, exclusive of the reticulum. On the proximal side of the spore the exine is laevigate, while the exine equatorially and distally is sculptured with a distinct reticulum. The muri are about 1 micron wide and about 5 microns high. The luminae are 7–12 microns in diameter. The meshes of the reticulum overlap and interlock each other.
Equatorial diameter: about 40 microns (1 specimen).
Remarks: Only one specimen was recorded, from sample Fj-16,c. The recorded specimen differs from the other species of *Lycopodiumsporites* in having a reticulum built up of interlocking meshes. The species *Retitriletes concavus* erected by Schulz (1966) is also characterized by having interlocking meshes, but it is further characterized by concave sides, and muri only 1–2 microns high. Furthermore the reticulum of the species recorded in the present study seems more regular than the specimens illustrated by Schulz (1966, textfig. 1; pl.2, figs 7–9).

Genus *Semiretisporis* Reinhardt 1962

Semiretisporis gothae Reinhardt
Pl.6, fig. 4

1962: *Semiretisporis gothae* – Reinhardt, p.709; pl.2, figs 5, 6.

Genus *Costatisulcites* Scheuring 1978

Costatisulcites cf. *ovatus* Scheuring
Pl.6, fig. 5

Remarks: Only one, very corroded specimen was recorded, from sample Fj-4,c. It is therefore not possible to compare it in detail with the species *Costatisulcites ovatus* erected by Scheuring (1978). The recorded specimen may be reworked.

Genus *Lycopodiacidites* Couper 1953

Lycopodiacidites rugulatus (Couper) Schulz

1958: *Perotriletes rugulatus* – Couper, p.147; pl.25, figs 7, 8.
1967: *Lycopodiacidites rugulatus* (Couper 1958) – Schulz, p.573; pl.7, figs 15, 16.

Genus *Tigrisporites* Klaus 1960

Tigrisporites scurrandus Norris
Pl.6, figs 6, 8, 11

1967: Tigrisporites scurrandus – Norris, p.91; pl.11, figs 3–7.

Remarks: The specimens referred to this species by Norris (1967) were recorded from a Lower Cretaceous sequence from Central Alberta. The species *Tigrisporites halleinis* Klaus 1960, known from the European Upper Triassic, shows the same main characteristics as *Tigrisporites scurrancus* but differs in having more closely spaced, and differently arranged, distal rugulae, a laevigate proximal surface, and a larger size (40–68 microns contra 25–39 microns in spore-diameter for *Tigrisporites scurrandus*).

Genus *Staplinisporites* Pocock 1962

Staplinisporites telatus (Balme) Döring

1957: *Microreticulatisporites telatus* – Balme, p.25; pl.4, figs 52, 53.
1965: *Staplinisporites telatus* (Balme 1957) – Döring, p.45; pl.15, figs 6–8.

Genus *Ischyosporites* Balme 1957

The two genera *Ischyosporites* Balme 1957 and *Klukisporites* Couper 1958 have been treated in the present study as two separate genera, in accordance with, among others, Dettmann (1963) and Filatoff (1975).

According to the rules of Botanical Nomenclature the genus *Klukisporites* should be considered as a junior synonym of *Ischyosporites*, as followed by several authors (e.g. Schulz 1967, Tralau 1968, Guy 1971, Van Konijnenburg-Van Cittert 1981, Guy Ohlson 1986). Two clearly distinguishable groups of specimens of the *Ischyosporites/Klukisporites* type were, however, recorded in the present study: One group of spores showed a regular foveo-reticulate exine with a uniform thickness, without valvae. These specimens have been recorded as *Klukisporites*. The other group consists of spores showing a more irregular foveo-reticulate sculpture, where the muri are raised and undulating, constituting a valvate sculpture. These specimens have been referred to the genus *Ischyosporites*.

To solve the problems concerning these two genera, the genus *Klukisporites* should be emended and a new type species should be chosen. The present type species, *Klukisporites variegatus* has a valvate sculpture, and generally shows the main characteristics of the genus *Ischyosporites*. It is therefore generally treated as a junior synonym of *Ischyosporites variegatus* and this has been followed here.

Ischyosporites variegatus (Couper) Schulz
Pl.6, fig. 7

1958: *Klukisporites variegatus* – Couper, p.137; pl.19, figs 6, 7.
1967: *Ischyosporites variegatus* (Couper 1958) – Schulz, p.569; pl.5, figs 9, 10.

Genus *Klukisporites* Couper 1958

Klukisporites lacunus Filatoff
Pl.7, fig. 1

1975: *Klukisporites lacunus* -Filatoff, p.69; pl.15, fig. 9, pl.16, figs 1, 2.

Subturma ***Zonotriletes*** Waltz 1935
Infraturma ***Auriculati*** (Schopf 1938) Dettmann 1963

Genus *Triancoraesporites* Schulz 1962

Triancoraesporites ancorae (Reinhardt) Schulz
Pl.7, figs 4, 5

1962: *Waltzispora ancorae* – Reinhardt, p.705, pl.1, fig. 14.
1967: *Triancoraesporites ancorae* (Reinhardt 1962) – Schulz, p.580; pl.11, figs 4, 5.

Triancoraesporites reticulatus Schulz
Pl.7, fig. 6

1962: *Triancoraesporites reticulatus* – Schulz, p.311; pl.2, figs 14, 15.

Genus *Platyptera* Naumova 1934 ex. Naumova 1938

Platyptera trilingua (Horst) Schulz

1943: *Triletes (Zonale) trilinguis* – Horst, figs 55, 56.
1967: *Platyptera trilingua* (Horst 1943) – Schulz, p.579; pl.11, figs 1, 2.

Remarks: The recorded specimens are probably reworked. *Platyptera trilingua* is generally known from Carboniferous strata (Smith & Butterworth 1967).

Infraturma ***Tricrassati*** Dettmann 1963

Genus *Gleicheniidites* Ross 1949

Gleicheniidites senonicus Ross
Pl.7, figs 7, 8

1949: *Gleicheniidites senonicus* – Ross, p.31; pl.1, figs 3, 4.

Remarks: The frequent occurrence of this species in the cuttings samples from the Frederikshavn-2 borehole (especially in sample Frh-20,s) is probably due to caving. Specimens referred to *Gleicheniidites senonicus* were, however, recorded sporadically from some of the core samples in the present study (Fj-15,c, Frh 12,c and Frh-22,c), referred to Early and/or Middle Jurassic.

Gleicheniidites conspiciendus (Bolchovitina) Krutzsch

1953: *Gleichenia conspicienda* – Bolchovitina, p.45; pl.8, figs 4, 5.
1959: *Gleicheniidites (Peregrinisporis) conspiciendus* (Bolchovitina 1953) – Krutzsch, p.114.

Genus *Skarbysporites* Van Erve 1977

Skarbysporites crassexinus (Nilsson) Lund

1958: *Concavisporites crassexinius* – Nilsson, p.35; pl.1, fig. 11.
1967: *Gleicheniidites umbonatus* (Bolchovitina 1953) – Schulz, p.556, pl.1, figs 3, 4.
1977: *Deltoidospora crassexina* (Nilsson 1958) – Lund, p.51; pl.1, figs. 4a, b; pl.12, figs 8 a, b.
1988: *Skarbysporites crassexinus* (Nilsson 1958) – Lund & Ecke, p.354; pl. 3, figs 7, 8.

Remarks: See photo in Dybkjær (1988, pl.1, fig. 3) (*Deltoidospora crassexina* (Nilsson 1958) Lund 1977).

Genus *Zebrasporites* Klaus 1960 emend. Schulz 1967

Zebrasporites interscriptus (Thiergart) Klaus

Pl.7, fig. 11

1949: *Sporites interscriptus* – Thiergart, pl.2, fig. 9.
1960: *Zebrasporites* (al. *Sporites*) *interscriptus* (Thiergart 1949) – Klaus, p.139.

Zebrasporites laevigatus (Schulz) Schulz

Pl.7, fig. 12

1962: *Thuringiasporites laevigatus* – Schulz, p.310; pl.1, fig. 6.
1967: *Zebrasporites laevigatus* (Schulz 1962) – Schulz, p.589; pl.15, figs 10, 11.

Genus *Perinosporites* Schulz 1962

Perinosporites thuringiacus Schulz

Pl.8, figs 2, 3

1962: *Perinosporites thuringiacus* – Schulz, p.309; pl.1, figs 1, 2.

Genus *Camarozonosporites* Pant 1954 ex Potonié 1956

Camarozonosporites laevigatus Schulz

Pl.8, fig. 1

1967: *Camarozonosporites* (*Camarozonosporites*) *laevigatus* – Schulz, p.572; pl.7, figs 7–9, pl.25, fig. 3.

Camarozonosporites rudis (Leschik) Klaus

Pl.8, fig. 4

1955: *Verrucosisporites rudis* – Leschik, p.15; pl.1, fig. 15.
1960: *Camarozonosporites rudis* (Leschik 1955) – Klaus, p.136; pl.29, fig. 16.
1963: *Camarozonosporites* (*Camarozonosporites*) *rudis* (Leschik 1955) Klaus 1960 – Krutzsch 1963, p.20.

Remarks: This species differs from *Camarozonosporites laevigatus* in having a murornate exine, resulting in a striated appearance.

Infraturma ***Cingulati*** Potonié & Klaus 1954

Genus *Lycospora* Schopf, Wilson & Bentall 1944 emend. Potonié & Kremp 1954

Lycospora salebrosacea (Maljavkina) Schulz

Pl.8, figs 5–7

1949: *Volucellina salebrosacea* – Maljavkina, p.65; pl.13, fig. 14.
1958: *Aequitriradites salebrosaceus* (Maljavkina 1949) – Nilsson, p.47; pl.3, fig. 8.
1967: *Lycospora salebrosacea* (Maljavkina 1949) – Schulz, p.584; pl.13, figs 8–10.

Remarks: This species is generally regarded as a Carboniferous form (Smith & Butterworth 1967). The recorded specimens are probably reworked, although most of them are well preserved and do not show any signs of corrosion or darkening.

Genus *Densosporites* Berry 1937 emend. Potonié & Kremp 1954

Densosporites fissus (Reinhardt) Schulz

Pl.8, fig. 8

1964: *Densoisporites fissus* – Reinhardt, p.54; pl.2, figs 1–3.
1967: *Densosporites fissus* (Reinhardt 1964) – Schulz, p.582; pl.12, figs 5, 6.

Remarks: Some of the specimens found could be reworked.

Densosporites cavernatus Orlowska-Zwolinska

Pl.8, figs 9, 10

1966: *Densosporites cavernatus* – Orlowska-Zwolinska, p.1013; pl.6, figs 26–30.
1967: *Densosporites foveocingulatus* – Schulz, p.582; pl.12, figs 7, 8.

Cf. *Densosporites* spp.

Pl.8, figs 11–13

Remarks: This group comprises several different types of specimens, some of which are shown in the photoplates. They are all presumed to be reworked and are generally in a very bad state of preservation. In the range-charts they compose the main part of the category "other Cingulati".

Genus *Crassispora* Bharadwaj 1957

Cf. *Crassispora* sp.

Pl.9, fig. 1

Description: Trilete spore with subtriangular to subcircular amb, convex sides and rounded angles. The slightly undulating trilete mark is distinct, bordered by a thick labrum. The delimitation between the body and the cingulum is indistinct. The cingulum is about 8 microns wide. The exine is about 2 microns thick, and sculptured with irregularly spaced granulae and coni, 0.5–1.5 microns wide, and 0.5–1 microns high.
Equatorial diameter: about 50 microns (1 specimen).
Remarks: Only one specimen of this type was recorded. It is in a rather poor state of preservation, and is presumed to be reworked, probably from the Carboniferous (see Smith & Butterworth 1967). The recorded specimen differs from the original diagnosis of *Crassispora* in having a distinct trilete mark with labrum.

Genus *Cingutriletes* Pierce 1961

Cingutriletes infrapunctus (Schulz) Morbey

Pl.9, fig. 3

1970: *Stereisporites* (*Cingutriletes*) *infrapunctus* – Schulz, p.688; pl.130, figs 22, 23; pl.131, fig. 1.
1975: *Cingutriletes infrapunctus* (Schulz 1970) – Morbey, pl.9, fig. 4.

Genus *Cingulizonates* Dybova & Jachowicz 1957

Cingulizonates rhaeticus (Reinhardt) Schulz

Pl.9, fig. 2

1962: *Aequitriradites? rhaeticus* – Reinhardt, p.709; pl.2, fig. 3.
1967: *Cingulizonates rhaeticus* (Reinhardt 1962) – Schulz, p.584; pl.13, figs 6, 7.

Genus *Striatella* Mädler 1964a emend. Filatoff & Price 1988

Remarks: Filatoff & Price (1988) discussed the problem of the numerous types of trilete, muronate spores generally ascribed to either *Contignisporites* Dettmann 1963 or *Duplexisporites* Deák 1962. They subdivided this group into the genera *Contignisporites* Dettmann 1963, *Striatella* Mädler 1964a emend. Filatoff & Price 1988, and *Crassitudisporites* Hiltmann 1967. The two first mentioned genera differ from the last mentioned in having a single tangential murus on the outer edge of each proximal interradial area. Furthermore *Contignisporites* is distinguishable from *Striatella* in lacking a "disto-equatorial" murus.

The two species recorded occur together in the range-chart, as *Striatella* spp.

Striatella seebergensis Mädler
Pl.10, fig. 5

1964a: *Striatella seebergensis* – Mädler, p.189; pl.3, fig. 8.

Striatella jurassica Mädler
Pl.10, figs 3,4

1964a: *Striatella jurassica* – Mädler, p.192; pl.3, fig. 12.

Genus *Limbosporites* Nilsson 1958

Limbosporites lundbladii Nilsson
Pl.9, figs 4,5

1958: *Limbosporites lundbladii* – Nilsson, p.47; pl.3, fig. 7.

Genus *Heliosporites* Schulz 1962

Heliosporites altmarkensis Schulz
Pl.9, fig. 8

1962: *Heliosporites altmarkensis* – Schulz, p.311; pl.1, fig. 9; pl.2, figs 10, 11.

Genus *Murospora* Somers 1952

Murospora florida (Balme) Pocock
Pl.9, fig. 7

1957: *Cingulatisporites floridus* – Balme, p.26; pl.5, figs 60–61.

1961: *Murospora florida* (Balme 1957) – Pocock, p.1233, text-figs 1–7.

Remarks: Only one specimen was recorded, from sample Frh-19,c. Schulz (1967) has recorded specimens referred to *Murospora florida* from Pliensbachian and Toarcian strata in East Germany.

Cf. *Murospora* sp.
Pl.9, fig. 9

Description: Trilete, cingulate spore with subtriangular amb, concave sides and rounded angles. The trilete mark is distinct, bordered by a labrum about 3 microns wide. The sutures extend for about ⅔ of the spore radius. The cingulum is about 6 microns wide, with a finely undulating edge. The exine is sculptured with closely spaced granulae or small verrucae, 1–2 microns wide, and 1–2 microns high.
Equatorial diameter: 47 microns (1 specimen).
Remarks: Only one specimen was recorded, from sample Fj-23,s. This specimen is probably reworked. It is most similar to the specimen presented by Guy-Ohlson, Lindqvist & Norling (1987, fig. 5,B), which was referred to *Murospora intorta* (Waltz in Luber & Waltz 1938) Playford 1962, and also presumed to be caved from Carboniferous strata.

Genus *Iraquispora* Singh 1964

Iraquispora laevigata (Mädler) Lund
Pl.9, fig. 6

1964a: *Kyrtomisporites laevigatus* – Mädler, p.188; pl.3, fig. 4.
1977: *Iraquispora laevigata* (Mädler 1964) – Lund, p.60; pl.3, fig. 12.

Genus *Polycingulatisporites* Simoncsics & Kedves 1961 emend. Playford & Dettmann 1965

Polycingulatisporites triangularis (Bolchovitina) Playford & Dettmann
Pl.10, figs 7, 8

1956: *Chomotriletes triangularis* – Bolchovitina, p.61; pl.7, fig. 98a, ?figs 98b, 98c.
1965: *Polycingulatisporites triangularis* (Bolchovitina 1956) – Playford & Dettmann, p.144.

Remarks: Only one specimen was recorded, from sample St-5,c.

Polycingulatisporites liassicus Schulz
Pl.10, figs 6, 9

1967: *Polycingulatisporites liassicus* – Schulz, p.587; pl.14, figs 7–9.

Turma ***Monoletes*** Ibrahim 1933
Subturma ***Azonomonoletes*** Luber 1955

Genus *Laevigatosporites* Ibrahim 1933

Laevigatosporites mesozoicus Schulz

1967: *Laevigatosporites mesozoicus* – Schulz, p.590; pl.16, figs 1, 2.

Genus *Marattisporites* Couper 1958

Marattisporites scabratus Couper
Pl.10, fig. 10

1958: *Marattisporites scabratus* – Couper, p.133; pl.15, figs 20–23.

Cf. *Marattisporites* sp.1
Pl.10, fig. 11

Description: Monolete spore, with a broadly elliptical amb. The monolete mark is distinct, and extends for about ½ of the spore length. The exine is about 1 micron thick, and sculptured with closely spaced gran-

ulae, 1 micron or less in diameter, and about ½ micron high.
Dimensions: length: 23 microns; width: 19 microns (1 specimen).
Remarks: Only one specimen was recorded, from sample St-6,c.

Subturma ***Zonomonoletes***

Genus *Aratrisporites* Leschik 1955 emend. Playford & Dettmann 1965

Aratrisporites minimus Schulz
Pl.11, fig. 1

1967: *Aratrisporites minimus* – Schulz, p.592; pl.16, figs 7–9.

Aratrisporites fimbriatus (Klaus) Playford & Dettmann
Pl.11, fig. 2

1960: *Saturnisporites fimbriatus* – Klaus, p.142; pl.32, figs 32, 33.
1965: *Aratrisporites fimbriatus* (Klaus 1960) – Playford & Dettmann, p.152.

Anteturma ***Pollenites*** Potonié 1931
Turma ***Saccites*** Erdtman 1947
Subturma ***Disaccites*** Cookson 1947

Genus *Vitreisporites* Leschik 1955

Vitreisporites pallidus (Reissinger) Nilsson
Pl.11, fig. 3

1950: *Pityopollenites pallidus* – Reissinger, p.109; pl.15, figs 1–5.
1958: *Caytonipollenites pallidus* – Couper, p.150; pl.26, figs 7, 8.
1958: *Vitreisporites pallidus* (Reissinger 1950) – Nilsson, p.78; pl.7, figs 12–14.

Vitreisporites bjuvensis Nilsson
Pl.11, fig. 4; Pl.22, fig. 1,2 (the holotype)

1958: *Vitreisporites bjuvensis* – Nilsson, p.79; pl.7, fig. 11(*).

Remarks: This species differs from *Vitreisporites pallidus* in having a larger size (27–36 microns contra 25–30 microns for *Vitreisporites pallidus* according to Nilsson (1958)), and slightly pointed sacci.

Genus *Pinuspollenites* Raatz 1937 ex. Potonié 1958

Pinuspollenites minimus (Couper) Kemp
Pl.11, figs 5, 7

1958: *Abietineaepollenites minimus* – Couper, p.153; pl.28, figs 14, 15.
1958: *Taedaepollenites scaurus* – Nilsson, p.87; pl.7, figs 16, 17 (*).
1967: *Pityosporites scaurus* (Nilsson 1958) – Schulz, p.595; pl. 17, figs 12, 13.
1970: *Pinuspollenites minimus* (Couper 1958) – Kemp, p.116; pl. 24, figs 1–6.

Pinuspollenites pinoides (Nilsson) Lund

1958: *Sulcatisporites pinoides* – Nilsson, p.86; pl.8, figs 6, 7.
1977: *Pinuspollenites pinoides* (Nilsson 1958) – Lund, p.76; pl. 9, fig. 7.

Genus *Protopinus* Bolkhovitina 1956

Protopinus scanicus Nilsson
Pl.11, fig. 6

1958: *Protopinus scanicus* – Nilsson, p.84; pl.8, figs 4, 5.

Genus *Alisporites* Daugherty 1941

Alisporites robustus Nilsson
Pl.11, fig. 8; Pl.22, figs 3, 4 (the holotype)

1958: *Alisporites robustus* – Nilsson, p.82; pl.8, figs 2, 3 (*).

Alisporites radialis (Leschik) Lund

1955: *Cunaetisporites radialis* – Leschik, p.66; pl.10, fig. 6.
1977: *Alisporites radialis* (Leschik 1955) – Lund, p.75; pl.9, figs 3, 4.

Alisporites thomasii (Couper) Nilsson

1958: *Pteruchipollenites thomasii* – Couper, p.150; pl.26, figs 10–12.
1958: *Alisporites thomasii* (Couper 1958) – Nilsson, p.83; pl.8, fig. 1.

Alisporites grandis (Cookson) Dettmann

1953: *Disaccites grandis* – Cookson, p.471; pl.2, fig. 41.
1963: *Alisporites grandis* (Cookson 1953) – Dettmann, p.102; pl.25, figs 1–4.

Alisporites microsaccus (Couper) Pocock

1958: *Pteruchipollenites microsaccus* – Couper, p.151; pl.26, fig. 13.
1962: *Alisporites* cf. *A. microsaccus* (Couper 1958) – Pocock, p.61; pl.9, figs 138, 139.

Genus *Ovalipollis* Krutzsch 1955

Ovalipollis ovalis Krutzsch
Pl.11, fig. 10

1955: *Ovalipollis ovalis* – Krutzsch, p.70; pl.1, fig. 2.

Genus *Quadraeculina* Maljavkina 1949

Quadraeculina anellaeformis Maljavkina
Pl.12, fig. 1

1949: *Quadraeculina anellaeformis* – Maljavkina, p.110; pl.39, fig. 3.
1958: *Chasmatosporites radiatus* – Nilsson, p.58; pl.4, fig. 9 (*).

Genus *Schismatosporites* Nilsson 1958

Schismatosporites ovalis Nilsson
Pl.22, fig. 5 (the holotype)

1958: *Schismatosporites ovalis* – Nilsson, p.76; pl.10, fig. 2 (*).

Genus *Umbrososaccus* Mädler 1964

Umbrososaccus keuperianus Mädler
Pl.12, fig. 2

1964b: *Umbrososaccus keuperianus* – Mädler, p.118; pl.11, figs 5, 8.

Genus *Taeniaesporites* Leschik 1955

Taeniaesporites sp.
Pl.12, fig. 3

Description: Bisaccate pollen grain with four parallel taeniae; two large and distinct, placed proximally; and two narrow and indistinct, placed equatorially, one at each side. The total outline is elliptical. The corpus is circular in polar view. The sacci are almost hemispherical, attached to the corpus equatorially. The sacci-roots are indistinct. The taeniae runs from one saccus to the other. The two distinct ones are 5–6 microns wide, with a 5 microns wide space between them, while there is about 3 microns between the distinct ones and the narrow ones.
Dimensions: corpus-length: 32 microns; width: 36 microns. Sacci length: 31 microns; width: 22 microns. Total length: 31 microns; width: 70 microns (1 specimen).
Remarks: Only one specimen was recorded, from sample Fj-3,c. This specimen is in a very bad state of preservation, which made determination at the species level impossible. This specimen may be reworked.

Turma ***Aletes*** Ibrahim 1933
Subturma ***Azonaletes*** (Luber 1935) Potonié & Kremp 1954

Genus *Araucariacites* Cookson 1947 ex. Couper 1953

Araucariacites australis Cookson

1947: *Granulonapites* (*Araucariacites*) *australis* – Cookson, p.130; pl.13, figs 1–4.

Genus *Perinopollenites* Couper 1958

Remarks: The endexine and ektexine are totally separated. The ektexine forms a velum, that is easily torn and is thus often missing (see pl. 12, figs 4–9). The "naked" inner-bodies could be taken for other palynomorph-genera, the inner-body of *Perinopollenites* cf. *elatoides* could in particular be confused with specimens of *Polypodiisporites*.

Perinopollenites elatoides Couper
Pl.12, figs 4–6

1958: *Perinopollenites elatoides* – Couper, p.152; pl.27, figs 9–11.

Perinopollenites cf. *elatoides* Couper
Pl.12, figs 7–9

Remarks: These specimens differ from *Perinopollenites elatoides* Couper 1958 in having a small, thick-walled, dark inner-body, and a smaller total size, 40–45 microns.

Genus *Cupressacites* (Bolkhovitina 1956) Krutzsch 1971

Cupressacites sp.

Description: Alete pollen grains with a spherical outline, though normally secondarily folded. The exine is very thin (about 0.5 microns), transparent, and laevigate.
Dimensions: 30 (39) 48 microns (3 specimens).
Remarks: See photo in Dybkjær (1988, pl.9, fig. 3).

Genus *Cerebropollenites* Nilsson 1958

Cerebropollenites macroverrucosus (Thiergart) Schulz
Pl.13, fig. 1

1949: *Pollenites macroverrucosus* – Thiergart, p.17; pl.2, fig. 19.
1958: *Tsugaepollenites mesozoicus* – Couper, p.155; pl.3, figs 8–10.
1958: *Cerebropollenites mesozoicus* (Couper 1958) – Nilsson, p.72; pl.6, figs 10–12.
1967: *Cerebropollenites macroverrucosus* (Thiergart 1949) – Schulz, p.603; pl.21, figs 4–6.

Remarks: According to Schulz (1967) the two species *Cerebropollenites macroverrucosus* and *Cerebropollenites thiergartii* differ in the size of the verrucae. Furthermore the verrucae on the former are hollow and often elongated, while those on the latter are compact and circular.

The specimens referred to *Cerebropollenites macroverrucosus* by Orbell (1973, pl. 2, figs 5–7) should not be referred to this species. According to Morbey (1975) they should be referred to *Tsugapollenites* ? *pseudomassulae* (Mädler 1964a) Morbey 1975.

Cerebropollenites thiergartii Schulz
Pl.13, figs 2–6

1967: *Cerebropollenites thiergartii* – Schulz, p.603; pl.21, figs 7, 8.

Remarks: Some of the specimens referred to this species in this study seem to have a regular sulcus (pl.13, figs 4–6), while others only have an area with thin exine (pl.13, figs 2 and 3). Nilsson (1958), who erected the genus *Cerebropollenites,* described it as inaperturate, while Schulz (1967), who erected the species *Cerebropollenites thiergartii,* described the genus as monocolpate. The variation seen in this study of *Cerebropollenites thiergartii* covers both possibilities, while no *Cerebropollenites macroverrucosus* was recorded with a sulcus-like aperture.

Genus *Spheripollenites* Couper 1958

Remarks: Specimens of this genus often occur in clusters, as mentioned for *Spheripollenites subgranulatus* by Schulz (1967), and for the genus by Batten (1978). In the present study this tendency is especially pronounced for *Spheripollenites psilatus* in samples St-15,w and Fj-15,c where this species occur in large numbers.

The present author doubts whether these specimens are pollen grains or algae, as they show no features that definitively confirm any of these relationships. Batten (1978) proposed an algal origin, especially for the clustered specimens, while Wille (1982) suggested that *Inaperturopollenites orbiculatus,* a junior synonym to *Spheripollenites psilatus,* represent a conifer related to the Cheirolepidiaceae, the same family which produced the *Corollina* type of pollen. An investigation of the geochemical composition of the exine may solve the problem.

Spheripollenites psilatus Couper
Pl.13, fig. 7

1958: *Spheripollenites psilatus* – Couper, p.159; pl.31, figs 4–8.
1958: *Inaperturopollenites orbiculatus* – Nilsson, p.68; pl.6, figs 2–4.

Spheripollenites subgranulatus Couper

1958: *Spheripollenites subgranulatus* – Couper, p.158; pl.31, figs 9–11.

Genus *Exesipollenites* Balme 1957

Exesipollenites tumulus Balme
Pl.13, fig. 8

1957: *Exesipollenites tumulus* – Balme, p.39; pl.11, figs 123–125.

Subturma ***Zonaletes*** Luber 1935 emend. Potonié 1958

Genus *Callialasporites* Dev 1961

Callialasporites trilobatus (Balme) Dev
Pl.14, fig. 1

1957: *Zonalapollenites trilobatus* – Balme, p.33; pl.8, figs 91, 92.
1961: *Callialasporites trilobatus* (Balme 1957) – Dev, p.48; pl.4, figs 28, 29.

Remarks: Only one specimen was recorded, from sample Frh-13,s. This specimen could be caved, but the species *Callialasporites trilobatus* is known from the Lower Jurassic (Filatoff 1975).

Callialasporites dampieri (Balme) Dev
Pl.14, fig. 2

1957: *Zonalapollenites dampieri* – Balme, p.32; pl.8, figs 88–90.
1961: *Callialasporites dampieri* (Balme 1957) – Dev, p.48; pl.4, figs 26, 27.
1963: *Tsugapollenites dampieri* (Balme 1957) – Dettmann, p.100; pl.24, figs 1–5.

Remarks: Schulz (1967) mentioned that specimens referred to *Callialasporites dampieri* sometimes show the indication of a trilete mark. Some of the specimens recorded in the present study, show a distinct trilete-mark.

Turma ***Plicates*** (Naumova 1939) Potonié 1960
Subturma ***Monocolpates*** Iversen & Troels-Smith 1950

Genus *Chasmatosporites* Nilsson 1958 emend. Pocock & Jansonius 1969

Remarks: Nilsson (1958) erected no less than 11 species, two new combinations, and one *Chasmatosporites* sp.A, referred to this genus. Morbey (1975) combined 9 of these species into one, *Chasmatosporites magnolioides* (Erdtman 1948) Nilsson 1958, while *Chasmatosporites apertus* was kept as a separate species. *Chasmatosporites crassus* and *Chasmatosporites* sp.A Nilsson 1958 were not mentioned by Morbey, while *Chasmatosporites radiatus* Nilsson 1958, was treated as a junior synonym of *Quadraeculina anellaeformis* Maljavkina 1949.

The stratigraphical distribution, according to earlier investigations, of 15 species of *Chasmatosporites* in Sweden has recently been presented by Guy-Ohlson (1988). Six of these species, all recorded from the Vilhelmsfält-1 borehole, Scania, were described, and the possible stratigraphical potential of these was proposed.

Nilssons (1958) type-material was investigated in connection with the present study. Unfortunately the slides with several of the type-species of, among others, *Chasmatosporites major* and *Chasmatosporites hians* have been lost.

The four species recorded in the present study could be distinguished relatively easily. Several of the species erected by Nilsson (1958) are here treated as junior synonyms. They are described in detail below to clarify the delimitation of the recorded species.

Chasmatosporites apertus (Rogalska) Nilsson
Pl.14, fig. 3

1954: *Pollenites apertus* – Rogalska, p.45; pl.12, figs 13–15.
1958: *Chasmatosporites apertus* (Rogalska 1954) – Nilsson, p.56; pl.4, figs 5, 6.
1958: *Chasmatosporites crassus* – Nilsson, p.57; pl.5, fig. 3.
1958: *Chasmatosporites flavus* – Nilsson, p.57; pl.5, fig. 4.

Description: The equatorial outline is circular, or nearly circular, with an irregular edge. The colpus is elliptical to circular, and wide open. The colpus-length is about 2/3 of the total diameter. The exine is thick (2–4 microns); the intrastructure of the exine is diffuse to fine intrareticulate. Dimensions: spore-diameter: 29–46 microns (17 specimens).

Chasmatosporites elegans Nilsson
Pl.14, fig. 6; Pl.22, fig. 6 (the holotype)

1958: *Chasmatosporites elegans* – Nilsson, p.58; pl.4, figs 11, 12 (*)
1958: *Chasmatosporites minor* – Nilsson, p.58; pl.4, fig. 10.

Description: The equatorial outline is elliptical, with a smooth edge. The colpus is elliptical to triangular, more or less wide open. The exine is 0.5–1 microns thick, tectate with a regular micro-intrareticulum. Dimensions: length: 35–50 microns; width: 30–46 microns (10 specimens).

Chasmatosporites hians Nilsson
Pl.14, figs 4, 5

1958: *Chasmatosporites hians* – Nilsson, p.55; pl.4, figs 3, 4.

Description: The equatorial outline is circular to ellipti-

cal, with a smooth to slightly irregular edge. The colpus is circular to elliptical, and wide open. The colpus-length is about 2/3 of the total length. The exine is 1–2 microns, with a distinct, irregular (vermiculate) micro-intrareticulum, with luminae about 1 micron in diameter and relatively narrow muri.
Dimensions: length: 44–76 microns; width: 30–51 microns (27 specimens).

Chasmatosporites major Nilsson
Pl.14, fig. 7

1958: *Chasmatosporites major* – Nilsson, p.54; pl.3, figs 10–15.

Description: The equatorial outline is elliptical, with a smooth edge. The colpus is elliptical. In some specimens the colpus has probably collapsed, resulting in a "closed" appearance, giving the grain a "spindle-shaped" outline. The colpus almost reaches the total length of the grain. The exine is 1–3 microns thick, and has a regular micro-intrareticulum with luminae of 0.5–1 microns, and relatively thick muri.
Dimensions: length: 61–88 microns; width: 49–55 microns (11 specimens).

Genus *Ricciisporites* Lundblad 1954 emend. Lundblad 1959

Ricciisporites tuberculatus Lundblad
Pl.14, figs 8, 9

1954: *Ricciisporites tuberculatus* – Lundblad, p.401; pl.4, figs 8, 9.

Remarks: This species normally occurs in tetrads. In the present study fragments are very common in some samples, especially in sample St-1,c. If a fragment constituted a quarter of a tetrad, or more, it was recorded as a "fragment". In the range-charts this species is therefore to be found both as *Ricciisporites tuberculatus* (tetrads), and as *Ricciisporites tuberculatus* (fragments).

Genus *Monosulcites* Cookson 1947 ex. Couper 1953

Monosulcites minimus Cookson
Pl.15, fig. 1

1947: *Monosulcites minimus* – Cookson, p.135; pl.15, figs 47–50.

Monosulcites punctatus Orlowska-Zwolinska

1958: *Entylissa reticulata* – Nilsson, p.62; pl.5, fig. 14 (*)
1966: *Monosulcites punctatus* – Orlowska-Zwolinska, p.1015; pl.9, fig. 46

Monosulcites cf. *punctatus* Orlowska-Zwolinska

Remarks: The recorded specimens differ from *Monosulcites punctatus* Orlowska-Zwolinska 1966 in having a thin exine that forms longitudinal folds. Comparable specimens were recorded from Rhaetian and Lower Jurassic strata by Lund (1977) and Dybkjær (1988).

Genus *Clavatipollenites* Couper 1958

Clavatipollenites hughesii Couper

1958: *Clavatipollenites hughesii* – Couper, p.159; pl.31, figs 19–22.

Subturma ***Praecolpates*** Potonié & Kremp 1954

Genus *Eucommiidites* Erdtman 1948 emend. Hughes 1961

Eucommiidites minor Groot & Penny

1960: *Eucommiidites minor* – Groot & Penny, p.234; pl.2, fig. 14.

Eucommiidites troedssonii Erdtman

1948: *Eucommiidites troedssonii* – Erdtman, p.267; figs 5–10, 13–15.

Turma ***Poroses*** (Naumova 1939) Potonié 1960
Subturma ***Monoporines*** Naumova 1939

Genus *Corollina* Maljavkina 1949 emend. Cornet & Traverse 1975

Remarks: See Dybkjær (1988, p.25) for a discussion of the validity of this genus-name.

Corollina torosus (Reissinger 1950) Klaus 1960 emend. Cornet & Traverse 1975
Pl.15, figs 2–5

1950: *Pollenites torosus* – Reissinger, p.115; pl.14, fig. 20.
1958: *Classopollis torosus* (Reissinger 1950) – Couper, p.156; pl.28, figs 2–7.
1960: *Corollina* (al. *Pollenites*) *torosus* (Reissinger 1950) – Klaus, p.168.
1975: *Corollina torosus* (Reissinger 1950) – Klaus 1960 emend. Cornet & Traverse, p.17; pl.5, figs 2–9, 14.

Remarks: In the range-chart this species is subdivided on the basis of its occurrence as single grains ("*Corollina torosus,* single grains") or in tetrads ("*Corollina torosus,* tetrads").

Corollina cf. *meyeriana* (Klaus) Venkatachala & Góczán
Pl.15, figs 6, 7

Remarks: The recorded specimens differ from *Corollina meyeriana* (Klaus 1960) Venkatachala & Góczán 1964 in having a weak, but recognizable, internal structure, resulting in an equatorial band composed of fused collumellae, as seen in *Corollina torosus*.

Aquatic palynomorphs

The classification used here for the aquatic palynomorphs is in accordance with Tappan (1980). The acritarch-group was subdivided as proposed by Downie, Evitt & Sarjeant (1963), with the revisions proposed by Diver & Peat (1979).

Division **Pyrrhophyta** Pascher 1914
Class **Dinophyceae** Fritsch 1929

Remarks: The dinoflagellate cyst species mentioned below are all known from core samples, and could be identified to at least genus level. All other presumed non-caved dinoflagellate cysts recorded have been counted together, and occur as "Other dinoflagellate cysts" in the range-charts.

In addition several presumably caved dinoflagellate cysts were recorded. These occur in the range-charts as "Other dinoflagellate cysts, presumed caved". Some of the species identified to species level are mentioned on p. 16, and are shown on the photo-plates.

Order ***Nannoceratopsiales*** Piel & Evitt 1980

Genus *Nannoceratopsis* Deflandre 1938 emend. Piel & Evitt 1980

Nannoceratopsis gracilis Alberti emend. Evitt
Pl.15, fig. 8

1961: *Nannoceratopsis gracilis* – Alberti, p.30; pl.7, figs. 16, 17.
1961b: *Nannoceratopsis deflandrei* – Evitt, p.308; pl.1, figs. 2–14.
1962: *Nannoceratopsis gracilis* (Alberti 1961) – Evitt, p.1129–1130.

Nannoceratopsis cf. *senex* van Helden
Pl.15, fig. 9

Remarks: *Nannoceratopsis senex,* erected by van Helden (1977) differs from *Nannoceratopsis gracilis* in possessing an "extremely rounded outline".... "with only the dorsal antapical horn (well) developed, and in the reduction or absence of the ornamentation (reticulation) on its surface that is characteristic for *Nannoceratopsis gracilis* Alberti emend.". Piel & Evitt (1980) stated that the outline is not a practical guide to distinguish *Nannoceratopsis senex* from *Nannoceratopsis gracilis* because of overlapping specimens, "although wall structure, when it can be clearly resolved, may be". The specimens referred to *Nannoceratopsis* cf. *senex* in the present study show an outline comparable to *Nannoceratopsis senex* van Helden 1977, but the wall structure is not preserved well enough to allow a safe determination.

Nannoceratopsis cf. *pellucida* Deflandre emend. Evitt
Pl.15, figs 11, 12

Remarks: Only one specimen was recorded, from sample Fj-15,c. This specimen differs from *Nannoceratopsis pellucida* erected by Deflandre (1938) and emended by Evitt (1961b), in having shorter, and wider antapical horns. It compares very well with the specimens referred to *Nannoceratopsis gracilis* var.A, by Johnson & Hills (1973), from a Bajocian sequence on Axel Heiberg Island, Arctic Canada.

Nannoceratopsis sp.1
Pl.15, fig. 10

Description: The main characters of this specimen correspond with the general morphology of the genus *Nannoceratopsis,* as described by Piel & Evitt (1980). It differs, however, in having no antapical horns, but a rounded antapical pole. The cyst wall is reticulate, as in *Nannoceratopsis gracilis.*
Dimensions: length: 68 microns; width: 47 microns (1 specimen).
Remarks: Only one specimen was recorded, from sample St-14,w.

Order ***Peridiniales*** Haeckel 1894

Genus *Dapcodinium* Evitt 1961 emend. Below 1987

Dapcodinium priscum Evitt emend. Below
Pl.15, fig. 13; Pl.16, figs 1, 2

1961a: *Dapcodinium priscum* – Evitt, p.996; pl.119, figs 1–14
1987: *Dapcodinium priscum* (Evitt 1961) – Below, p.149; pl.23, figs 6–11, 19

Genus *Liasidium* Drugg 1978

Liasidium variabile Drugg
Pl.16, figs 3, 6

1978: *Liasidium variabile* – Drugg, p.69; pl.4, fig. 10, pl.5, figs 1–9.

Genus *Rhaetogonyaulax* Sarjeant 1966 emend. Below 1987

Rhaetogonyaulax rhaetica (Sarjeant) Loeblich & Loeblich emend. Below
Pl.16, figs 4, 5

1963: *Gonyaulax rhaetica* – Sarjeant, p.353, figs 1, 2 (left).
1968: *Rhaetogonyaulax rhaetica* (Sarjeant 1963) – Loeblich & Loeblich p.212.
1975: *Rhaetogonyaulax rhaetica* (Sarjeant 1963) – Harland, Morbey & Sarjeant, p.862; pl.100–104.
1987: *Rhaetogonyaulax rhaetica* (Sarjeant 1963) – Below, p. 105, pl.9, figs 1–18, pl. 10, figs 1–18, text-figs 60, 61.

Dinocyst sp.1
Pl.17, fig. 1

Description: A very small dinoflagellate cyst with an ovoid outline. The cingulum is distinct, but no tabulation could be observed. The wall is thin, sculptured with densely spaced micro granulae or -spinae.
Dimensions: 23 (26) 30 microns high (8 specimens).
Remarks: This species was commonly recorded from samples referred to Late Pliensbachian – Toarcian.

The following dinoflagellate cyst species were all recorded sporadically, and occur in the range-charts as "Other dinoflagellate cysts".

Genus *Escharisphaeridia* Erkmen & Sarjeant 1980

Escharisphaeridia pocockii (Sarjeant) Erkmen & Sarjeant
Pl.16, figs 7, 8

1968: *Chytroeisphaeridia pocockii* – Sarjeant, p.230; pl.3, fig. 9.
1980: *Escharisphaeridia pocockii* (Sarjeant 1968) – Erkmen & Sarjeant, p.62.

Remarks: Only one specimen recorded, from sample Fj-16,c. This species has been reported from Upper Callovian strata in England and Scotland (Erkman & Sarjeant 1980).

Escharisphaeridia sp.
Pl.16, fig. 9

Description: A relatively small dinoflagellate cyst with an ovoid outline. The paratubulation is relatively distinct. At the apical end, some of the plates are partly broken off, probably functioning as a part of the archaeopyle. The wall structure is finely reticulate.
Dimensions: length: about 40 microns; width: 37 microns (1 specimen).
Remarks: Only one specimen recorded, from sample St-13,w.

Genus *Prolixosphaeridium* Davey, Downie, Sarjeant & Williams 1966 emend. Davey 1969

Prolixosphaeridium sp.
Pl.17, fig. 2

Description: Elongated elliptical outline, with morphological characters as described for this genus by Davey (1969). The wall ornamentation consists of thin processes, pointed or bifurcating, and about 10 microns long.
Dimensions: length: about 67 microns; width: 42 microns (1 specimen).
Remarks: Only one specimen recorded, from sample Frh-14,c.

Group ***Cryptarcha*** Diver & Peat 1979

Subgroup **Sphaeromorphitae** Downie, Evitt & Sarjeant 1963
Pl.18, figs 5, 6

Group ***Acritarcha*** (Evitt 1963) Diver & Peat 1979

Subgroup ***Acanthomorphitae*** Downie, Evitt & Sarjeant 1963
Pl.18, figs 7–9; Pl.19, fig. 1

Subgroup ***Polygonomorphitae*** Downie, Evitt & Sarjeant 1963
Pl.19, figs 2, 4–6

Subgroup **Netromorphitae** Downie, Evitt & Sarjeant 1963

Genus *Leiofusa* Eisenack 1938

Leiofusa jurassica Cookson & Eisenack
Pl.19, fig. 3

1958: *Leiofusa jurassica* – Cookson & Eisenack, p.51; pl.10, figs 3, 4

Remarks: This species is treated separately as it probably has stratigraphical potential, see p.38.

? Group ***Acritarcha***:

Genus *Schizocystia* Cookson & Eisenack 1962

Schizocystia rara Playford & Dettmann 1965
Pl.20, fig. 3

Remarks: This species is referred to the Group Acritarcha, as the origin is unknown. However, it does not seem to belong to any of the above mentioned Subgroups or to any other Subgroup known to the author.

Genus *Diexallophasis* Loeblich 1970

Diexallophasis denticulata (Stockmans & Williére) Loeblich 1970. Pl.19, fig. 8

1963: *Baltisphaeridium denticulatum* – Stockmans & Williére
1970: *Diexallophasis denticulata* (Stockmans & Williére 1963) – Loeblich

Remarks: Only one specimen was recorded, from sample St-17,w. This specimen is probably reworked. The acritarch species *Diexallophasis denticulata* is known from Silurian and Devonian strata from several localities in North America and Europe (e.g. Reaugh 1978, Smelror 1987).

Genus *Multiplicisphaeridium* Staplin 1961 emend. Staplin, Jansonius & Pocock 1965

Multiplicisphaeridium sp.
Pl.19, fig. 9

Description: The vesicle is circular in outline, about 30 microns in diameter, and with a laevigate wall surface. It is sculptured with about 20 hollow, laevigate processes, that open into the vesicle interior. At their base the processes are 3–4 microns in diameter; they are about 10 microns long, furcating in the outermost 2–3 microns, up to third order. The tips are pointed, some of them are distinct, while others are delicate.
Dimensions: diameter: about 50 microns (1 specimen).
Remarks: Only one specimen was recorded, from sample Frh-19,c. This specimen is probably reworked. The acritarch genus *Multiplicisphaeridium* is known from Silurian and Devonian strata in the U.S.A. and Europe (e.g. Dorning 1981, Wicander & Playford 1985, Smelror 1987).

Division **Prasinophyta** Round 1971
Order **Pterospermatales** Schiller 1925

Family **Tasmanaceae** Sommer 1956

Family **Cymatiosphaeraceae** Mädler 1963

Genus *Schizosporis* Cookson & Dettmann 1959

Schizosporis reticulatus (Cookson & Dettmann) emend. Pierce
Pl.20, fig. 4

1959: *Schizosporis reticulatus* – Cookson & Dettmann, p.213; pl.1, figs 1–4
1974: *Schizosporis reticulatus* – (Cookson & Dettmann 1959) emend. Pierce, p. 27.

Remarks: According to Pierce the stratigraphical range of this species is Berriasian to Cenomanian-Turonian or possibly Maastrichtian. In the present study it was recorded from the core sample Frh-18,c, referred to the Toarcian.

Genus *Cymatiosphaera* (Wetzel 1932) Deflandre 1954
Pl.20, fig. 2

Remarks: Mentioned in the range-charts as *Cymatiosphaera* spp.

Family **Pterospermellaceae** Eisanack 1972

Genus *Pterospermella* Eisenack 1972

Remarks: Mentioned in the range-charts as *Pterospermella* spp.

Division **Chlorophyta** Pascher 1914
Class **Chlorophyceae** Kützing 1843
Family **Botryococcus** Wille 1909

Genus *Botryococcus* Kützing 1849
Pl.20, fig. 1

Remarks: Mentioned in the range-charts as *Botryococcus* spp.

Other microfossils

Foraminiferal test-linings.
Pl.20, fig. 5

Fungi-remains
Pl.20, fig. 6

Species indet., type 1
Pl.19, fig. 10

Description: Elliptical to circular outline. A rounded triangular aperture (Pylome?) with a diameter of about ⅓ of the total diameter. The exine is punctate to granulate.
Dimensions: length: 50 microns; width: 40 microns (1 specimen).
Remarks: Not mentioned in the range-charts. Only one specimen recorded, from sample Frh-13,c.

Species indet., type 2
Pl.20, figs 7, 8

Description: Elliptical to circular outline. No apertures. A girdle, about 8 microns wide surrounds the grain. The exine is about 1 micron thick, sculptured with sparse, but regularly spaced, baculae, about 1 micron wide, 4 microns high.
Dimensions: length: about 72 microns; width: 60 microns (excluding the girdle) (1 specimen).
Remarks: Not mentioned in the range-charts. Only one specimen recorded, from sample Frh-16,c.

Palynostratigraphy

Introduction

On the basis of the variations in the microflora assemblages in the core samples from the Fjerritslev-2, Frederikshavn-2, and Stenlille-2 boreholes, five spore/pollen zones and four dinoflagellate cyst zones are proposed (fig. 6). This zonation is based on first appearances, last appearances, abundance variations, and associations of specific taxa.

The relative abundance of marine palynomorphs, the mutual variations of the main morphological groups of terrestrial palynomorphs (spores, saccate and non-saccate pollen), and of the different types of aquatic palynomorphs (appendices A-D; figs 13, 15, 17) have been used to characterize the proposed zones. The usefulness of the proposed zonation throughout the Danish Subbasin, has been evaluated by comparison with earlier palynological investigations of Lower Jurassic sequences in the Danish region. These investigations comprise the Gassum-1 borehole (Evitt 1961a, 1961b, Dybkjær 1988), the Rødby-1 borehole (Lund 1977), and the Hobro-1 borehole (Bertelsen 1979).

The proposed dating of the zones is based on results from earlier palynological investigations of ammonite- (or other macrofossils) or microfossil-dated sequences in northwest Europe (figs 4 and 5).

The proposed spore/pollen zonation is correlated with earlier palynologically zoned sequences from northwest Europe. The most important references for correlation of the spore/pollen zones are Schulz (1967), Orbell (1973), Morbey (1975, 1978), Lund (1977), Bertelsen (1979), Hoelstad (1985), Lund & Pedersen (1985), and Dybkjær (1988) (fig. 6).

The proposed dinoflagellate cyst zonation is correlated with the zonation proposed by Morbey (1978), and Woollam & Riding (1983) (fig. 6).

Definition of spore-pollen zones

Four new spore/pollen zones are proposed: the *Corollina – Ricciisporites* Zone, the *Cerebropollenites macroverrucosus* Zone, the *Spheripollenites – Leptolepidites* Zone, and the *Perinopollenites elatoides* Zone. These zones, and the *Pinuspollenites – Trachysporites* Zone Lund 1977, are proposed for use in the entire Danish Subbasin.

The *Corollina – Ricciisporites* Zone

Occurrence: Fjerritslev-2, samples Fj-2,c and Fj-3,c (2304m-2303m b.r.t.), Frederikshavn-2, sample Frh-1,c (930m b.r.t.), and Stenlille-2, samples St-1,c to St-3,c (1513m-1510m b.r.t.).

Reference section: The Fjerritslev-2 borehole, 2304m-2303m (samples Fj-2,c and Fj-3,c).

Base: The base of this zone is not defined here.

Top: Immediately below the distinct increase of *Pinuspollenites minimus* and of sculptured, trilete spores, and the decrease of *Corollina torosus*, defining the base of the *Pinuspollenites – Trachysporites* Zone.

Characteristics: This zone is characterized by the dominance of *Corollina torosus* together with a common occurrence of *Ricciisporites tuberculatus*.

The remaining assemblage is dominated by, mainly, Early Jurassic species, such as *Deltoidospora toralis, Stereisporites stereoides, Intrapunctisporis toralis, Monosulcites punctatus, Pinuspollenites minimus, Perinopollenites elatoides, Marattisporites scabratus,* and *Aratrisporites minimus*. The small bisaccate species *Vitreisporites pallidus,* known from the Late Permian to the Early Cretaceous, was also recorded frequently. Furthermore this zone is characterized by the sporadic to common occurrence of mainly Rhaetian species, such as *Polypodiisporites polymicroforatus, Taneaesporites* sp., *Zebrasporites laevigatus, Densosporites fissus, Densosporites cavernatus, Ovalipollis ovalis, Cingulizonates rhaeticus, Camarozonosporites rudis, Semiretisporis goetae, Triancoraesporites reticulatus, Triancoraesporites ancorae, Limbosporites lundbladii,* and *Perinosporites thuringiacus*.

The terrestrial palynomorphs are dominated by non-saccate pollen (mainly due to the acme of *Corollina torosus,* and *Ricciisporites tuberculatus*) (figs 13, 15 and 17), while the saccate pollen only constitute a minor part of the assemblage.

The aquatic palynomorphs are dominated by acanthomorphe and polygonomorphe acritarchs, and by the dinoflagellate cyst species *Dapcodinium priscum*. Furthermore, the sporadic to common occurrence of *Rhaetogonyaulax rhaetica, Leoifusa jurassica, Tasmanites,* and *Botryococcus* is often recorded.

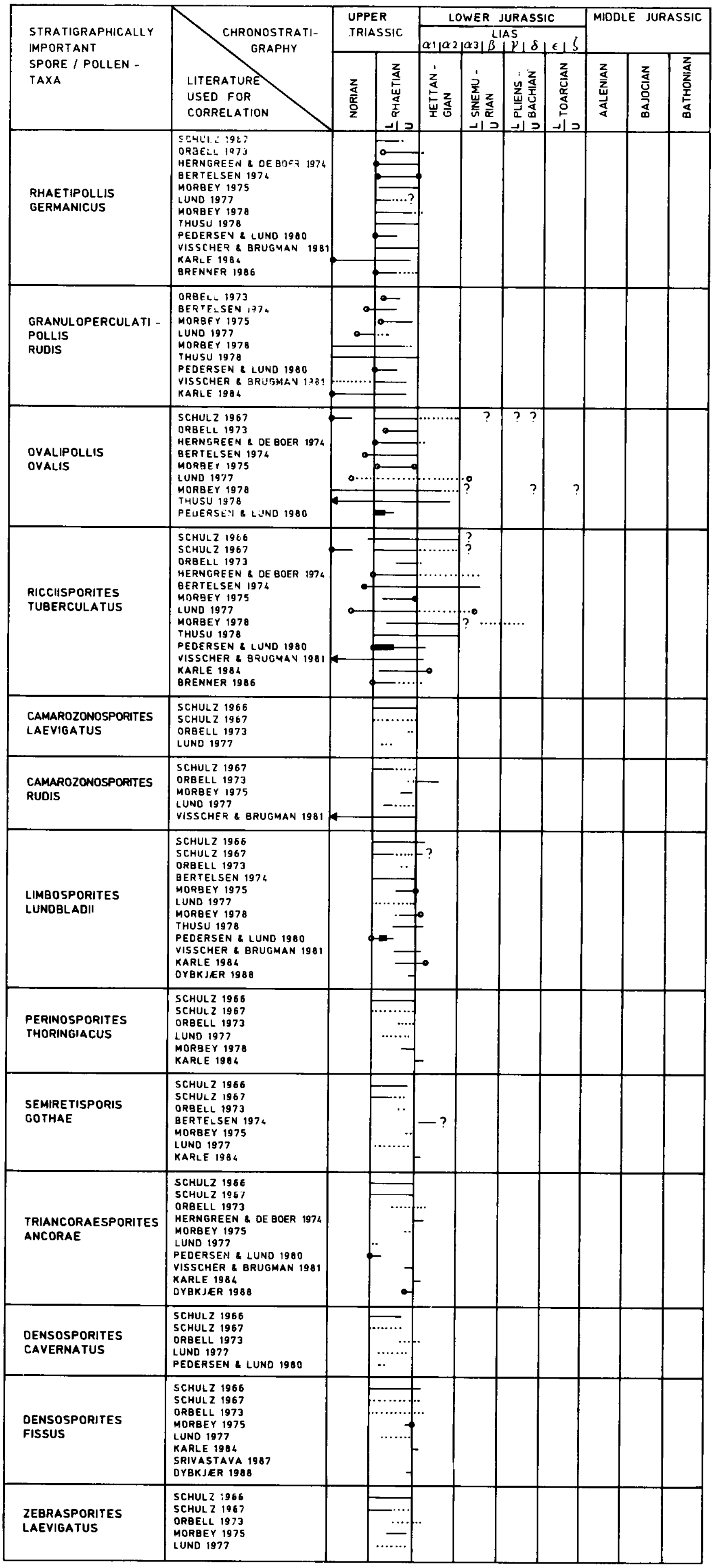
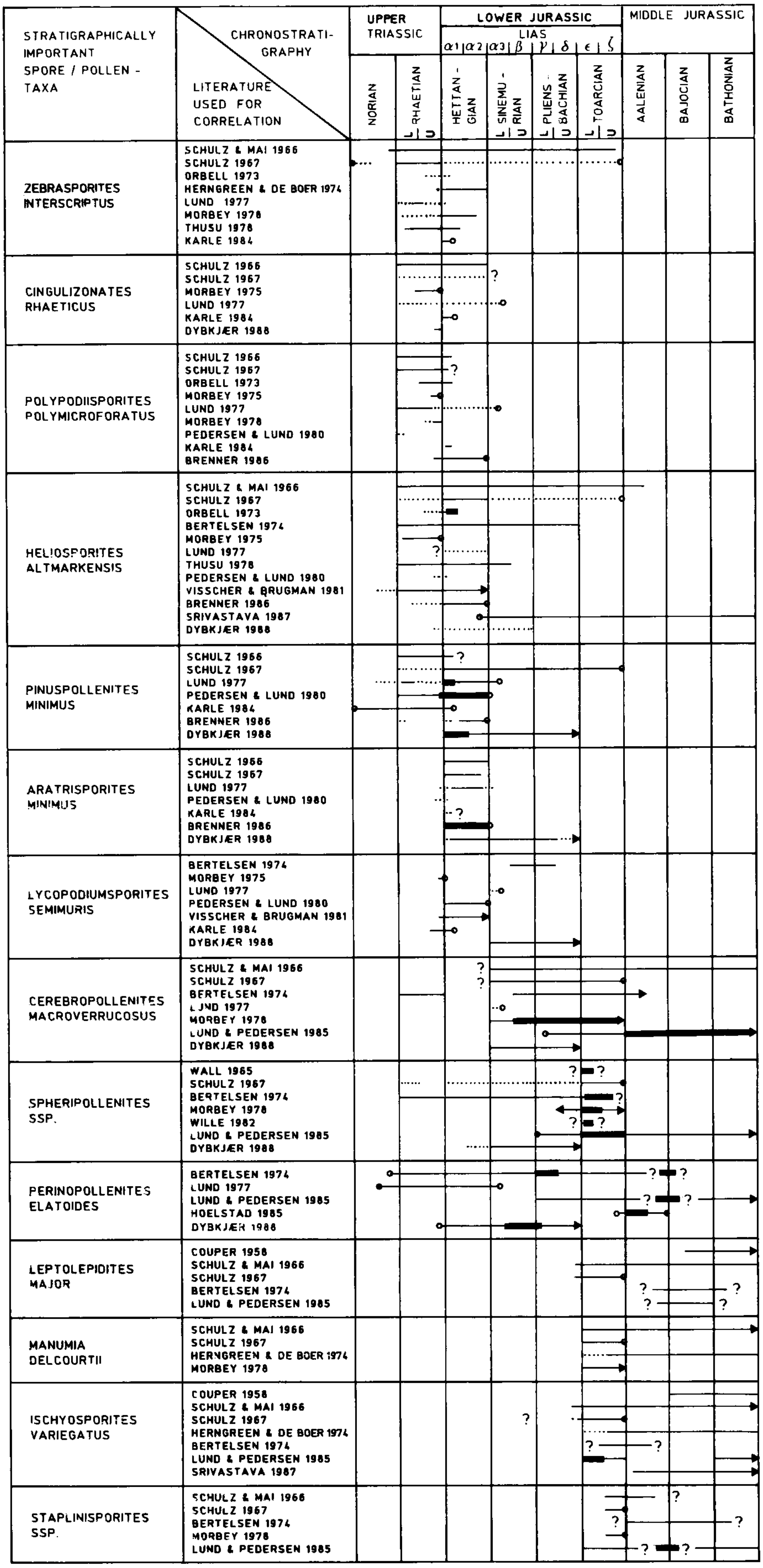


Fig. 4. Ranges of stratigraphically important spore- and pollen species, according to the literature. The chronostratigraphical subdivision indicated with greek letters is the old German subdivision of the Lower Jurassic (Lias).



—▸ *continued range*
—o *limits of the specific investigation*
—● *doubtful record, or imprecisely indicated range*
···· *sporadic record*
— *common to frequent*
▬ *abundant*

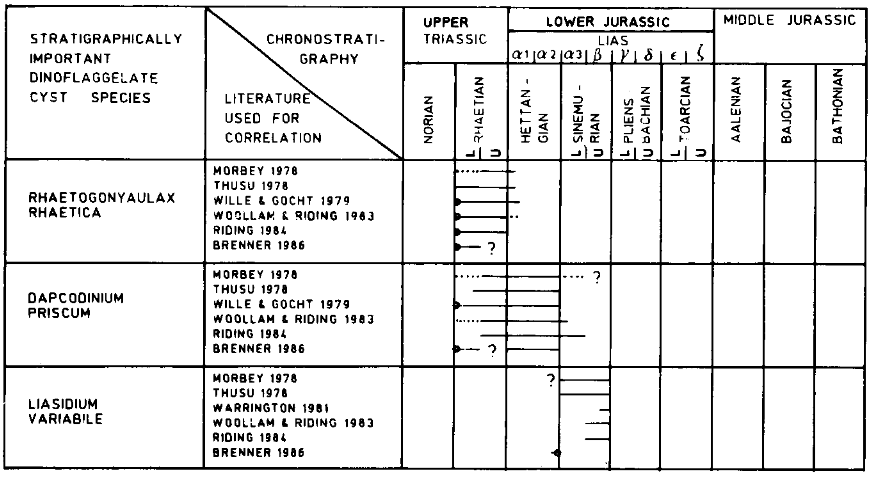


Fig. 5. Ranges of stratigraphically important dinoflagellate cyst species, according to the literature. See text to fig. 4 for further explanation.

Suggested age: This zone can be assigned a Late Rhaetian age. The palynomorph assemblage corresponds very well with several other latest Late Rhaetian assemblages from northwest Europe. These include the "Oberrät" micro-flora from the North German Basin described by Schulz (1967) (= Zone 3 in fig. 6), the upper part of the *Rhaetipollis* Zone from England (Orbell 1973), and the lowermost part of the FG-Subzone defined in the Kendelbachgraben, Austria (Morbey 1975).

The "Upper Rhaetic" microflora assemblage named as the *Ricciisporites – Polypodiisporites* Zone, defined by Lund (1977), is characterized by the common occurrence of either *Polypodiisporites polymicroforatus* or *Semiretisporis*. These two taxa only occur sporadically in the *Corollina – Ricciisporites* Zone in this study.

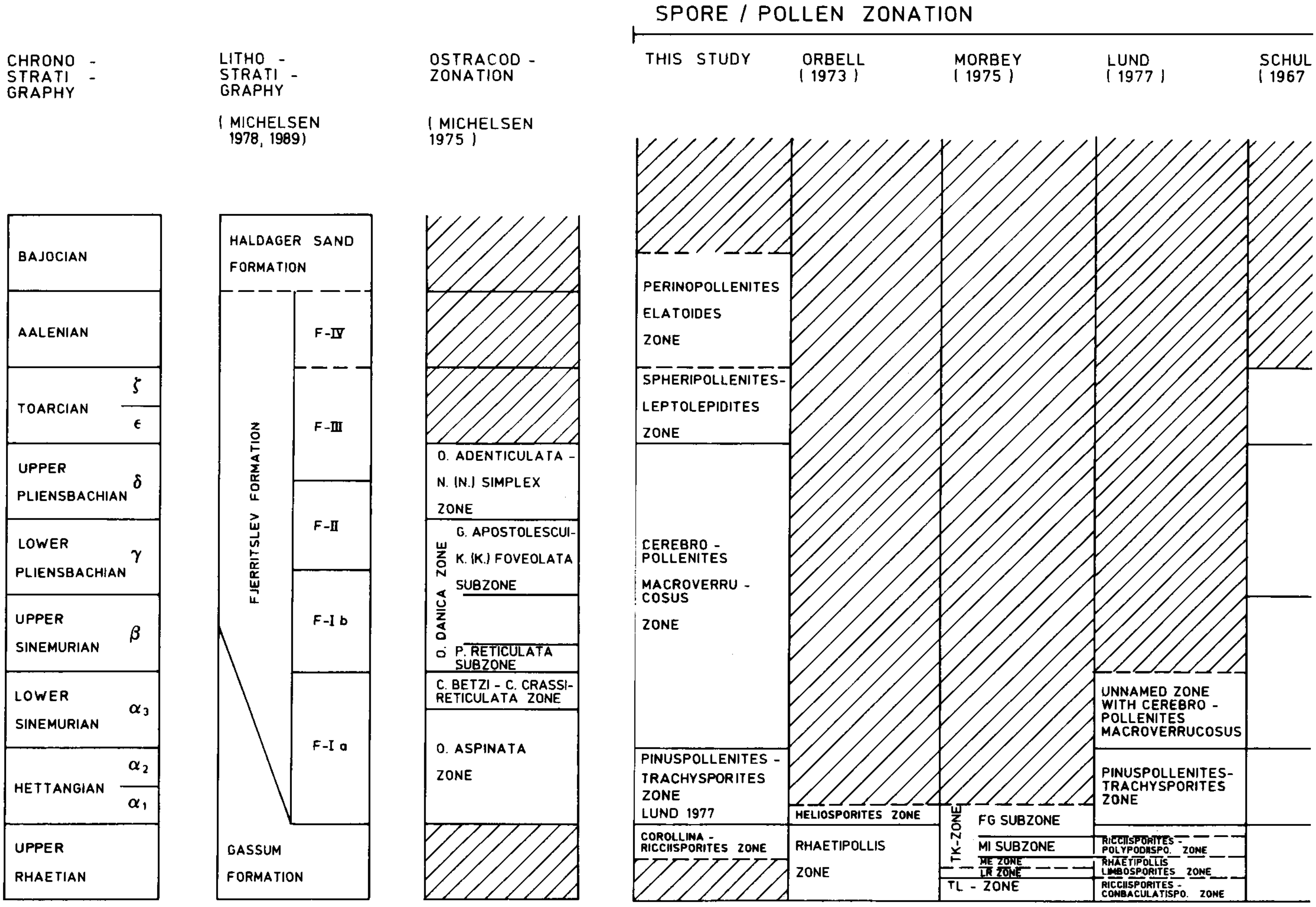


Fig. 6. Correlation of the spore/pollen zonation and dinoflagellate cyst zonation proposed here, with previous bio-zonations from Northwestern Europe. The chronostratigraphical subdivision indicated with greek letters is the old German subdivision of the Lower Jurassic (Lias).

With this exception, the two zones correlate well. Furthermore Lund (1977, p. 31) describes a level in the Rødby-1 borehole, dated as "topmost Upper Rhaetic?" characterized by the dominance of Early Jurassic (Liassic) types (*Punctatisporites major, Deltoidospora toralis, Trachysporites, Conbaculatisporites, Baculatisporites,* and *Aratrisporites minimus*) but with a number of Rhaetian types (*Zebrasporites laevigatus, Densosporites fissus, Densosporites cavernatus, Limbosporites lundbladii, Semiretisporis,* and *Perinosporites thuringiacus*) occurring sporadically. This assemblage correlates very well with that defining the *Corollina – Ricciisporites* Zone, as proposed here.

Comparison with previous zonations proposed for the Danish region: The *Corollina – Ricciisporites* Zone of this study, correlates well with Lund's (1977) *Ricciisporites – Polypodiisporites* Zone (fig. 6), but, as mentioned above, it correlates even better with the interval 1842' to 1843' (b.r.t.) in the Rødby-1 borehole, which was not referred to any zone, but was suggested to have a "topmost Upper Rhaetic?" age (Lund 1977). Zone A in the Gassum-1 borehole (Dybkjær 1988) also corresponds well to the *Corollina – Ricciisporites* Zone (this study), when comparing the Rhaetian/Hettangian forms, but Zone A is totally dominated by spores (*Deltoidospora toralis* and *Baculatisporites*) instead of *Corollina torosus.*

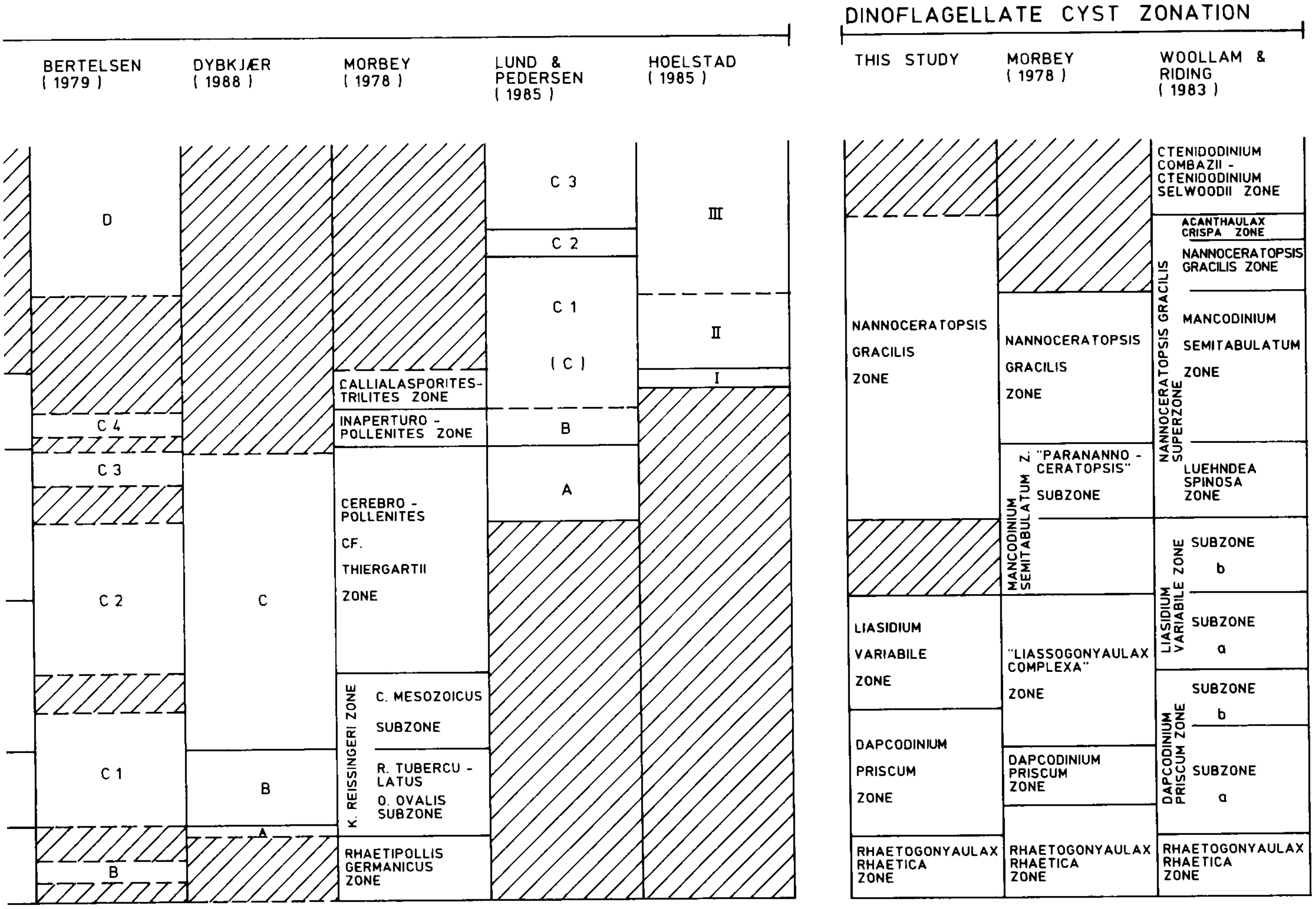
The *Pinuspollenites – Trachysporites* Zone Lund 1977

Occurrence: In Fjerritslev-2, sample Fj-4,c (2106m b.r.t.), and in Stenlille-2, samples St-6,c to St-8,w (1494m-1392m b.r.t.).

Base: At the level where the saccate pollen species *Pinuspollenites minimus* shows a distinct rise in abundance, together with a more gradual rise in abundance of the sculptured trilete spores.

Top: Immediately below the first appearance of *Cerebropollenites macroverrucosus.*

Characteristics: This zone is characterised by a relatively high abundance of *Pinuspollenites minimus,* especially in the lower part of the zone, together with a common occurrence of the sculptured trilete spore-genera *Trachysporites, Conbaculatisporites* and *Baculatisporites.*



In the present study *Deltoidospora toralis* dominates the assemblage, and, in addition to the taxa mentioned above, the species *Perinopollenites elatoides, Corollina torosus,* and *Marattisporites scabratus* occur frequently, while the species *Calamospora tener, Stereisporites stereoides, Monosulcites punctatus, Punctatisporites globosus, Vitreisporites pallidus, Deltoidospora minor, Aratrisporites minimus, Perinopollenites* cf. *elatoides, Intrapunctisporis toralis, Alisporites robustus,* and the genus *Chasmatosporites* are common. The mainly Rhaetian species *Zebrasporites interscriptus,* and *Ricciisporites tuberculatus* occur sporadically in the lower part of the zone, while the other mainly Rhaetian species that characterize the *Corollina – Ricciisporites* Zone are not recorded.

In general spores dominate the spore/pollen assemblage, whereas bisaccate pollen, and non-saccate pollen constitute a minor part.

The aquatic palynomorphs are dominated by acritarchs, especially acanthomorphe, polygonomorphe, and sphaeromorphe types. *Dapcodinium priscum* is relatively abundant, while *Rhaetogonyaulax rhaetica* was not recorded. *Tasmanites* and *Botryococcus* occur sporadically, and the polygonomorphe acritarch species *Leiofusa jurassica* is recorded in high numbers in the lower part of the Stenlille-2 borehole, in sample St-8,c.

Suggested age: Hettangian. Lund (1977) dated the *Pinuspollenites – Trachysporites* Zone as Hettangian. Furthermore, Schulz (1967), Pedersen & Lund (1980), Brenner (1986), and Dybkjær (1988) recorded distinctly higher abundances of *Pinuspollenites minimus* in the Hettangian than in the Rhaetian (see fig. 4). In the Rødby-1 borehole as well as in the Northwest German Basin (Lund 1977) an acme of *Leiofusa jurassica* was recorded from the basal part of the *Pinuspollenites-Trachysporites* Zone. This level could possibly be correlated with the acme of *Leiofusa jurassica* in Stenlille-2.

Comparison with other zonations proposed for the Danish region: The *Pinuspollenites – Trachysporites* Zone Lund 1977 correlates very well with the C1 Unit in the Hobro-1 borehole (Bertelsen 1979). Zone B in the Gassum-1 borehole (Dybkjær 1988) compares rather well, but is dominated by *Corollina torosus* rather than *Deltoidospora toralis.*

The *Cerebropollenites macroverrucosus* Zone

Occurrence: In Fjerritslev-2, samples Fj-5,c to Fj-12,c (2105m-2003m b.r.t.), in Frederikshavn-2, samples Frh-2,c to Frh-14,c (892m-851m b.r.t.), and in Stenlille-2, samples St-9,w to St-14,w (1390m-1240m b.r.t.).

Reference section: The Frederikshavn-2 borehole, 892m-851m b.r.t. (samples Frh-2,c to Frh-14,c).

Base: At the first appearance of *Cerebropollenites macroverrucosus.*

Top: Immediately below the distinct rise in the genera *Spheripollenites,* and first appearance of either the genus *Leptolepidites* or *Ischyosporites,* or both.

Characteristics: This zone is characterized by the (often sporadic) presence of *Cerebropollenites macroverrucosus.*

The species *Corollina torosus, Pinuspollenites minimus, Perinopollenites elatoides,* and *Deltoidospora toralis* occur frequently, while *Calamospora tener, Marattisporites scabratus, Deltoidospora minor, Aratrisporites minimus, Punctatisporites globosus, Lycopodiumsporites austroclavatidites, Alisporites robustus, Araucariacidites australis, Cerebropollenites thiergartii, Intrapunctisporis toralis, Eucommiidites troedssonii, Monosulcites punctatus,* and the genus *Chasmatosporites* all occur commonly. The species *Lycopodiumsporites semimuris* often appears immediately below, or at the base of this zone.

Generally the non-saccate pollen show a slightly higher abundance than spores and bisaccate pollen in this zone, but there are no distinct differences in the relative abundances of the three main groups.

The aquatic palynomorphs are dominated by acanthomorphe and polygonomorphe acritarchs. Furthermore the dinoflagellate cyst species *Dapcodinium priscum, Liasidium variabile,* and *Nannoceratopsis gracilis* are recorded at different levels and/or from different boreholes in sections all referred to the *Cerebropollenites macroverrucosus* Zone.

Suggested age: Sinemurian – Pliensbachian. The first appearance of *Cerebropollenites macroverrucosus* was recorded at the Hettangian-Sinemurian boundary by Schulz (1967), Lund (1977), Morbey (1978), and Dybkjær (1988) (see fig. 4). The specimens recorded by Orbell (1973) from Late Rhaetian do not belong to this species (see p. 27 in the systematic section). Bertelsen (1979) recorded *Cerebropollenites macroverrucosus* from two sidewall core samples, dated as Late Triassic on the basis of the palynomorph assemblage in the Hobro-1 borehole. A study of these slides by the author confirmed the occurrence of *Cerebropollenites macroverrucosus* together with a palynomorph assemblage that clearly indicated a Late Triassic age. These observations could be due to contamination, but it is clear that the range of this species in the Danish area should be investigated further. The distinct rise in abundance of *Spheripollenites,* defining the top of this zone, is probably of Early Toarcian age, as discussed below.

Comparison with previous zonations proposed for the Danish region: The Unit C2 in Hobro-1 (Bertelsen 1979), the "unnamed zone with *Cerebropollenites macroverrucosus*" in Rødby-1 (Lund 1977), and Zone C in the Gassum-1 borehole (Dybkjær 1988) (fig. 6) all compare well with the *Cerebropollenites macroverrucosus* Zone.

The *Spheripollenites – Leptolepidites* Zone

Occurrence: In Fjerritslev-2, sample Fj-15,c (1561m b.r.t.), in Frederikshavn-2, samples Frh-17,c to Frh-22,c (787m-782m b.r.t.), and in Stenlille-2, samples St-15,w, and St-16,w (1234m-1228m b.r.t.).

Reference section: The Stenlille-2 borehole, 1234m-1228m b.r.t. (samples St-15,w and St-16,w).

Base: At a distinct increase in *Spheripollenites,* and the first appearance of *Leptolepidites* and/or *Ischyosporites.*

Top: Immediately below a distinct increase in *Perinopollenites elatoides* and a decrease in *Spheripollenites psilatus.*

Characteristics: A high abundance of *Spheripollenites* and the presence of specimens of either *Leptolepidites* or *Ischyosporites.* According to Lund & Pedersen (1985) the maximum of *Spheripollenites* in the Early Toarcian coincides with a maximum of *Corollina*, and a minimum of bisaccate pollen. This tendency was clearly seen in this study, as discussed for the assemblages from the individual boreholes.

In addition to the taxa mentioned above, *Perinopollenites elatoides* occurs frequently, and the following taxa are common: *Deltoidospora toralis, Deltoidospora minor, Araucariacidites australis, Monosulcites punctatus, Cerebropollenites macroverrucosus, Marattisporites scabratus, Calamospora tener,* and species of the genus *Chasmatosporites.* The assemblage includes (sporadically) specimens referred to the stratigraphically important taxa *Manumia delcourtii* and *Staplinisporites telatus,* both known from the earliest Toarcian, and younger sequences.

The samples referred to this zone are generally characterized by a clear dominance of non-saccate pollen, and sparse bisaccate pollen.

The aquatic palynomorph assemblage is far more diverse at this level than in the preceeding zones, comprising *Cymatiosphaera, Pterospermella, Leiofusa jurassica, Tasmanites,* and the limnic algae *Botryococcus* and *Schizosporis reticulatus.* Acanthomorphe acritarchs occur in relatively lower numbers than in the preceeding zones, while the dinoflagellate cyst species *Nannoceratopsis gracilis* and Dinocyst sp. 1 are recorded commonly, and dominate the marine assemblage at some levels. *Nannoceratopsis* cf. *senex* is recorded sporadically in some samples.

Suggested age: Toarcian. The relatively high abundance of *Spheripollenites psilatus,* (especially in St-15,w, and St-16,w) may possibly be related to the Early Toarcian anoxic event. A mass occurrence of small, spherical bodies, comparable to the genus *Spheripollenites,* is known from layers deposited during the Early Toarcian anoxic event over wide areas of northwest Europe: from Yorkshire, England ("*Inaperturopollenites orbiculatus*" and "*Inaperturopollenites globulus*") (Wall 1965); from Swabia, southwest Germany ("*Inaperturopollenites orbiculatus*", reaching a dominance of 99%!) (Wille 1982); and from Jameson Land, East Greenland (*Spheripollenites subgranulatus*) (Lund & Pedersen 1985).

The relatively low record of acritarchs, the dominance of *Nannoceratopsis gracilis,* and the occurrence of several taxa of the Prasinophyta, compare well with the observations from earlier investigations of Lower Toarcian deposits from western Germany. According to Riegel et al. (1986), the Posidonia Shale is characterized by a greatly reduced number of acritarchs, while *Nannoceratopsis gracilis* is the only recorded dinoflagellate cyst species. Wille & Gocht (1979) recorded a few species of non excysted dinoflagellate cysts, together with specimens referable to the Division Prasinophyta (Tasmanaceae, Cymatiosphaeraceae, Leiosphaeridiaceae, Pterospermellaceae), and small acritarchs.

The first appearance of taxa such as *Leptolepidites, Ischyosporites, Klukisporites, Manumia, Staplinisporites,* and *Clavatipollenites hughesii* in this zone, clearly indicates an Early Toarcian age (Couper 1958, Schulz 1967, Herngren & de Boer 1974, Morbey 1978, Hoelstad 1985, Lund & Pedersen 1985) (fig. 4). Zone B from the Vardekløft Ravine, Jameson Land, East Greenland (Lund & Pedersen 1985) (fig. 6), referred to Early Toarcian (to Late Pliensbachian), consisted of an assemblage that compares very well to the *Spheripollenites – Leptolepidites* Zone, with 75% *Spheripollenites,* the first appearance of *Leptolepidites bossus, Ischyosporites variegatus,* and of *Manumia* spp.

Comparison with previous zonations proposed for the Danish region: The upper part of Bertelsen's (1979) Unit C4 from the Hobro-1 borehole (fig. 6) corresponds very well to the *Spheripollenites – Leptolepidites* Zone. More than 50% *Spheripollenites* was recorded in the sample which represents the upper part of Unit C4. The associated trend, as mentioned above, towards an increase in the relative abundance of *Corollina* and a decrease in bisaccate pollen grains, was also recognizable in the Hobro-1 borehole, where the relative abundance of the genus *Corollina* increased from 2.5% in the preceeding sample to 10.4%, and the bisaccate pollen grains showed an exceptionally low value of 2% of the total spore/pollen assemblage. The first appearance of *Ischyosporites variegatus* in this sample further comfirms the correlation.

Palynomorph assemblages comparable to the *Spheri-*

pollenites – Leptolepidites Zone are also present in the Haldager-1 and Børglum-1 boreholes (Helle Ravn Sørensen, pers. comm., 1989) at levels that have been referred to the late Early Jurassic-lowermost Middle Jurassic (Sorgenfrei & Buch 1964).

The *Perinopollenites elatoides* Zone

Occurrence: In Fjerritslev-2, sample Fj-16,c (1329m b.r.t.).

Reference section: The Fjerritslev-2 borehole, 1329m b.r.t. (sample Fj-16,c).

Base: At a distinct increase in abundance of *Perinopollenites elatoides,* and a concurrent decrease in *Corollina torosus* and *Spheripollenites psilatus.*

Between this zone and the previous one, there is a 232m interval (in the Fjerritslev-2 borehole) without any core recovery. The flora recorded from the cuttings samples from this interval (samples Fj-32,s, Fj-35,s, and Fj-38,s) shows a gradual increase in the relative abundance of *Perinopollenites elatoides* and a concurrent decrease of *Corollina torosus* and *Spheripollenites psilatus,* indicating that the *Perinopollenites elatoides* Zone succeeds the *Spheripollenites – Leptolepidites* Zone.

Top: The top of this zone is not defined in the present study. Hoelstad's (1985) definition of the boundary between his zone II and III could be adopted. This boundary is defined primarily by the concurrent increase in relative abundance of *Corollina torosus* and *Contignisporites problematicus* (junior synonym to *Crassitudisporites problematicus* (Couper 1958) Hiltman 1967, see p. 25).

Characteristics: Dominance of *Perinopollenites elatoides,* and a relatively low abundance of *Corollina torosus,* and of bisaccate pollen.

The genus *Spheripollenites* is recorded frequently, while the following species occur commonly: *Deltoidospora toralis, Pinuspollenites minimus, Marattisporites scabratus, Intrapunctisporis toralis, Deltoidospora minor, Araucariacidites australis, Monosulcites punctatus, Alisporites robustus, Monosulcites* cf. *punctatus, Exesipollenites tumulus, Clavatipollenites hughesii,* and the genus *Chasmatosporites.* The species *Ischyosporites variegatus, Manumia delcourtii, Leptolepidites major,* and *Staplinisporites telatus*, known from the latest Early Jurassic or younger strata, occur sporadically. Generally the non-saccate pollen dominate the spore/pollen assemblage, while the saccate pollen and the spores form only a minor part.

The aquatic palynomorphs are dominated by acanthomorphe acritarchs. *Nannoceratopsis gracilis* and *Nannoceratopsis* cf. *senex* were recorded sporadically.

Suggested age: Middle Jurassic. *Leptolepidites major* and *Manumia delcourtii* are both known to appear at the Pliensbachian-Toarcian boundary (Schulz & Mai 1966, Schulz 1967, Herngren & de Boer 1974, Morbey 1978) (fig. 4). *Ischyosporites variegatus* is known from the Toarcian in North Germany and in the Netherlands (Schulz 1967, Herngren & de Boer 1974), from the Toarcian-Aalenian boundary in France (Srivastava 1987), and from the Bajocian in Britain (Couper 1958). *Staplinisporites telatus* is known from the upper part of the Toarcian (Schulz 1967, Morbey 1978, Lund & Pedersen 1985).

The *Perinopollenites elatoides* Zone corresponds rather well to the lower part of Hoelstad's (1985) Zone II from Bornholm, which has been assigned an Aalenian age (fig. 6). The lower part of Hoelstad's Zone II is characterized, in part, by relatively high abundances of *Perinopollenites elatoides,* and the concurrent occurrence of all recognized species of the genera *Leptolepidites* and *Lycopodiumsporites.* Furthermore, the species *Manumia delcourtii* (= *Manumia variverrucata*) first appear at the lower boundary of Hoelstad's (1985) Zone II, together with several other mainly Middle Jurassic species, many of which, however, were not recorded in this study. Zone II is also characterized by a high relative abundance of pollen (mainly non-saccate) relative to spores, which is also the case in the *Perinopollenites elatoides* Zone.

Bertelsen's (1979) Zone D from the Hobro-1 borehole, dated as Middle Jurassic, is characterized by a dominance of *Perinopollenites elatoides,* and by a complete absence of *Corollina.* In addition, several, mainly Middle Jurassic taxa, including *Manumia delcourtii* (= *Converrucosisporites variverrucatus*) and *Leptolepidites major* were recorded by Bertelsen at this level.

A maximum of *Perinopollenites elatoides* was recorded from Subassemblage C1 (Lund & Pedersen 1985) from the Vardekløft Ravine, Jameson Land, East Greenland, together with *Leptolepidites bossus* and *Leptolepidites major.* This subassemblage was assigned a Middle to Late Bajocian age. The sporadic record of *Nannoceratopsis gracilis* and *Nannoceratopsis* cf. *senex* indicates an age not younger than the Bathonian-Callovian boundary (Schulz & Mai 1966, Thusu 1978, Woollam & Riding 1983) (fig. 5).

Comparison with previous zonations proposed for the Danish region: The *Perinopollenites elatoides* Zone can possibly be correlated with Bertelsen's (1979) Zone D from the Hobro-1 borehole (fig. 6). Furthermore, palynomorph assemblages comparable to the *Perinopollenites elatoides* Zone have been recorded in the Børglum-1 and Haldager-1 boreholes, immediately above a level comparable with the *Spheripollenites – Leptolepidites* Zone as defined here (Helle Ravn Sørensen, pers. comm. 1989).

Definition of dinoflagellate cyst zones

Four dinoflagellate cyst zones are defined (fig. 6): The *Rhaetogonyaulax rhaetica* Zone, the *Dapcodinium priscum* Zone, the *Liasidium variabile* Zone, and the *Nannoceratopsis gracilis* Zone. They are all recognizable in several sections in the Danish region, and are therefore preliminarily proposed for use throughout the Danish Subbasin. Previous records of the stratigraphically most important species in the Danish region are briefly mentioned.

The *Rhaetogonyaulax rhaetica* Zone

Occurrence: In Fjerritslev-2, samples Fj-2,c and Fj-3,c (2304m-2303m b.r.t.), and in Stenlille-2, samples St-1,c to St-3,c (1513m-1510m b.r.t.).

Reference section: The Fjerritslev-2 borehole, 2304m-2303m b.r.t. (samples Fj-2,c and Fj-3,c).

Base: At the first joint occurrence of the two species *Rhaetogonyaulax rhaetica* and *Dapcodinium priscum.*

Top: At the last occurrence of *Rhaetogonyaulax rhaetica.*

Characteristics: This zone is characterized by the presence together of the species *Rhaetogonyaulax rhaetica* and *Dapcodinium priscum.* Other dinoflagellate cyst species occur only sporadically.

Suggested age: Rhaetian. The *Rhaetogonyaulax rhaetica* Zone proposed by Woollam & Riding (1983) (defined by the presence and abundance of *Rhaetogonyaulax rhaetica*), was dated as Rhaetian. The *Rhaetogonyaulax rhaetica* Zone proposed by Morbey (1978) was dated as Rhaetian to earliest Hettangian (fig. 6). The range of *Rhaetogonyaulax rhaetica* and *Dapcodinium priscum* according to the literature is shown in fig. 5.

Comparison with earlier recordings in the Danish region: In the Gassum-1 borehole the association of *Rhaetogonyaulax rhaetica* and *Dapcodinium priscum* was recorded from two samples, taken at 1587m and 1588m b.r.t. (Marianne Vasard Nielsen, pers. comm., 1988).

The *Dapcodinium priscum* Zone

Occurrence: In Fjerritslev-2, sample Fj-4,c (2106m b.r.t.), in Frederikshavn-2, samples Frh-1,c to Frh-12,c (930m-880m b.r.t.), and in Stenlille-2, samples St-5,c to St-9,w (1496m-1390m b.r.t.).

Reference section: The Stenlille-2 borehole, 1496m-1390m b.r.t. (samples St-5,c to St-9,w).

Base: Immediately above the last occurrence of *Rhaetogonyaulax rhaetica.*

Top: At the last occurrence of *Dapcodinium priscum.*

Characteristics: This zone is characterized by the presence of *Dapcodinium priscum,* and the absence of *Rhaetogonyaulax rhaetica.* Other dinoflagellate cyst species occur only sporadically.

Suggested age: latest Rhaetian to earliest Sinemurian. According to Thusu (1978), Wille & Gocht (1979) and Brenner (1986) *Dapcodinium priscum* does not range beyond the Hettangian, while Morbey (1978), Woollam & Riding (1983), and Riding (1984) indicated a range of this species into the Early Sinemurian (see fig. 5). *Dapcodinium priscum* was recorded in the Gassum-1 borehole from samples dated as Early Sinemurian, based on ostracods and miospores (Dybkjær 1988, the range-chart).

Comparison with earlier recordings in the Danish region: Evitt (1961a) recorded *Dapcodinium priscum* from the Gassum-1 borehole in the core interval 1440m – 1434m b.r.t. (dated as Early Sinemurian by Michelsen 1975, on the basis of ostracods). According to Dybkjær (1988), *Dapcodinium priscum* occurs, without *Rhaetogonyaulax rhaetica,* from 1534m to 1420m b.r.t. in Gassum-1 (samples Ga-3 to Ga-26), an interval that was referred to uppermost Rhaetian to Early Sinemurian on the basis of palynomorphs and ostracods (Dybkjær 1988).

Bertelsen (1979) recorded "cf. *Dapcodinium*" in Hobro-1, in samples dated as Early Jurassic. Lund (1977) recorded "cf. Dapcodinium" in the Rødby-1 borehole from two samples dated as Late Rhaetian (Upper Rhaetic sensu germanico) and Hettangian, respectively.

The *Liasidium variabile* Zone

Occurrence: In Fjerritslev-2, in samples Fj-5,c to Fj-13,s (2105m-2038m b.r.t.), and in Stenlille-2, samples St-1,s to St-2,s (1359m-1341m b.r.t.).

Reference section: The Fjerritslev-2 borehole, 2105m-2038m b.r.t. (samples Fj-5,c to Fj-13,s).

Base: At the first appearance of *Liasidium variabile.* According to Woollam and Riding (1983), there is an interval (their Subzone B of the *Dapcodinium priscum* Zone (fig. 6)) between the last occurrence of *Dapcodinium priscum* and the first appearance of *Liasidium variabile* where no dinoflagellate cyst species are recorded. Riding (1984), however, extended the range of *Dapcodinium priscum* to cover all of the Early Sinemurian, and Subzone B was thus no longer recognized. No such barren interval was recognized in the core samples from the Fjerritslev-2 borehole, but in the Gassum-1 borehole the interval covering the sequence from 1401m to 1376m b.r.t. (samples GA-29 to GA-33) could correspond to Subzone B of Woollam & Riding (1983) (Dybkjær 1988, the range-chart).

Top: At the last occurrence of *Liasidium variabile.*

Characteristics: This zone is characterized by the presence of *Liasidium variabile.* Other dinoflagellate cyst species occur only sporadically.

Suggested age: Sinemurian. According to Thusu (1978) and Morbey (1978), *Liasidium variabile* ranges throughout the Sinemurian. According to Warrington (1981), Woollam & Riding (1983), and Riding (1984), the range is restricted to the Late Sinemurian. Brenner (1986), however, recorded this species from samples referred to the uppermost Hettangian (fig. 5). In the Gassum-1 borehole *Liasidium variabile* was recorded some distance above the Hettangian-Sinemurian boundary (determined by ostracods and miospores) (Dybkjær 1988).

Comparison with earlier recordings in the Danish region: In sample GA-36 (1373m b.r.t.), in the Gassum-1 borehole, *Liasidium variabile* was recorded in large numbers (Dybkjær 1988).

The *Nannoceratopsis gracilis* Zone

Occurrence: In Fjerritslev-2, samples Fj-15,c and Fj-16,c (1561m-1329m b.r.t.), in Frederikshavn-2, samples Frh-15,c to Frh-22,s (789m-772m b.r.t.), and in Stenlille-2, samples St-11,w to St-16,w (1258m-1228m b.r.t.).

Reference section: The Frederikshavn-2 borehole 789m-772m b.r.t. (samples Frh-15,c to Frh-22,s).

Base: At the first appearance of *Nannoceratopsis gracilis,* and/or *Nannoceratopsis* cf. *senex.*

In the Fjerritslev-2 borehole there is an interval between this zone and the *Liasidium variabile* Zone below, comprising samples Fj-7,c to Fj-12,c where no dinoflagellate cyst species were recorded. This interval probably corresponds to Subzone B of the *Liasidium variabile* Zone, proposed by Woollam & Riding (1983) (fig. 6).

Top: No definite upper boundary was recognized in this study. Above the *Nannoceratopsis gracilis* Superzone, Woollam & Riding (1983) recorded the incoming of widespread ctenidodinioid dinocysts. The incoming of this group could be used to define this boundary.

Characteristics: The presence of *Nannoceratopsis gracilis,* and/or *Nannoceratopsis* cf. *senex.* An additional dinoflagellate cyst species, Dinocyst sp. 1, was recorded from this zone, often in large numbers.

Age: Late Pliensbachian to ?Bajocian/Bathonian. According to several earlier investigations, *Nannoceratopsis gracilis* has its first appearance close to the Early-Late Pliensbachian boundary (Evitt 1961b, Schulz & Mai 1966, Wille & Gocht 1979, Warrington 1981, Woollam & Riding 1983), although Morbey (1978) indicated that the species also occurs sporadically in the Early Pliensbachian (fig. 5).

Nannoceratopsis gracilis has not been recorded above the Bathonian/Callovian boundary (Schulz & Mai 1966, Thusu 1978, Woollam & Riding 1983). Furthermore, according to Woollam and Riding (1983), the widespread record of ctenidodinioid dinocysts begins at the Bajocian/Bathonian boundary. This event was not recorded here.

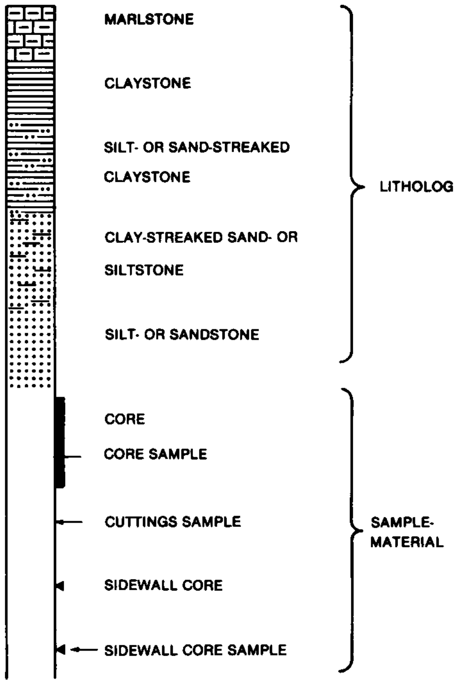
Comparison with earlier recordings in the Danish region: Specimens referred to *Nannoceratopsis gracilis* have been recorded from the Gassum-1 borehole, from samples dated as Late Pliensbachian on the basis of ammonites and ostracods (Evitt 1961b, Dybkjær 1988).

Bertelsen (1979) recorded *Nannoceratopsis gracilis* in two samples from the Hobro-1 borehole. The species was recorded to occur commonly in a sample assigned a Late Pliensbachian age, and more sporadically in a sample assigned a Toarcian age on the basis of palynomorphs and ostracods.

Stratigraphic conclusions

The general palynomorph assemblages from each borehole are discussed below, on the basis of the proposed spore/pollen zonation and dinoflagellate cyst zonation. The chronostratigraphical subdivision of each borehole will also be presented.

LEGEND (for figs.7-10):



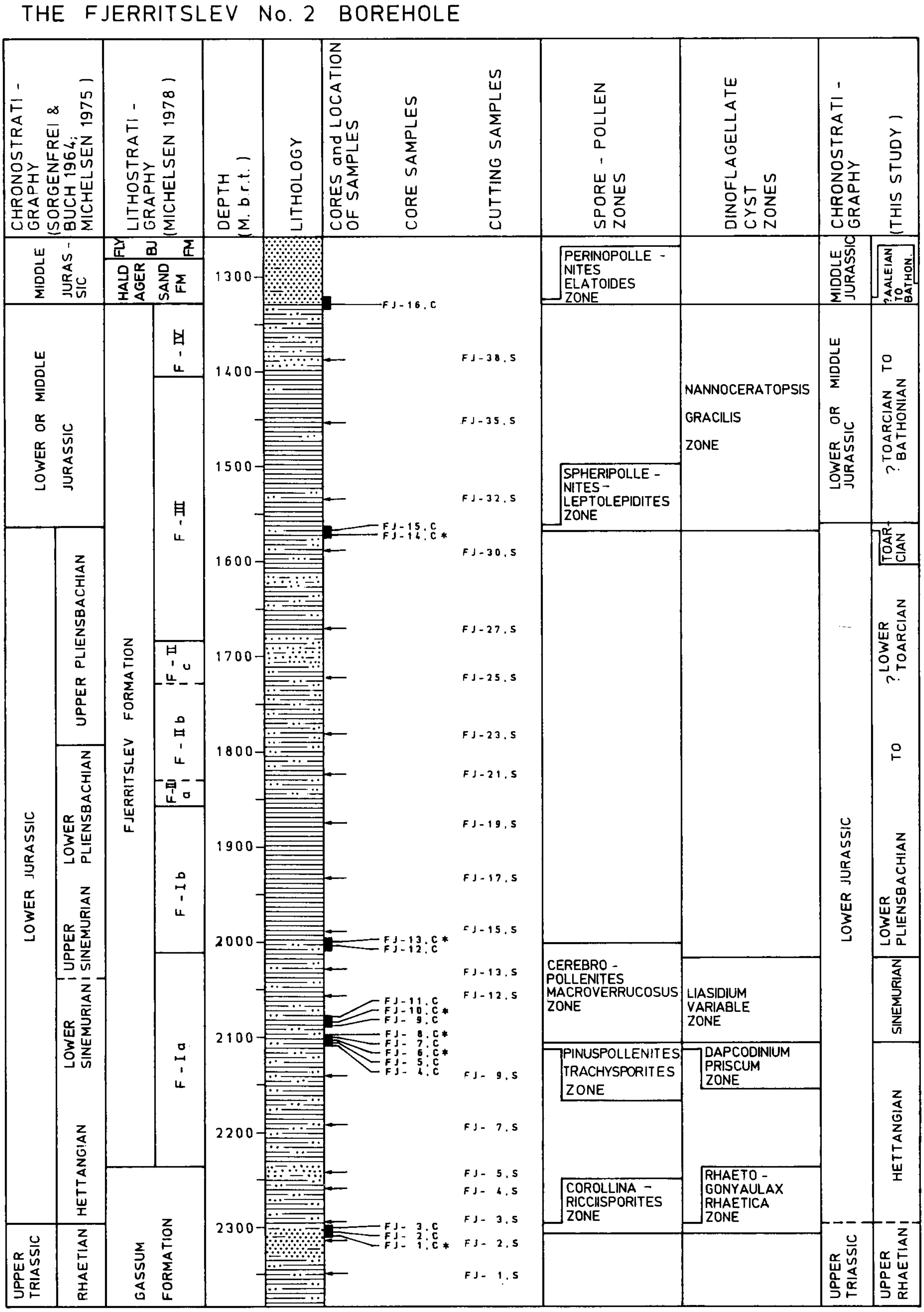


Fig. 7. The Lower Jurassic sequence of the Fjerritslev-2 borehole, showing the distribution of samples, palynological zones, and chronostratigraphy. Samples only used for the palynofacies investigation are marked by an asterisk.

A few core samples that could not be referred to any of the proposed zones are treated seperately as "unnamed intervals", and their ages are discussed.

The palynological zonations and stratigraphical conclusions for each borehole are shown in figs 7–10. In these figures, the zones are only indicated where they have been recorded with certainty. The indicated lower boundary of each zone is based on data from core samples, while the upper boundary is based on data from either core samples or last-occurrences in cuttings samples.

Fjerritslev-2

Only a few, short cores were taken from the Jurassic sequence in this borehole (Fig. 7). It is not possible to deduce whether or not caving has contributed to the cuttings samples from this borehole. Thus only last occurrences have been used as stratigraphical markers from the cuttings samples.

Spore/pollen zonation:

The *Corollina – Ricciisporites* Zone:
Samples Fj-2,c and Fj-3,c (2304m-2303m b.r.t.).
This zone is very well developed in the Fjerritslev-2 borehole. *Corollina torosus* clearly dominates the palynoflora assemblage (42% and 35% respectively), while *Ricciisporites tuberculatus* occurs commonly (about 4% and 11% respectively). Several, mainly Rhaetian, species occur sporadically to commonly: Cf. *Taneaesporites, Zebrasporites laevigatus, Zebrasporites interscriptus, Densosporites fissus, Triancoraesporites ancorae,* and *Polypodiisporites polymicroforatus.*

Stratigraphically useful last-occurrences:
In the cuttings sample Fj-3,s (2294m b.r.t.) the species *Ricciisporites tuberculatus, Zebrasporites interscriptus,* and *Polypodiisporites polymicroforatus* all have their last occurrences, indicating an age not younger than earliest Hettangian for this level.

The *Pinuspollenites – Trachysporites* Zone:
Sample Fj-4,c (2106m b.r.t.).
This sample is not typical of the *Pinuspollenites – Trachysporites* Zone. *Pinuspollenites minimus* only constitutes about 5% of the spore/pollen assemblage, and *Deltoidospora* toralis only 8%. With these exceptions, the general assemblage corresponds well with the *Pinuspollenites – Trachysporites* Zone. None of the mainly Rhaetian species known from the *Corollina – Ricciisporites* Zone were recorded, and no *Cerebropollenites macroverrucosus* were observed.

The *Cerebropollenites macroverrucosus* Zone:
Samples Fj-5,c to Fj-12,c (2105m-2003m b.r.t.).
Cerebropollenites macroverrucosus was only recorded sporadically in the samples composing this zone. *Perinopollenites elatoides* dominates the assemblage, together with *Pinuspollenites minimus* and *Deltoidospora toralis,* while *Corollina torosus* is reduced in abundance compared to the preceding zone, and only occurs commonly in this interval. A number of species appear for the first time in the lowermost sample in this zone, including *Protopinus scanicus, Schismatosporites ovalis, Cerebropollenites thiergartii, Camarozonosporites rudis, Stereisporites cicatricosus, Uvaesporites argenteaeformis* and three species of the genus Chasmatosporites.

The *Spheripollenites – Leptolepidites* Zone:
Sample Fj-15,c (1561m b.r.t.).
The palynomorph assemblage in this sample is clearly dominated by *Corollina torosus,* while *Spheripollenites psilatus* constitutes 13%. The stratigraphically important species *Leptolepidites major,* and *Tripartina variabilis* appear in this sample.

As mentioned earlier, the maximum of *Spheripollenites* in the Early Toarcian coincides with a maximum of *Corollina,* and a minimum of bisaccate pollen (Lund & Pedersen 1985). In sample Fj-15, c, *Corollina torosus* constitutes about 36% of the total spore/pollen assemblage, showing a distinct increase from 9% in the previous sample (Fj-12,c), whilst the bisaccate pollen shows a decrease from about 34% to 17%.

The *Perinopollenites elatoides* Zone:
Sample Fj-16,c (1329m b.r.t.).
The species *Perinopollenites elatoides* forms about 26% of the terrestrial palynomorphs in this sample, while *Corollina torosus* only constitutes about 5%.

Dinoflagellate cyst zonation:

The *Rhaetogonyaulax rhaetica* Zone:
Samples Fj-2,c and Fj-3,c (2304m-2303m b.r.t.).
Rhaetogonyaulax rhaetica was recorded in low numbers in both samples, while *Dapcodinium priscum* is common to frequent.

The *Dapcodinium priscum* Zone:
Sample Fj-4,c (2106m b.r.t.).
A single specimen of *Dapcodinium priscum* was recorded from this sample.

The *Liasidium variabile* Zone:
Samples Fj-5,c (2105m b.r.t.) to Fj-13,s (2038m b.r.t.).
Only a single specimen was recorded in sample Fj-5,c during counting, but several specimens were observed whilst scanning the slide. *Liasidium variabile* was recorded in large numbers in the cuttings samples Fj-12,s and Fj-13,s.

Unnamed interval:
Sample Fj-12,c (2003m b.r.t.). This sample shows none of the dinoflagellate cyst species used for zonation, and is thus not referred to any dinoflagellate cyst zone.

The *Nannoceratopsis gracilis* Zone:
Samples Fj-15,c and Fj-16,c (1561m-1329m b.r.t.).
Nannoceratopsis gracilis was recorded commonly in sample Fj-15,c whereas *Nannoceratopsis* cf. *senex* and *Nannoceratopsis* cf. *pellucida* were recorded sporad-

ically. Only a few specimens of *Nannoceratopsis gracilis* were recorded in sample Fj-16,c.

The chronostratigraphical subdivision of the Fjerritslev-2 sequence is thus suggested to be as follows (see also fig. 7):

1329m b.r.t. (Fj-16,c)	Middle Jurassic ?Aalenian – Bathonian)
1561m b.r.t. (Fj-15,c)	Toarcian
2038m-2105m b.r.t. (Fj-13,s to Fj-5,c)	Sinemurian
2106m (Fj-4,c)	Hettangian
2294m (Fj-3,s)	uppermost Rhaetian lowermost Hettangian
2303m-2348m b.r.t. (Fj-3,c to Fj-1,s)	Upper Rhaetian

Frederikshavn-2

The cored intervals from this borehole are sparse (Fig. 8). Furthermore, several of the cuttings samples are seriously contaminated by material referable to the Barremian or Aptian (Early Cretaceous) (see discussion on p. 16–17). These factors in combination precluded detailed palynostratigraphy and dating. In addition, the palynomorph assemblage in this borehole generally shows less distinct stratigraphical changes than in the other investigated sequences (see the range-charts, enclosures 3 and 4).

Spore/pollen zonation:

The *Corollina – Ricciisporites* Zone:
Sample Frh-1,c (930m b.r.t.).
This zone is not well developed in Frederikshavn-2. *Ricciisporites tuberculatus* only occurs sporadically, and *Corollina torosus* is not as dominant as in the other boreholes (constituting 16% of the terrestrial palynomorphs). The species *Deltoidospora toralis,* and *Perinopollenites elatoides* occur frequently (11% and 10% respectively), whereas the mainly Rhaetian species *Polypodiisporites ipsviciensis* occurs sporadically. The terrestrial palynomorph assemblage in this sample is composed of roughly equal amounts of spores and non-saccate pollen (43% and 44% respectively), while the saccate pollen only constitutes 13%.

Stratigraphically useful last-occurrence:
In sample Frh-5,s (897m b.r.t.) *Zebrasporites interscriptus* has its last appearance, indicating an age not younger than Early Sinemurian.

The *Pinuspollenites – Trachysporites* Zone:
This zone was not recorded in Frederikshavn-2.

The *Cerebropollenites macroverrucosus* Zone:
Samples Frh-2,c to Frh-14,c (892m-851m b.r.t.).
Cerebropollenites macroverrucosus was recorded sporadically in this interval. *Lycopodiumsporites semimuris* appears at the base of this zone. The freshwater algae *Botryococcus* was sporadically to commonly recorded throughout the zone.

Stratigraphically useful last-occurrence:
Camarozonosporites rudis has its last appearance in sample Frh 11,s (862m b.r.t.), indicating an age not younger than Hettangian. This does not agree with the presence of *Cerebropollenites macroverrucosus* from Frh-2,c (892m b.r.t.), which indicates an age not older than Early Sinemurian. The *Camarozonosporites rudis* forms could be reworked.

Unnamed interval:
Sample Frh-15,c (789m b.r.t.).This sample is characterized by a dominance of *Perinopollenites elatoides, Pinuspollenites minimus,* and *Chasmatosporites hians.* Furthermore the stratigraphically important species *Staplinisporites telatus* and *Manumia delcourtii* were both recorded from this sample. In contrary to the samples above, relatively few *Corollina torosus* and many saccate pollen were recorded. No specimens referred to either *Leptolepidites* or *Ischyosporites* were recorded from this sample. Non-saccate pollen dominates the terrestrial palynomorphs, constituting 49%, while saccate pollen constitutes 21%, and spores 30%.

The first appearance of *Staplinisporites telatus* and *Manumia delcourtii* together indicate a Toarcian age for this sample (Schulz & Mai 1966, Schulz 1967, Herngren & de Boer 1974, Morbey 1978) (fig. 4).

The *Spheripollenites – Leptolepidites* Zone:
Samples Frh-17,c to Frh-22,c (787m-782m b.r.t.).
The abundance of *Spheripollenites* in these samples is very low compared to the other boreholes, but the first appearance of both *Leptolepidites major* and *Ischyosporites variegatus* in sample Frh 17,c, and the coincident distinct increase in *Corollina torosus* (from 8% in sample Frh-15,c to 23% in Frh-17,c), and decrease of the saccate pollen (from 21% in sample Frh-15,c, to 13% in Frh 17,c), refers this level to the *Spheripollenites – Leptolepidites* Zone. *Spheripollenites psilatus* was only commonly recorded from the two youngest samples in this zone. The stratigraphically important species *Manumia delcourtii* was recorded sporadically.

The *Perinopollenites elatoides* Zone:
This was not recorded in Frederikshavn-2.

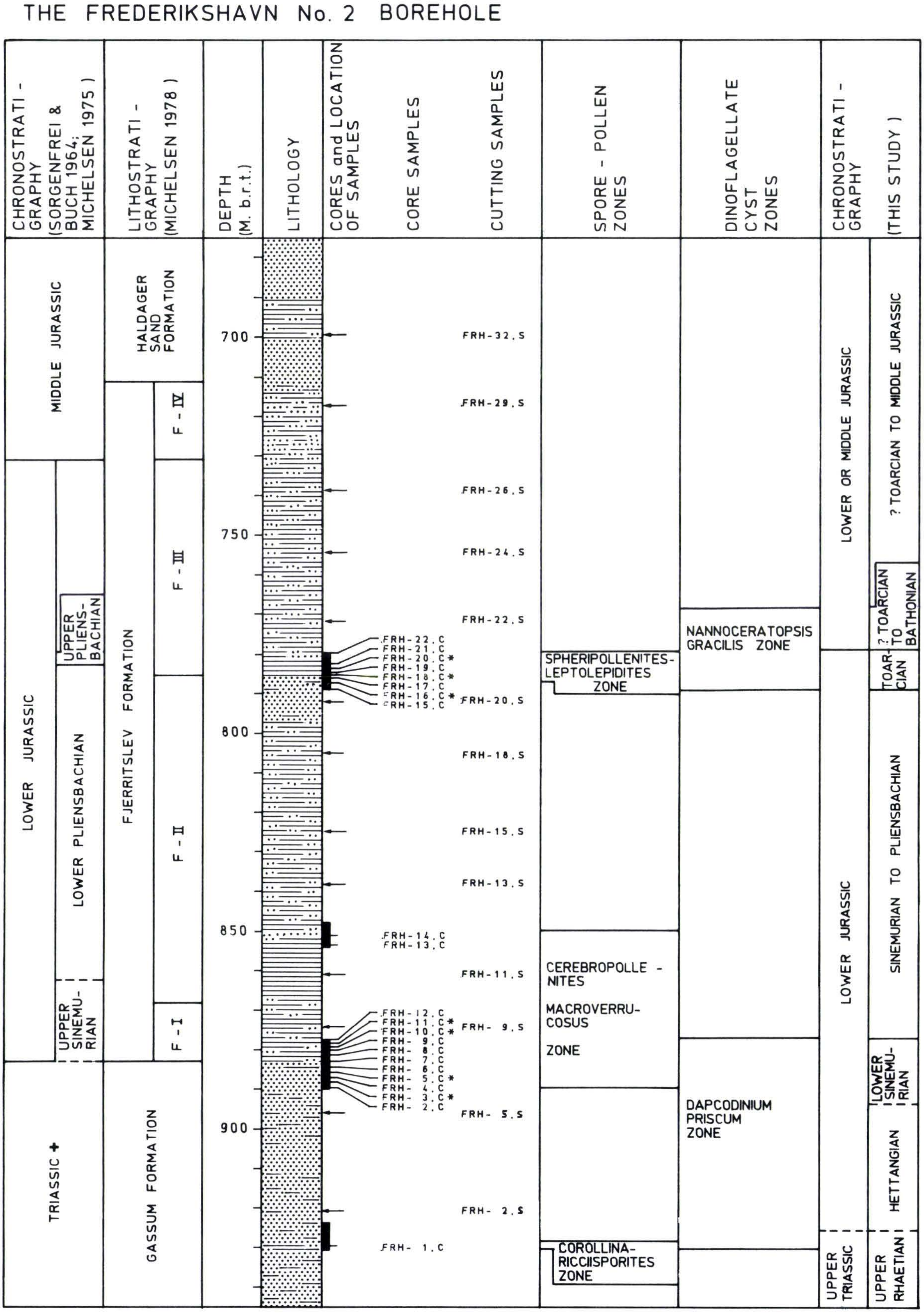


Fig. 8. The Lower Jurassic sequence of the Frederikshavn-2 borehole, showing the distribution of samples, palynological zones, and chronostratigraphy. Legend: see text to fig. 7.

+*: This complete sequence was previously referred erroneously to the Triassic (Michelsen, 1975, text-fig. 3). The Triassic- Jurassic boundary probably occurs somewhere within the sequence referred to the Gassum Formation (pers. comm., Michelsen, 1989).*

Dinoflagellate cyst zonation:

The *Rhaetogonyaulax rhaetica* Zone:
This was not recorded from this borehole.

The *Dapcodinium priscum* Zone:
Samples Frh-1,c to Frh-12,c (930m-880m b.r.t.). *Dapcodinium priscum* was only recorded sporadically in the lower part of the zone, but was more common in sample Frh-12,c.

Unnamed interval:
Samples Frh-13,c and Frh-14,c (854m-851m b.r.t.). As the samples Frh-13,c and Frh-14,c contain none of the dinoflagellate cyst species that define the zones, they are not referred to any dinoflagellate cyst zones.

The *Liasidium variabile* Zone:
This was not recorded in this borehole.

The *Nannoceratopsis gracilis* Zone:
Samples Frh-15,c to Frh-22,s (789m-772m b.r.t.). *Nannoceratopsis gracilis* was recorded commonly to frequently throughout this interval, and *Nannoceratopsis* cf. *senex* was recorded from sample Frh-22,c.

The following chronostratigraphical subdivision of the sequence from the Frederikshavn-2 borehole is suggested:

772m b.r.t. (Frh-22,s)	?Toarcian to Bathonian
782m-789m b.r.t. (Frh-22,c to Frh-15,c)	Toarcian
880m-892m b.r.t. (Frh-12,c to Frh-2,c)	lowermost Sinemurian
930m b.r.t. (Frh-1,c)	transitional Rhaetian – Hettangian

Stenlille-2

This borehole was intensively cored in the lower and upper part of the investigated sequence, but the middle part is only represented by cuttings samples (see fig. 9). It is presumed that caving is responsible for the palynomorph assemblage in sample St-5,s (see the range-charts, tables 5 and 6). The caved material is thought to come from a level close to sample St-15,w, as the palynomorph assemblage in St-5,s correlates very well with this sample. Other distinct signs of caving were not recorded in the cuttings samples from this borehole.

Spore-pollen zonation:

The *Corollina – Ricciisporites* Zone:
Sample St-1,c to St-3,c (1513m-1510m b.r.t.).
The lowermost sample in this borehole (sample St-1,c, 1513m b.r.t.) yielded a very distinct palynomorph assemblage, overwhelmingly dominated by *Ricciisporites tuberculatus* (92%). Only a few other species were recorded from this level, including *Densosporites fissus, Calamospora tener, Corollina torosus,* and *Deltoidospora toralis*. None of the mainly Early Rhaetian species *Rhaetipollis germanicus, Granuloperculatipollis rudis,* and *Ovalipollis ovalis,* and none of the mainly Late Rhaetian species characterizing the *Corollina – Ricciisporites* Zone were recorded from this sample. The dominance of *Ricciisporites tuberculatus* is therefore thought to be a function of facies dependency, and the sample St-1,c should possibly be seen as belonging to the *Corollina – Ricciisporites* Zone.

Samples St-2,c, and St-3,c (1512m to 1510m b.r.t.) yielded a palynoflora assemblage most typical of the *Corollina – Ricciisporites* Zone, with a marked dominance of *Corollina torosus* (39% and 21% respectively), and with common occurrences of *Ricciisporites tuberculatus* (6–7%), and several mainly Rhaetian spore/pollen species: *Densosporites cavernatus, Ovalipollis ovalis, Cingulizonates rhaeticus, Camarazonosporites rudis, Aratrisporites fimbriatus, Semiretisporis goetae, Triancoraesporites reticulatus, Limbosporites lundbladii, Zebrasporites interscriptus, Perinosporites thuringiacus, Triancoraesporites ancorae,* and *Polypodiisporites polymicroforatus*. The freshwater algae *Botryococcus* occurs commonly.

Unnamed interval:
Sample St-5,c (1496m b.r.t.). In this sample, a palynomorph assemblage was recorded that could not be referred to any of the proposed zones. The assemblage is dominated by *Deltoidospora toralis* (constituting about 17% of the spore/pollen assemblage), and by *Calamospora tener* (constituting about 14%). *Corollina torosus* only constitutes a minor part (about 3%) of this assemblage. None of the mainly Rhaetian species that were recorded from the zone below, were recorded from this sample, except for sporadic occurrences of *Ricciisporites tuberculatus* (<1%). The species *Perinopollenites elatoides, Marattisporites scabratus,* and *Punctatisporites globosus* occur frequently, while *Trachysporites fuscus, Trachysporites sparsus, Punctatisporites major* and species of the genus *Stereisporites* are common. Spores overwhelmingly dominate this assemblage, constituting 82% of the spore/pollen assemblage.

This assemblage can be tentatively assigned a basal Hettangian age. As *Ricciisporites tuberculatus* is the only representative of the Rhaetian species, the assemblage is presumably slightly younger than the "topmost Upper Rhaetic?" assemblage from the Rødby-1 borehole (Lund 1977) (see discussion concerning the *Corollina – Ricciisporites* Zone, p. 37, this study). The dominance of *Deltoidospora toralis* and the common occurrence of *Trachysporites fuscus* points towards a Hettangian age. The sporadic occurrence of *Pinuspollenites minimus* is probably facies controlled.

THE STENLILLE No. 2 BOREHOLE

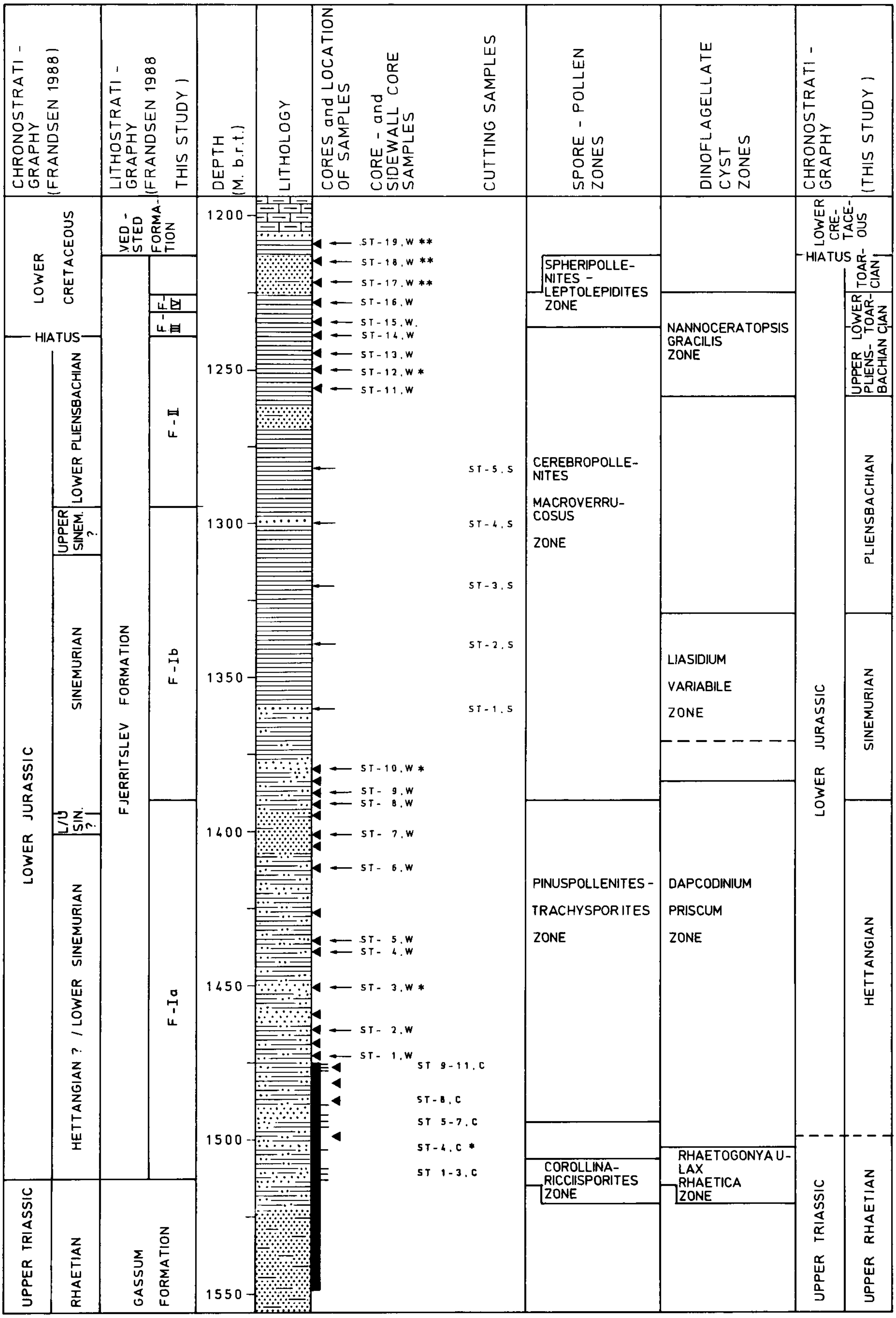


Fig. 9. The Lower Jurassic sequence of the Stenlille-2 borehole, showing the distribution of samples, palynological zones, and chronostratigraphy. Legend: see text to fig. 7.

The indicated presence of F-III and F-IV Member in this borehole is a proposal, based on biostratigraphic- and palynofacies correlations from this study (see discussion on p. 52).

The general assemblage, the high abundance of *Deltoidospora toralis*, and the low abundances of *Corollina torosus* and *Pinuspollenites minimus* correspond very well with the upper part of the Late Rhaetian Zone A (Dybkjær 1988), with the exception of the absence of the Rhaetian types recorded in Zone A.

The *Pinuspollenites – Trachysporites* Zone:
Samples St-6,c to St-8,w (1494m-1392m b.r.t.)
This zone is very well developed in Stenlille-2. *Deltoidospora toralis* clearly dominates the assemblage (with a relative abundance between 14% and 32 %). *Pinuspollenites minimus* is relatively abundant at the base of this zone, (12–19% in samples St-6,c to St-1,w), decreasing towards the top. The mainly Rhaetian species, *Zebrasporites interscriptus* and *Ricciisporites tuberculatus,* occur sporadically in the lower part of the zone. *Botryococcus* occurs sporadically.

The *Cerebropollenites macroverrucosus* Zone:
Samples St-9,w to St-14,w (1390m-1320m b.r.t.).
Cerebropollenites macroverrucosus occurs sporadically to commonly throughout this interval. The species *Deltoidospora toralis* decreases in abundance upwards, whereas *Pinuspollenites minimus* shows a distinct increase in abundance upwards in the zone. The species *Lycopodiumsporites semimuris* has its first appearance in sample St-8,w (1392m b.r.t.), immediately below the base of this zone.

The *Spheripollenites – Leptolepidites* Zone:
Samples St-15,w, and St-16,w (1234m-1228m b.r.t.).
The genus *Spheripollenites psilatus* is overwhelmingly dominant in these samples, constituting about 99% of St-15,w and about 68% of St-16,w; this is clearly a reflection of the Early Toarcian anoxic event (see discussion on p. 64). Sample St-16,w shows the characteristic features of the zone i.e. the high relative abundance of *Corollina torsosus* and the paucity of saccate pollen. *Corollina torosus, Deltoidospora toralis,* and *Intrapunctisporis toralis* occur sporadically in sample St-15,w. Three species of *Leptolepidites* were recorded in sample St-16,w, together with *Striatella* spp. in atypically high abundance; this sample also included *Manumia delcourtii* and *Tripartina variabilis.*

The *Perinopollenites elatoides* Zone:
This zone was not recorded in Stenlille-2.

Dinoflagellate cyst zonation:

The *Rhaetogonyaulax rhaetica* Zone:
Samples St-1,c to St-3,c (1513m-1510m b.r.t.).
Sample St-1,c is referred to the *Rhaetogonyaulax rhaetica* Zone on the basis of frequent records of *Dapcodinium priscum* from all three samples, combined with the occurrence of *Rhaetogonyaulax rhaetica* in the two upper samples. *Rhaetogonyaulax rhaetica* was observed frequently in sample St-2,c, whereas only a single specimen was recorded from St-3,c.

The *Dapcodinium priscum* Zone:
Samples St-5,c to St-9,w (1496m-1390m b.r.t.).
Dapcodinium priscum occurs regularly in all samples in this zone. *Tasmanites* occurs sporadically, and *Leiofusa jurassica* occurs frequently in sample St-8,c.

The *Liasidium variabile* Zone:
Samples St-1,s to St-2,s (1359m-1341m b.r.t.).
The location of the lower boundary of this zone is questionable, as *Liasidium variabile* was only recorded from cuttings samples.

The *Nannoceratopsis gracilis* Zone:
Samples St-11,w to St-16,w (1258m-1228m b.r.t.).
Nannoceratopsis gracilis was recorded sporadically to commonly from all samples in this zone. In addition Dinocyst sp.1 was recorded from sample St-11,w, *Nannoceratopsis* sp.1 from sample St-14,w, and *Nannoceratopsis* cf. *senex* from samples St-15,w, and St-16,w.

Qualitative biostratigraphical examination of the uppermost sidewall cores from the Stenlille-2 borehole, St-17,w (1222m b.r.t.), St-18,w (1216m b.r.t.), and St-19,w (1210m b.r.t.) was carried out to clarify the location of the lower boundary of the Cretaceous and the age of the samples immediately below the Cretaceous.

The palynomorph assemblages recorded from samples St-17,w and St-18,w indicated a Toarcian age. These samples showed common occurrences of specimens referable to the genera *Ischyosporites, Leptolepidites* and *Manumia,* indicating a Toarcian to Middle Jurassic age. The species *Taurocusporites verrucatus* Schulz 1967 and *Polycingulatisporites liassicus* Schulz 1967 were also recorded. These two species both occur sporadically from the Norian to the lowermost Toarcian (Lias epsilon 1) and commonly in the upper part of the Early Toarcian and the lower part of the Late Toarcian (in Lias epsilon 2 to Lias zeta 2) in East Germany (Schulz & Mai 1966, Schulz 1967). Neither of these two species were recorded above the Toarcian in East Germany (Schulz & Mai 1966). No specimens indicative of an Early Cretaceous age were recorded from these samples.

The palynomorph assemblage recorded from sample St-19,w was overwhelmingly dominated by dinoflagellate cyst species indicating an Early Cretaceous age (e.g. *Pseudoceratium pelliferum* Gocht 1957, *Oligosphaeridium complex* (White 1842) Davey & Williams 1966, and *Kleithriasphaeridium corrugatum* Davey 1974. (See the range of these species in Heilmann-Clausen, 1987).

The lower boundary of the Cretaceous should thus be placed between samples St-18,w (1216m b.r.t.) and St-19,w (1210m b.r.t.). It is probably located at 1215m b.r.t., at the top of the sandstone sequence. This boundary represents an extensive hiatus, probably comprising the Middle and Late Jurassic.

Deposits of uppermost Early Jurassic age have not been recorded from the nearby Slagelse-1 borehole, possibly due to uplift of the Ringkøbing-Fyn High during the Mid Kimmerian Tectonic Phase.

The chronostratigraphical subdivision of the sequence investigated from the Stenlille-2 borehole is thus suggested to be as follows:

1210m b.r.t. (St-19,w)	Lower Cretaceous
Hiatus	
1216m-1222m b.r.t. (St-18,w to St-17,w)	Toarcian
1228m-1234m b.r.t. (St-16,w to St-15,w)	Lower Toarcian
1240m-1258m b.r.t. (St-14,w to St-11,w)	Upper Pliensbachian
1341m-1390m b.r.t. (St-2,s to St-9,w)	Sinemurian
1392m-1494m b.r.t. (St-8,w to St-6,c)	Hettangian
1496m b.r.t. (St-5,c)	basal Hettangian
1510m to 1513m b.r.t. (St-3,c to St-1,c)	Upper Rhaetian

Gassum-1

A spore/pollen zonation and dating of the Jurassic sequence in the Gassum-1 borehole was presented by Dybkjær (1988). However, on the basis of the dinoflagellate cyst zonation, and the dating proposed here, it was possible to propose a more detailed chronostratigraphical subdivision of the Jurassic sequence in this borehole. The dinoflagellate cyst zonation and the resulting dating are shown in fig. 10. All the investigated samples were core samples.

The *Rhaetogonyaulax rhaetica* Zone:
This zone was not recorded in Gassum-1.

The *Dapcodinium priscum* Zone:
Samples GA-3 to GA-26 (1513m-1420m b.r.t.).

The *Liasidium variabile* Zone:
Sample GA-36 (1373m b.r.t.).

The *Nannoceratopsis gracilis* Zone:
Samples GA-49 to GA-60 (1303m-1210m)

The following chronostratigraphical subdivision is proposed from a combination of this dinoflagellate cyst zonation and the previous spore/pollen zonation of Dybkjær (1988):

1144m-1149m b.r.t. (GA-71 to GA-67)	Middle Volgian
1173m b.r.t. (GA-65)	Kimmeridgian to Lower Volgian
Hiatus	
1210m-1303m b.r.t. (GA-60 to GA-49)	Upper Pliensbachian
1305m-1360m b.r.t. (GA-47 to GA-38)	Pliensbachian
1373m-1404m b.r.t. (GA-36 to GA-29)	Sinemurian
1420m-1439m b.r.t. (GA-26 to GA-20)	Lower Sinemurian
1464m-1513m b.r.t. (GA-18 to GA-4)	Hettangian
1534m-1536m b.r.t. (GA-3 to GA-1)	Upper Rhaetian

Comparison with previous work

Fjerritslev-2

The results of the present study correlate very well with the ostracod-stratigraphy presented by Michelsen (1975) (fig. 7), with the exception of the dating of the core 1561m-1564m b.r.t. According to Michelsen (1975), this core contains an ostracod fauna of Late Pliensbachian age, whereas the palynomorph assemblage indicates a Toarcian age.

Frederikshavn-2

The stratigraphical results of this study are broadly compatible with the ostracod-stratigraphy presented by Michelsen (1975) (fig. 8).

The core from 886m to 880m b.r.t. (samples Frh-8,c to Frh-12,c) is dated here as being of Early Sinemurian age on the basis of the presence of *Dapcodinium priscum*. The dating of this sequence as Late Sinemurian by Michelsen (1975) was based on the occurrence of the ostracod species *Progonoidea aucuticostata* which is only known from the Late Sinemurian.

There is also a difference in the dating of the cores from 789m to 783m b.r.t., and 783m to 780m b.r.t. (sample Frh-15,c to Frh-22,c). Michelsen (1975) assigned the first of these to the Early Pliensbachian, and the second to the Late Pliensbachian, while both sequences are dated as Toarcian in this study.

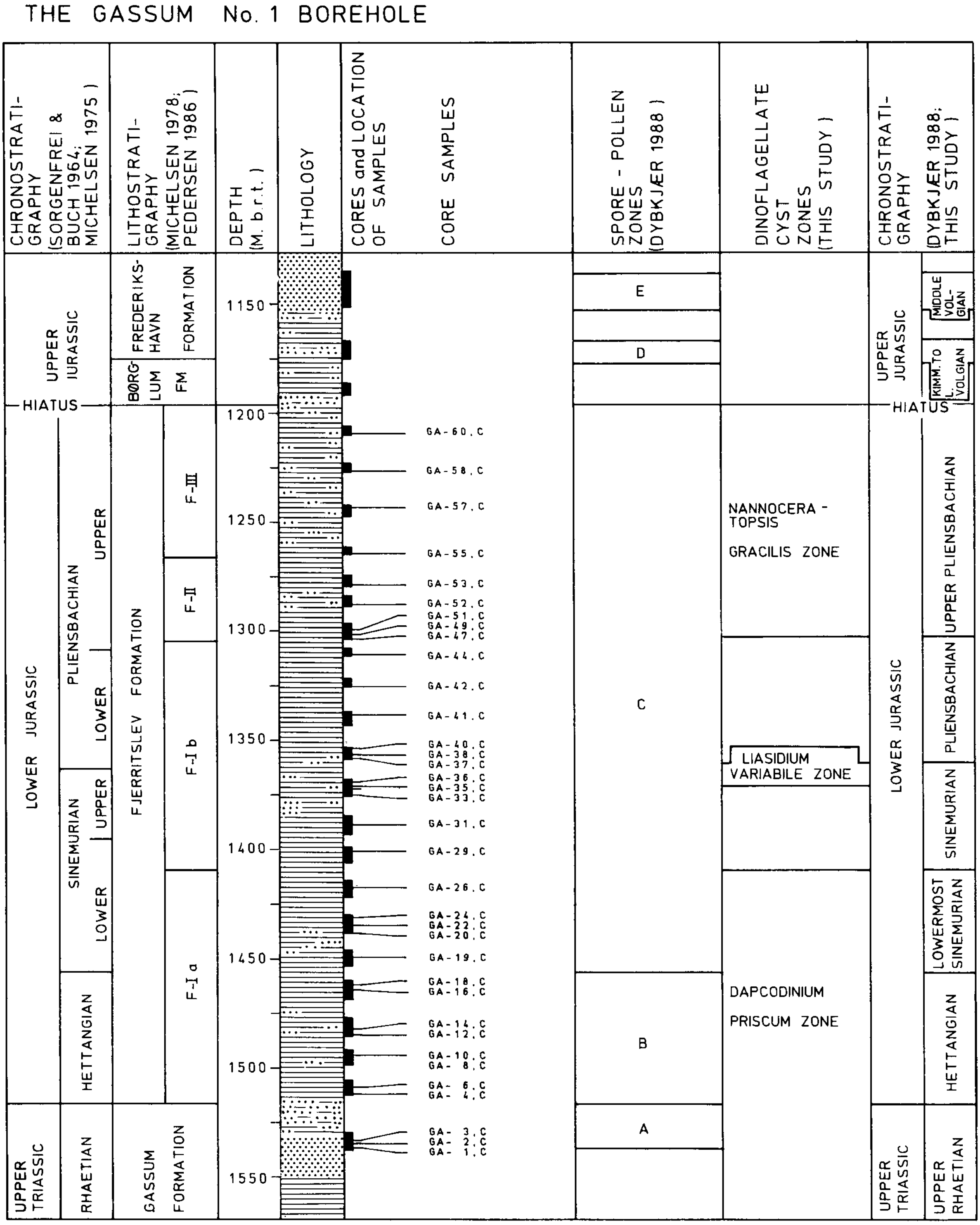

THE GASSUM No. 1 BOREHOLE

Fig. 10. The Lower Jurassic sequence of the Gassum-1 borehole, showing the distribution of samples, palynological zones, and chronostratigraphy. Legend: see text to fig. 7.

These disagreements concerning the dating of the sequences from the Fjerritslev-2 and Frederikshavn-2 boreholes indicate that an integrated biostratigraphical study, comprising palynomorphs as well as ostracods and other fossil-groups (especially ammonites) is necessary to clarify these problems.

Stenlille-2

No previous biostratigraphical studies of the Stenlille-2 borehole have been published. The chronostratigraphical subdivision shown in fig. 9, from an unpublished report by Frandsen (1988), is based on preliminary results from ostracod- and palynostratigraphy in Stenlille-1 (Michelsen 1980, Hansen 1981), correlated to Stenlille-2 by means of petrophysical logs.

This subdivision does not correlate very well with the stratigraphical results from the present study. The disagreements in the lower part of the sequence will not be discussed in detail, as the previous dating was only preliminary, but a major disagreement in the uppermost part of the investigated sequence will be discussed. The two sidewall core samples St-15,w and St 16,w (1234m and 1228m b.r.t.) are, in this study, assigned an Early Toarcian age, while the earlier studies (of cuttings samples) in Stenlille-1 indicated a Late Jurassic/Early Cretaceous age for this level. This disagreement is probably due to caving in the cuttings samples from Stenlille-1, used in the earlier investigations. The brief palynological investigation of samples St-17,w to St-19,w (this study) revealed that a major hiatus, comprising the Middle and Late Jurassic, is located between samples St-18,w (1216m b.r.t.) and St-19,w (1210m b.r.t.).

Gassum-1

The chronostratigraphical subdivision of the Jurassic sequence in Gassum-1 presented by Dybkjær (1988) has been improved in the present study by using the dinoflagellate cyst zonation. The resulting, more detailed, chronostratigraphical subdivision of the sequence corresponds very well with the subdivision of Michelsen (1975), based on ostracods.

Chronostratigraphic boundaries compared with lithostratigraphic units

An overall picture of the lateral and vertical distribution of the resulting chronostratigraphical boundaries in relation to the lithostratigraphical subdivision of Michelsen (1978) is shown in fig. 11. The ages of the members of the Fjerritslev Formation according to Michelsen (1978, fig. 3) are mentioned on p.10.

The suggested presence of the F-III and F-IV members in Stenlille-2 should be regarded solely as a proposal; it is NOT based on lithological evidence. A relationship with these lithological units is, however, strongly indicated by the kerogen assemblages recorded here, (see p. 64) and by the Toarcian age of the samples (St-15,w and St-16,w) representing this interval. The sandy sequence immediately below the hiatus in Stenlille-2, represented by sample St-17,w and St-18,w, was dated as Toarcian, but is not referred to any lithostratigraphic unit.

It is clear that the top of the Gassum Formation is diachronous, as also stated by Michelsen (1973, 1975, 1978). In the central and southern parts of the basin (e.g. in the Fjerritslev-2, Gassum-1 and Stenlille-2 boreholes) the sand-rich Gassum Formation was succeeded by mud-dominated deposits of the Fjerritslev Formation during topmost Rhaetian to Early Hettangian times, whereas, according to this study, this depositional shift did not occur in the northeastern parts of the basin, e.g. in the Frederikshavn-2 borehole, before the earliest Sinemurian. According to Michelsen (1975), the overstepping in the northeastern parts did not take place until the Late Sinemurian.

The transition from F-Ia member to F-Ib member is dated as Sinemurian in the Gassum-1 and Stenlille-2 boreholes. In Fjerritslev-2, this transition is dated as Sinemurian or at the Sinemurian-Pliensbachian boundary. In Frederikshavn-2 the “old” F-I member (as defined by Michelsen 1978) has not been subdivided. According to Michelsen (1978, fig. 3) the F-Ia member is of Hettangian to Early Sinemurian age, whereas the F-Ib member is of Late Sinemurian to earliest Early Pliensbachian age.

The boundary between the F-Ib member (or the “old” F-I member in Frederikshavn-2) and the F-II member occurs within the Sinemurian or Pliensbachian in all four boreholes. It was not possible to date this event more precisely on the basis of palynological evidence.

The boundary between the F-II member and the F-III member occurs within the Pliensbachian in the Gassum-1 borehole. In Stenlille-2 and Frederikshavn-2, this contact occurs at the Pliensbachian-Toarcian boundary, or (in the latter borehole) within the Toarcian. In Fjerritslev-2, this boundary can not be dated more accurately than Pliensbachian or Toarcian. According to Michelsen (1978, fig. 3), the F-II member is of Early to middle Late Pliensbachian age, and the F-III member of middle Late Pliensbachian to Toarcian age.

In the Stenlille-2 borehole, the transition from the interval here referred to the F-III member to the interval referred to the F-IV member occurs within the Toarcian. In Fjerritslev-2 and Frederikshavn-2, this boundary cannot be dated more accurately than Toarcian to Middle Jurassic. The F-IV member is missing in the Gassum-1 borehole.

The boundary between the Fjerritslev Formation and the overlying Haldager Sand Formation is dated as Middle Jurassic in the Fjerritslev-2 borehole, and as Middle Jurassic, possibly transitional Toarcian-Middle Jurassic in Frederikshavn-2. Due to the major hiatus in the Gassum-1 borehole, the sequence succeeding the Fjerritslev Formation in this borehole is of Late Jurassic age. The uppermost part of the Fjerritslev Formation is here of Late Pliensbachian age. The upper boundary of the Fjerritslev Formation has not been defined in Stenlille-2. The beds immediately below the hiatus have been assigned a Toarcian age.

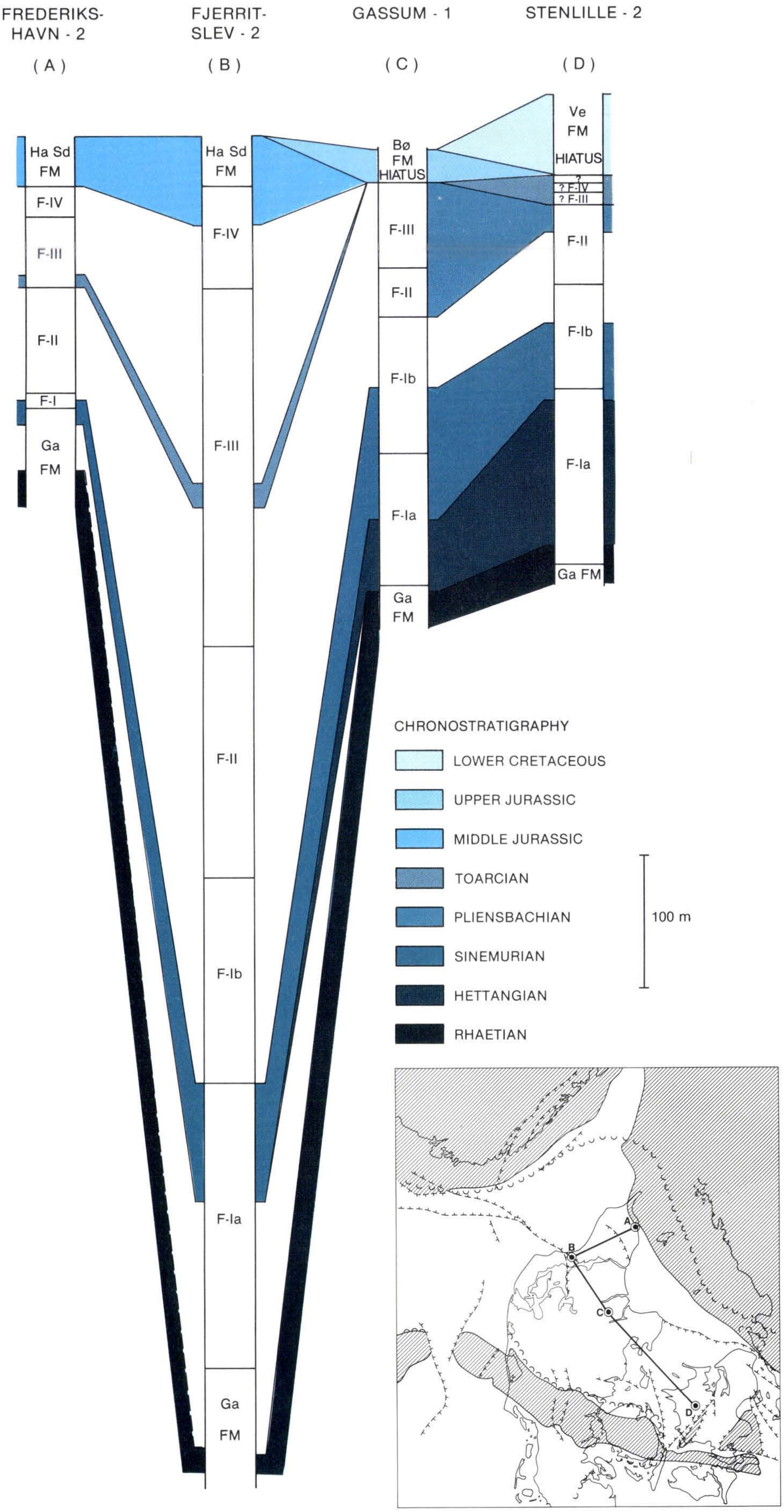


Fig. 11. Correlation of the lithostratigraphic units of the Fjerritslev Formation, based on the chronostratigraphic results presented here. The presence of the F-III Member and the F-IV Member in the Stenlille-2 borehole is based on the biostratigraphical- and palynofacies results from this study. The blank areas indicate intervals of questionable age.

Ga FM: Gassum Formation. Ha Sd FM: Haldager Sand Formation.
Bø FM: Børglum Formation. Ve FM: Vedsted Formation.

Palynofacies analysis

Introduction

The term "palynofacies" is used here to refer to the general aspect of the total kerogen content in the investigated slides, in accordance with the original definition of the term by Combaz (1964). Palynofacies analysis is most commonly utilized for palaeoenvironmental interpretations but it is also a useful technique for studies of maturation and source potential.

Interpretation of the broad depositional environment of the Fjerritslev Formation has been included in several previous studies (e.g. Michelsen 1975, 1978, Pedersen 1983, 1985, 1986, Thomsen et al. 1987). The present study aims to characterize the general composition of the organic matter in a well-documented depositional environment, and to show the variability that may occur within such a lithologically uniform formation as the Fjerritslev Formation.

Kerogen classification

Unfortunately, there are large differences of opinion concerning the classification and terminology that should be applied to the particulate organic matter found in sediments. This controversy has been intensified by the use of different methods (transmitted light versus reflected light microscopy) and by the differing approaches and objectives of the investigations that employ these methods (e.g. "kerogen typing" for source rock assessment versus "palynofacies" for palaeoenvironmental analysis). The current confusion emphasises the fact that coal maceral terminology should never be applied to transmitted light observations.

The term "kerogen" is used here in the sense of Brooks (1981, p. 2) to refer to "disseminated organic matter of rocks that is insoluble in non-oxidising mineral acids, bases, and organic solvents".

MAIN CATEGORIES	SUB-CATEGORIES	DESCRIPTION/DEFINITION	REMARKS
Palynomorphs		Microspores, pollen, acritarchs, dinoflagellate cysts, prasinophysean algae, limnic algae, and foraminiferal testlinings	The percentage variations of the main morphological groups of palynomorphs are based on the biostratigraphical counting (figs 13, 15 and 17).
Terrestrial plant debris (phytoclasts)	*Brown wood*	Partly or totally translucent, brownish to black, rounded to angular fragments, often exhibiting longitudinal structural thickenings	Batten (1973) introduced the terms "brown wood" and "black wood", but with slightly different definitions than adopted here. The two categories were subdivided into three subgroups, based on the size of the grains: <20 µm, 20–80 µm, and >80 µm, in order to assess sorting effects related to the energy levels in the depositional environment.
	Black wood	Totally opaque, rounded to angular with no visible structures	
	Cuticle and membranes	Yellow to colourless, thin, platy fragments, with (cuticle) or without (membranes) cellular structures.	Most of the membraneous particles recorded probably represent degraded cuticle.
	Resins		These two categories were recorded in such low numbers (maximum one particle per slide) that they were excluded from the calculation and presentation of percentage variations.
	Fungal remains	Hyphae and spores	
Amorphous organic matter (A.O.M.)			Several varieties of A.O.M. were recognized, but it was impossible to subdivide the A.O.M. into well-defined subgroups.

Table 7.

The deposition of kerogen particles depends on their origin, mode of transportation, buoyancy and density, just as for mineral particles. They can be reworked several times and may become chemically oxidised or biodegraded. However, the resulting kerogen assemblage in a sediment still reflects many aspects of the depositional environment, such as the energy regime, the redox conditions, and the salinity. In order to obtain as much information about these factors as possible, a relatively detailed classification of the kerogen particles must be made. The kerogen particles recorded in this study were grouped into the categories shown in Table 7.

The palaeoenvironmental indications of these categories are discussed in details in Appendix F.

Palaeoenvironmental parameters

The reliability of a specific kerogen-category as an indicator of changes in the depositional environment depends very much on the overall depositional setting and the stratigraphic period in question. For example, the ratio dinoflagellate cysts/sporomorphs has been used (e.g. Davey 1971, Scott 1982, Piasecki 1986) as an indication of the degree of freshwater-influence on a marine environment. This ratio was not used in this study, since the diversification of dinoflagellate cyst species was in its initial stages in the Early Jurassic. The variation recorded could thus be a reflection of the evolution of this group rather than of environmental conditions. The ratio of the total marine palynomorphs (dinoflagellate cyst, acritarchs, prasinophycean algae, and foraminiferal test-linings) versus the terrestrial + limnic palynomorphs (microspores, pollen and limnic algae) was calculated instead.

Additional problems arise if one tries to interpret variations in the relative percentage-abundances of the kerogen categories. It is not possible to deduce whether the individual category actually varies, or if the apparent variation is due to changes in abundance of other kerogen-categories. In order to make reliable interpretations, therefore it is necessary to use ratios of specific kerogen-categories, or to calculate "absolute" abundances, by including the Total Organic Carbon (T.O.C.)-values.

The parameters presented in table 8 were thought to be valuable as environmental indicators in the sequences investigated here.

PARAMETER	DEFINITION	ENVIRONMENTAL SIGNIFICANCE	REMARKS
PhytOC	(% brown wood + % black wood + % cuticle) × T.O.C.	An increase in the PhytOC-value indicates an increased amount of terrestrially-derived organic matter, either due to closer proximity to eustaries or river-mouths, or to an increased supply.	The parameters PhytOC and AmexOC were introduced by Tyson (1988). Here the AmexOC-parameter has been used in a slightly modified form to include all A.O.M. recognized under the light-microscope, whereas Tyson (1989) only included fluorescent A.O.M. and exinitic components.
AmexOC	% Amorphous Organic Matter (A.O.M.) × T.O.C.	High AmexOC-values indicate an environment with variable degrees of oxygen-deficiency in the bottom waters.	
$\frac{\text{Saccate pollen}}{\text{spores}}$	The ratio of bisaccate pollen to microspores	An increase in this ratio indicates increased distance to shorelines and freshwater sources.	
$\frac{P + N}{A}$	The ratio of: (Polygonomorphitae + Netromorphitae)/ Acanthomorphitae	An increase in this ratio indicates increased water-depth.	Polygonomorphitae, Netromorphitae, and Acanthomorphitae represent three acritarch-subgroups.
% Marine palynomorphs	% Marine palynomorphs in relation to the total number of palynomorphs	An increase in the relative abundance of marine palynomorphs indicates a decrease in freshwater influence within the marine environment.	Marine palynomorphs encompass dinoflagellate cysts, acritarchs, prasinophysean algae, and foraminiferal testlinings.

Table 8.

The parameters outlined above are used in the following section to interpret the vertical and lateral variations in the depositional environment of the Fjerritslev Formation. The usefulness of these parameters will be evaluated by comparing the results with earlier environmental interpretations.

Palynofacies results

Introduction

The results from the palynofacies investigation are presented in figs 12, 14, 16 and 18, and in appendices A-D.

On the basis of the results from the biostratigraphical counting, the relative abundances of the main morphological groups of palynomorphs have been calculated for the three boreholes Fjerritslev-2, Frederikshavn-2, and Stenlille-2. These results are presented in figs 13, 15 and 17. Corresponding curves for the Jurassic sequence in the Gassum-1 borehole were presented by Dybkjær (1988, fig. 10). In addition, the relative abundance of marine palynomorphs, and the ratios of saccate pollen/spores, and (Polygonomorphitae + Netromorphitae)/Acanthomorphitae (three acritarch subgroups) are shown. These results will be included in the interpretation of the results from the palynofacies investigation.

General environmental interpretation of the Gassum and Fjerritslev Formations

The kerogen assemblages in the Gassum Formation, in all four investigated boreholes, generally indicate a low salinity environment with a very high influx of terrestrially derived organic matter and well oxygenated bottom water. These observations correlate very well with earlier interpretations of this formation as being of fluvio-deltaic origin (Bertelsen 1978) or shallow marine to fluvial (Nielsen, Larsen & Frandsen 1989). In the uppermost parts of the Gassum Formation the records of marine palynomorphs herald the marine depositional environment of the succeeding Fjerritslev Formation.

The kerogen assemblages in the samples referred to the Fjerritslev Formation generally show the same overall composition in all four boreholes. The presence of marine palynomorphs in all samples clearly indicates a marine depositional environment for the whole of this formation. However, the dominance of brown wood among the kerogen particles, especially in the lower part of the formation, indicates a high influx of terrestrially-derived organic matter. This is further supported by low relative abundances of marine palynomorphs, and of saccate pollen. The dominance, among the marine palynomorphs, of acanthomorph acritarchs, indicates a shallow-water environment. Low relative abundances of amorphous organic matter (A.O.M.) (except for a few samples referred to F-III and F-IV member) indicate generally well-oxygenated bottom waters. The brown and black wood particles are mainly of small- or medium-size, with only sporadic representation of coarse particles. According to Davey (1971), this indicates relatively nearshore deposition in a low energy environment. Fluctuations in the energy-regime are, however indicated by the changing lithology, especially in the most proximal borehole, Frederikshavn-2.

The results from the palynofacies investigations of the Fjerritslev Formation clearly support the earlier environmental interpretations by Michelsen (1978) and Pedersen (1985, 1986).

Stratigraphic variation

The stratigraphic variations in the kerogen assemblages recorded from the Fjerritslev-2 and Frederikshavn-2 boreholes generally correlate very well with the lithostratigraphic subdivisions of Michelsen (1978), although detailed comparison was not possible because of incomplete core coverage.

The lithostratigraphic subdivision of the Stenlille-2 borehole by Frandsen (1988), correlates with the va-

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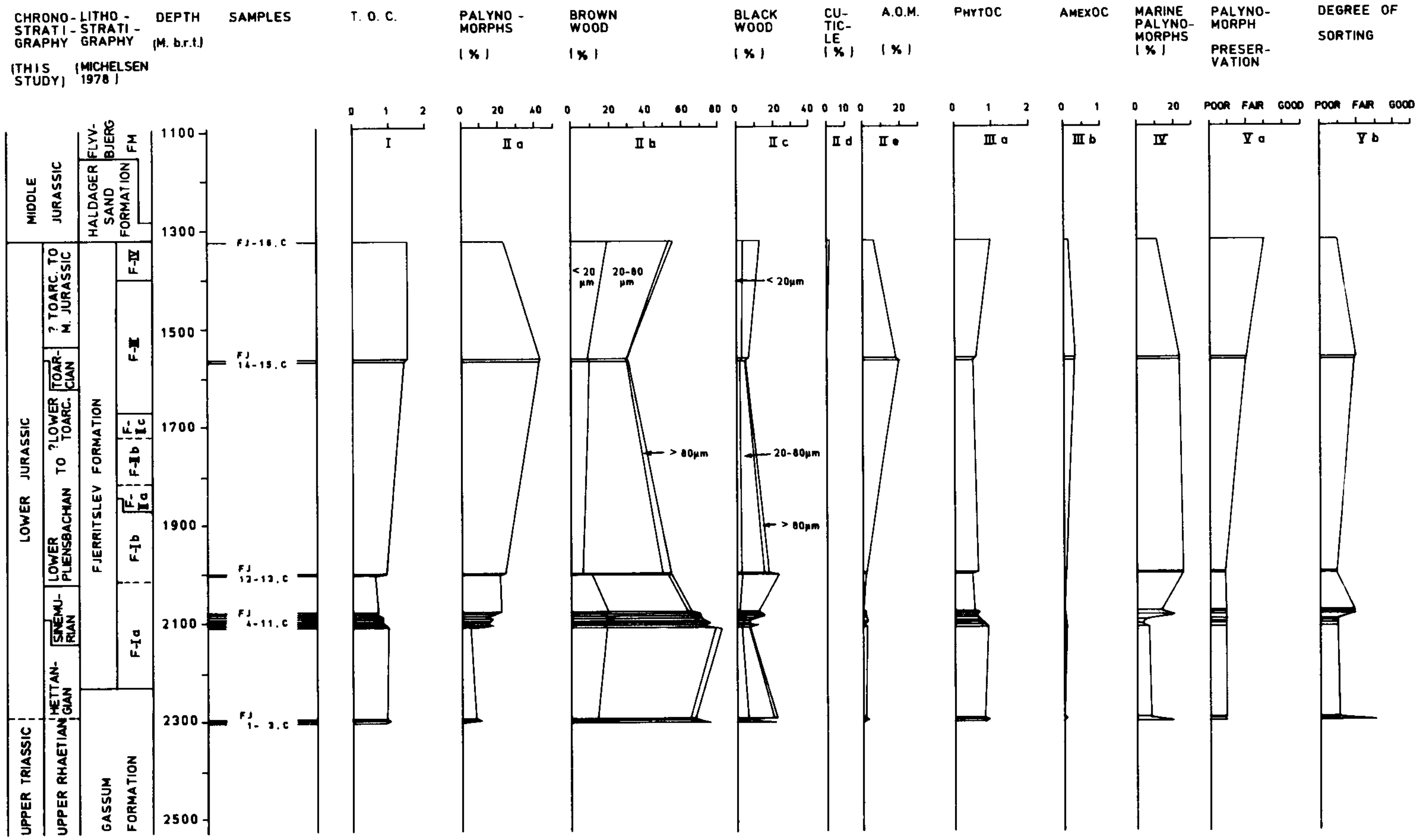
Fig. 12. Palynofacies results from the Fjerritslev-2 borehole. →

I:	*Total Organic Carbon- (T.O.C.-) content.*
II a-e:	*Relative abundances of the various categories of kerogen particles. 100% = total kerogen particles counted. The two categories, brown wood (IIb) and black wood (IIc), are further subdivided into size categories, <20 microns, 20–80 microns, and >80 microns.*
III a,b:	*PhytOC = (%brown wood + %black wood + %cuticle) × T.O.C.* *AmexOC = %Amorphous Organic Matter (A.O.M.) × T.O.C.*
IV:	*Marine palynomorphs as a percentage of total palynomorphs, based on the results from the biostratigraphical investigation.*
V a:	*Palynomorph preservation. Palynomorphs were not recorded in samples marked with an asterisk.*
V b:	*Degree of sorting.*

THE FJERRITSLEV No. 2 BOREHOLE



riations in the kerogen assemblages in the lower part of the sequence. In the upper part of the sequence, assigned to the Lower Cretaceous by Frandsen (1988), the intervals represented by samples St-15,w and St-16,w showed kerogen assemblages that are more closely comparable with assemblages recorded from the F-III member and the F-IV member, respectively, from the Fjerritslev-2 borehole. This is supported by the biostratigraphical investigation which referred these two samples to the Toarcian. In order to compare the sequences investigated, these samples will be included in discussion of the F-III and F-IV members, respectively.

The stratigraphic variations in the kerogen-assemblages in the Fjerritslev-2, Frederikshavn-2 and Stenlille-2 boreholes generally show a high degree of correlation. The stratigraphic variation in the kerogen-assemblages from the Gassum-1 borehole, however, does not correlate with those recorded in the other three boreholes, nor with the lithostratigraphic subdivision of this sequence proposed by Pedersen (1986, fig. 6).

General variations in the kerogen assemblages from Fjerritslev-2, Frederikshavn-2 and Stenlille-2 are discussed below in relation to the lithostratigraphical units. The kerogen assemblages from Gassum-1 will be discussed separately. The differences in the kerogen assemblages between the lithostratigraphical units are shown for each of the four boreholes in fig. 19 (part c).

The Gassum Formation:

Samples referred to the Gassum Formation were obtained from all three boreholes. The samples are relatively coarse-grained, comprising sandstone, siltstone and sandy and silty claystone, in contrast to the samples referred to the Fjerritslev Formation (see appendices A-C).

The kerogen assemblages are strongly dominated by brown wood (figs 12, 14 and 16). As relatively high T.O.C.-values were also recorded (especially from the Frederikshavn-2 borehole, sample Frh-1,c and Frh-4,c), maximum PhytOC-values characterize this level, indicating a high influx of terrestrially-derived organic matter, and/or proximity to the source. The amount of black wood varies, but is generally high, especially in some of the most coarse-grained samples (for example Fj-1,c, Fj-3,c and Frh-4,c). Well-oxygenated bottom waters is indicated by the distinctly low AmexOC-values.

The relative abundance of marine palynomorphs is generally low, but show relatively high abundances in a few samples (for example Fj-2,c and St-2,c) from the uppermost part of the Gassum Formation.

Among the terrestrial palynomorphs, non-saccate pollen dominate strongly in the Fjerritslev-2 and Stenlille-2 boreholes, whereas distinctly low amounts of bisaccate pollen were recorded. Among the non-saccate pollen the two species *Ricciisporites tuberculatus* and *Corollina torosus* clearly form the major part. The former species is known to occur in high relative abundances in relatively coarse-grained samples, and indicates proximity to a freshwater source. The environmental significance of *Corollina torosus* is more complex and not fully understood.

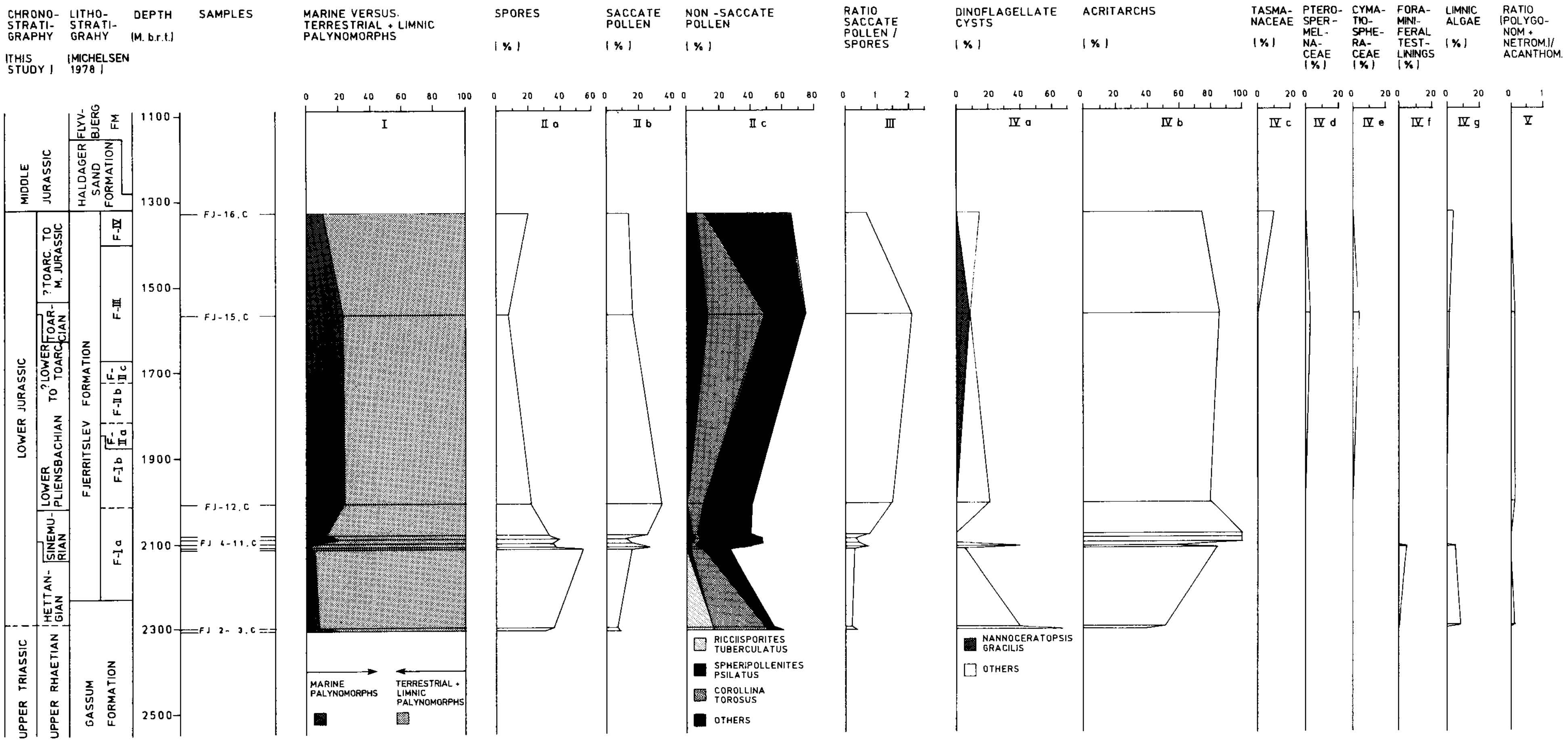
In Frederikshavn-2 the terrestrial palynomorphs are dominated by spores but non-saccate pollen also show high relative abundances.

The transition from the Gassum Formation to the Fjerritslev Formation is clearly reflected in the kerogen assemblages in all three boreholes. A distinct decrease in the PhytOC-values (see fig. 19, and Appendix E)

Fig. 13. Relative abundances of the main morphological groups of palynomorphs in the Fjerritslev-2 borehole. →

I: Marine versus terrestrial + limnic palynomorphs. 100% = total of palynomorphs.
II a-c: Relative abundances of the main morphological groups of terrestrial palynomorphs. 100% = total of terrestrial palynomorphs.
III: Ratio of saccate pollen/microspores.
IV a-g: Relative abundances of the main morphological groups of aquatic palynomorphs. 100% = total of aquatic palynomorphs (=marine palynomorphs + freshwater algae).
V: Ratio of (Polygonomorphitae + Netromorphitae)/ Acanthomorphitae.

THE FJERRITSLEV No. 2 BOREHOLE



clearly indicates a reduced influx of terrestrially-derived organic matter. An associated increase in the ratio of saccate pollen/spores indicates an increased distance to shorelines (or river-mouths). The increase in the ratio (Polygonomorphitae + Netromorphitae)/Acanthomorphitae (in Frederikshavn-2 and Stenlille-2) further indicates a general increase in water depth. The AmexOC-values and the relative abundances of marine palynomorphs are more or less constant. The decrease in the relative abundance of marine palynomorphs in Stenlille-2 is due to the atypically high levels of marine palynomorphs in sample St-2,c which is the uppermost sample referred to the Gassum Formation.

Together the changes in the kerogen assemblages clearly reflect the overall sea-level rise resulting in the transition from the fluvio/deltaic Gassum Formation to the marine Fjerritslev Formation.

In the Frederikshavn-2 borehole the "old" F-I member, as defined by Michelsen (1978), has not been subdivided into a F-Ia and F-Ib member. The samples referred to the F-I member in this borehole generally show a dominance of brown wood, although not to the extent observed in the Gassum Formation. The PhytOC-values are significantly lower than those recorded from the Gassum Formation, mainly because of lower T.O.C.-values. Low AmexOC values indicate well--oxygenated bottom waters. Among the terrestrial palynomorphs, the ratio of saccate pollen/spores shows distinctly higher values than in the Gassum Formation indicating a greater distance to the shoreline. Acanthomorph acritarchs dominate the marine palynomorphs, indicating a shallow-water environment.

The F-Ia member:

The F-Ia member is represented in the Fjerritslev-2 and Stenlille-2 boreholes. The kerogen assemblages recorded from this member are generally dominated by brown wood, but show marked variations, even between closely spaced samples.

These observations correspond very well with the lithological interpretations by Michelsen (1978) and Pedersen (1986). The F-Ia member shows the greatest lithological variation of the entire formation, and was interpreted as being the most coast-near, deposited in a well-oxygenated shallow-water environment and with changing energy levels.

The F-Ib member:

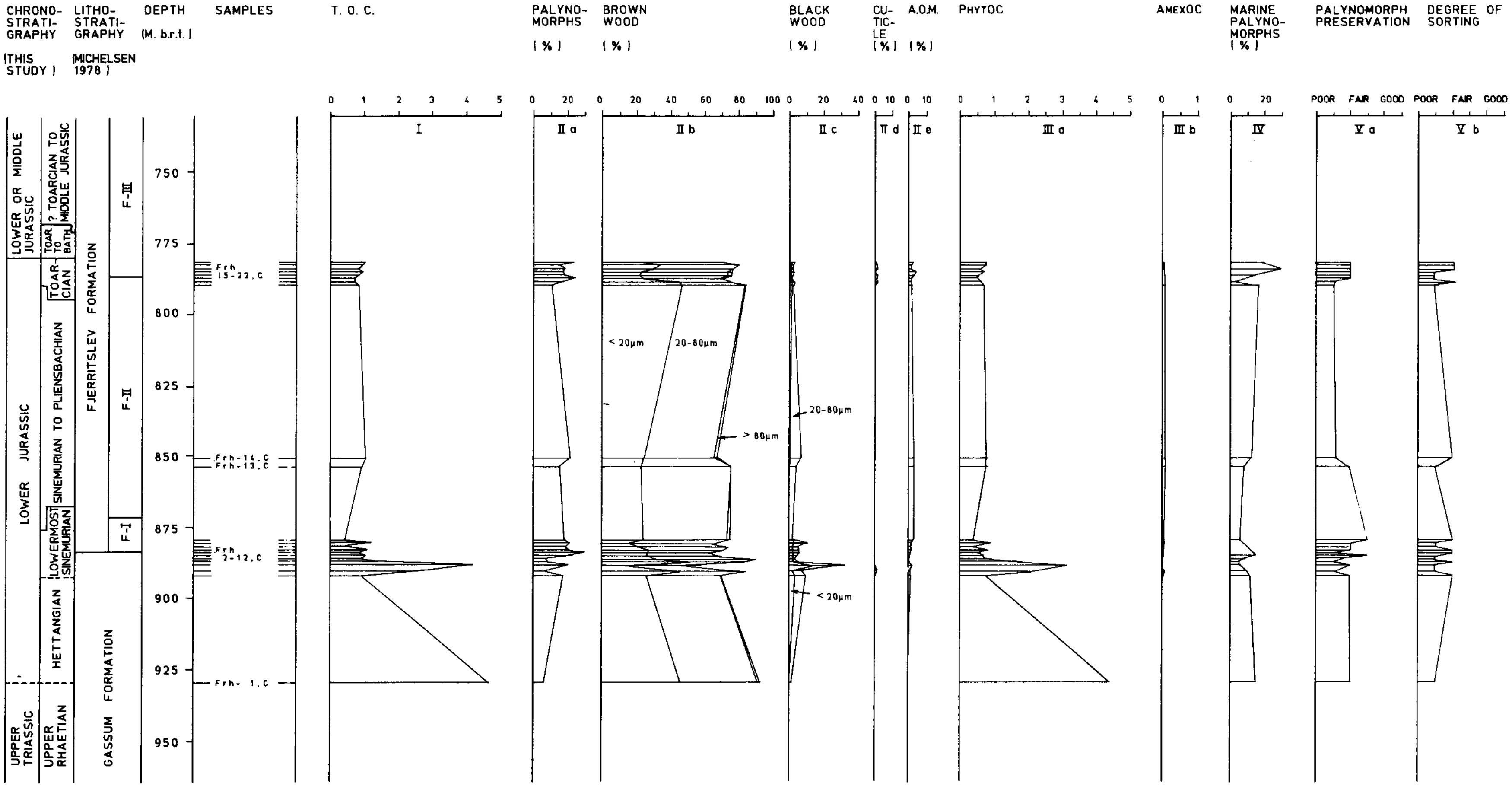
No cores exist from the interval referred to the F-Ib member in the Stenlille-2 borehole.

The samples referred to the F-Ib member in Fjerritslev-2 show slightly lower PhytOC-values than the samples referred to the F-Ia member, indicating a reduced supply of terrestrially derived organic matter. A decrease in freshwater influence is indicated by a general increase in the relative abundance of marine palynomorphs. A concurrent increase in the ratio of (Polygonomorphitae + Netromorphitae)/Acanthomorphitae indicates an increase in water depths passing from the F-Ia to the F-Ib member. These interpretations are supported by a distinct increase in the ratio of saccate pollen/spores, indicating a greater distance to the shoreline.

In accordance with Michelsen (1978) the kerogen assemblages from this member indicate a depositional environment very similar to that envisaged for the F-Ia member, but with slightly deeper water conditions. However, according to Michelsen (1975, 1978), the ostracod fauna indicated reducing conditions; no indications of oxygen deficiency in the bottom waters were recorded here.

Fig. 14. Palynofacies results from the Frederikshavn-2 borehole. For further explanation, see text to fig. 12. →

THE FREDERIKSHAVN No. 2 BOREHOLE



Due to incomplete coring, samples from the F-Ib member and F-II member were not obtained from the same borehole. Thus possible changes in the kerogen assemblage between these two units cannot be investigated.

In the Frederikshavn-2 borehole, a weak increase in relative abundance of PhytOC-values was recorded passing from the F-I member to the F-II member (see Appendix E), indicating an increased influx of terrestrially-derived organic matter. This conflicts, however, with a concurrent increase in the ratios saccate pollen/spores and (Polygonomorphitae + Netromorphitae)/Acanthomorphitae, indicating increased distance to the shoreline, and a deeper-water regime, respectively. The reason for this apparent contradiction is presently not clearly understood.

In the Stenlille-2 borehole, a marked decrease in PhytOC-values from the F-Ia member to the F-II member indicates a reduced influx of terrestrially-derived organic matter. The concurrent increase in the ratio of saccate pollen/spores, and a weak increase in the ratio of (Polygonomorphitae + Netromorphitae)/Acanthomorphitae indicate increased distance to the shoreline and increased water depth.

The F-II member:

The F-II member is represented by samples from the Frederikshavn-2 and Stenlille-2 boreholes. They are generally dominated by brown wood, especially in Frederikshavn-2, while samples from Stenlille-2 also show rather high relative abundances of palynomorphs. Amongst the palynomorphs, non-saccate pollen dominate in the Frederikshavn-2 borehole, whereas the three groups of terrestrial palynomorphs in the Stenlille-2 borehole were recorded in more or less equal numbers. Low AmexOC-values from both boreholes indicate well-oxygenated bottom waters.

The overall kerogen assemblage of the F-II member corresponds very well with the earlier interpretations by Michelsen (1978) and Pedersen (1986), indicating a relatively shallow-water environment with well-oxygenated bottom waters.

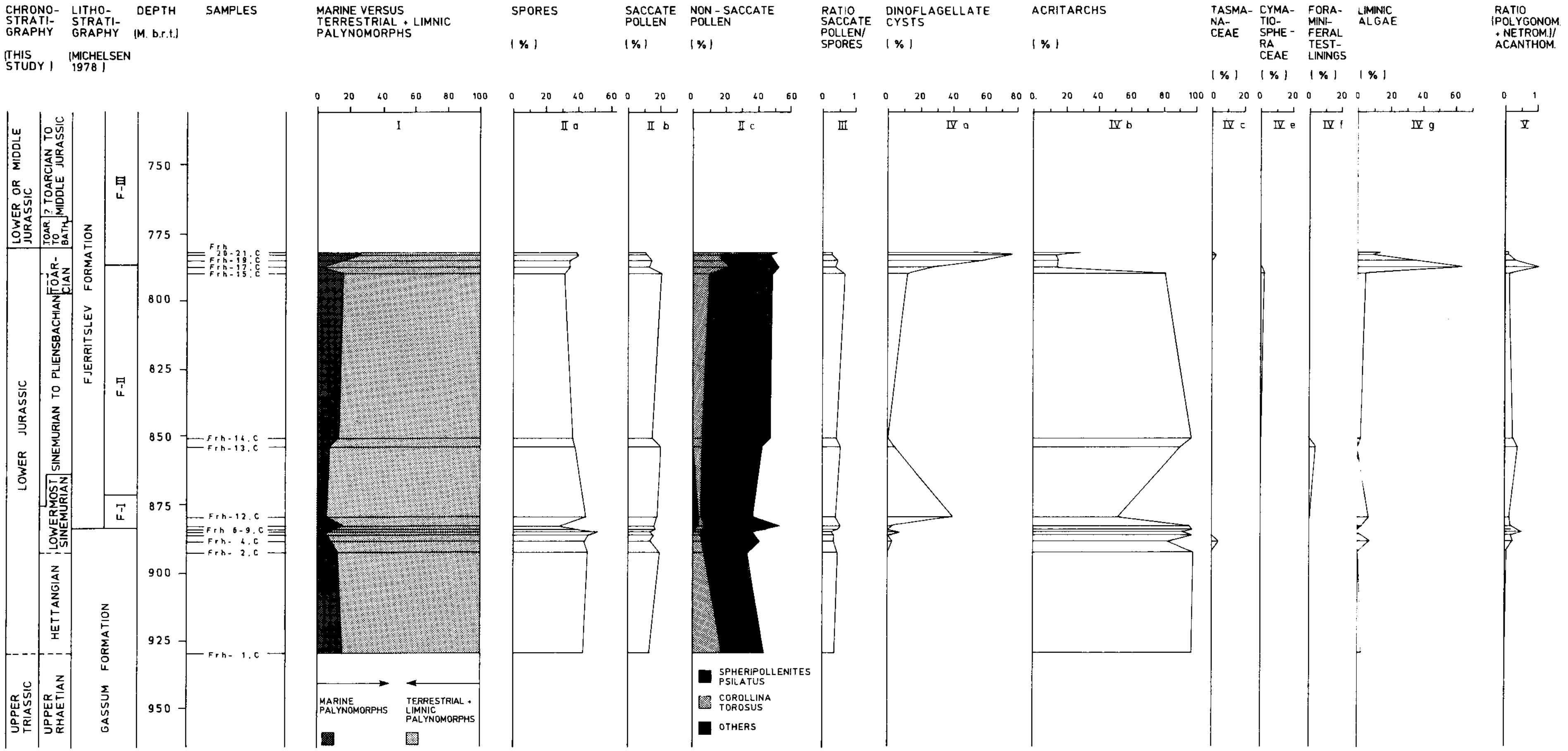
The transition from the F-II member to the F-III member is represented in cores from the Stenlille-2 and Frederikshavn-2 boreholes.

The transition is clearly reflected in the kerogen assemblages in Stenlille-2. A decrease in PhytOC-values, and a simultaneous marked increase in AmexOC-values, clearly indicate significant environmental changes including a marked reduction in influx of terrestrially-derived organic matter, combined with pronounced oxygen-deficiency in the bottom waters. The decrease in ratios of saccate pollen/spores and (Polygonomorphitae + Netromorphitae)/Acanthomorphitae and the decrease in relative abundance of marine palynomorphs could be due to the overwhelming dominance (98%), within the palynomorphs, of one species of alete pollen, *Spheripollenites psilatus.* This results in there being no record of bisaccate pollen, polygonomorph acritarchs or netromorph acritarchs, and a relative abundance of marine palynomorphs of only 7%.

In Frederikshavn-2, this transition is not reflected in the kerogen assemblage. No distinct changes were recorded in the PhytOC- or the AmexOC-values. However, decreases in the ratios of saccate pollen/spores and (Polygonomorphitae + Netromorphitae)/Acanthomorphitae, indicate a reduced distance to the shoreline, and a shallow-water regime. These interpretations contrast with the marked increase in the relative abundance of marine palynomorphs, indicating a decreased freshwater influence.

Fig. 15. Relative abundance of the main morphological groups of palynomorphs in the Frederikshavn-2 borehole. For further explanation, see text to fig. 13. No specimens referred to the Pterospermellaceae (IVd) were recorded from this borehole. →

THE FREDERIKSHAVN No. 2 BOREHOLE



The F-III member:

Core samples referred to the F-III member are available from the Fjerritslev-2, Frederikshavn-2, and (probably) from the Stenlille-2 boreholes (see discussion on p. 52).

The kerogen assemblages from the F-III member in Fjerritslev-2 and Stenlille-2 are clearly different from the underlying F-II member assemblages. The main difference is the high AmexOC-values in these samples, a result of high relative abundances of A.O.M. combined with relatively high T.O.C.-values. These observations indicate oxygen deficiency in the bottom waters, resulting in a high preservation of organic matter. The PhytOC-values in Fjerritslev-2 are comparable with those from the F-Ia, F-Ib and F-II members, indicating that the supply of terrestrial phytoclasts was relatively constant. In Stenlille 2, however, a distinct minimum in PhytOC has been recorded, indicating a very low influx of terrestrially-derived organic matter. Amongst the terrestrial palynomorphs, the non-saccate pollen are dominant; the species *Spheripollenites psilatus* shows particularly high relative abundances. The marine palynomorphs show rather high relative abundances in Fjerritslev-2, while low relative abundances were recorded in Stenlille-2.

This association of high relative abundances of A.O.M. and *Spheripollenites* is recognized widely across NW-Europe in black bituminous shales deposited during the Early Toarcian transgressive anoxic event (Wall 1965, Wille 1982, Riegel et al. 1986). Correlation with this "anoxic event" is further indicated by the composition of the marine palynomorph assemblage. The only dinoflagellate cyst genus recorded from this level in this study is *Nannoceratopsis*. Furthermore, relatively high abundances of Prasinophysean algae and a maximum of *Pterospermella* were recorded. *Nannoceratopsis* is one of the few dinoflagellate cyst genera that has been recorded from Early Toarcian bituminous strata where it occurs together with Prasinophycean algae (Wall 1965, Wille 1982, Riegel et al. 1986).

The relatively high T.O.C. values recorded from the F-III member, reflect good preservation of organic matter, probably due to oxygen deficiency in the bottom waters (resulting in reduced levels of bioturbation and thus less bacterial degradation (see Tyson 1987)). This is further supported by the relatively good palynomorph preservation at this level compared with the underlying samples (figs 12 and 16).

The kerogen assemblages recorded from samples referred to the F-III member in the Frederikshavn-2 borehole do not show any appreciable difference from the assemblages referred to the F-I and F-II members. The assemblage is overwhelmingly dominated by brown wood, with only a few percent of A.O.M. The palynomorph assemblage is diverse, with a composition comparable to that seen in the sequence below.

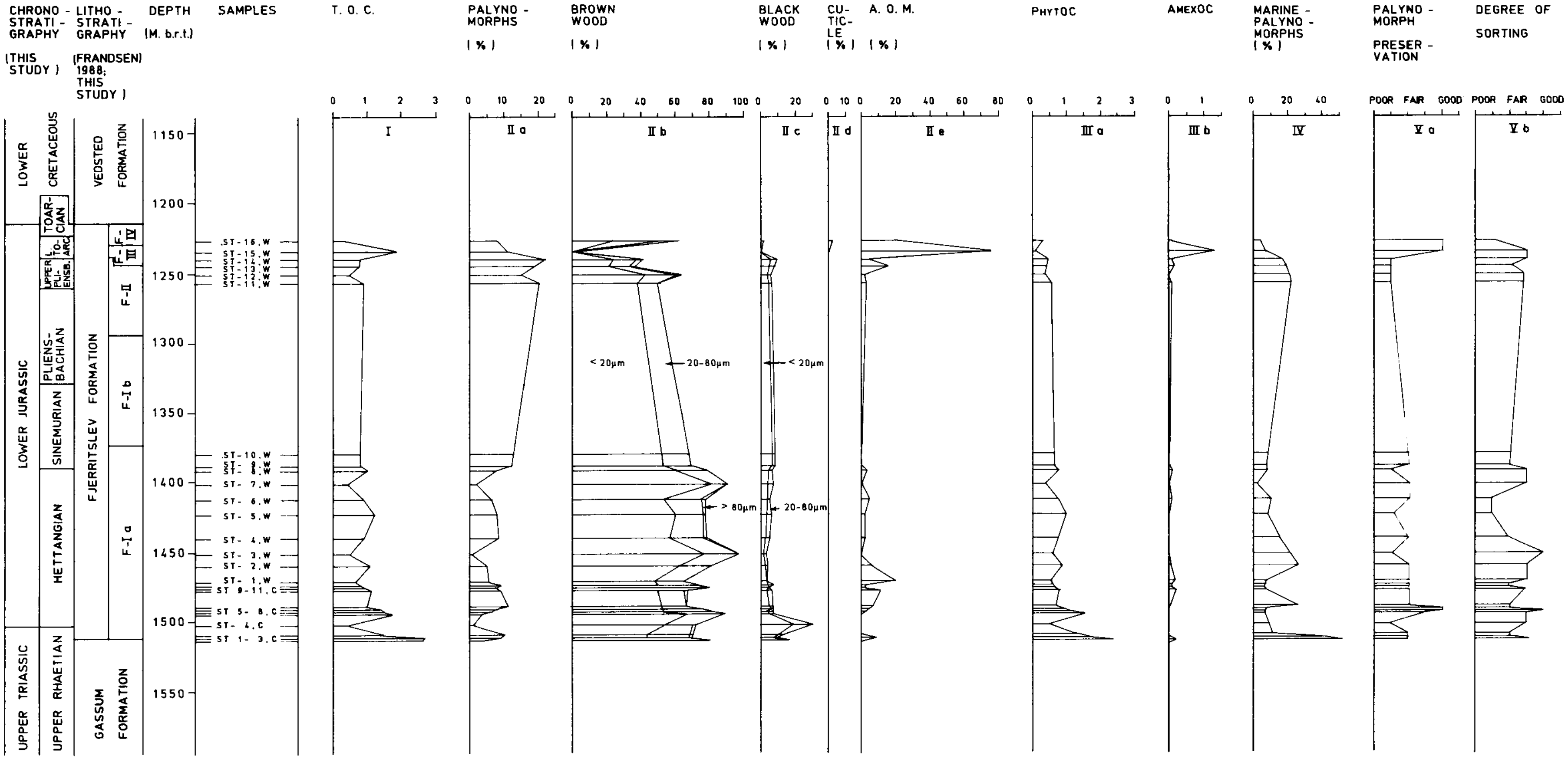
The kerogen assemblages of the F-III member in the Fjerritslev-2 and Stenlille-2 boreholes clearly support the interpretation by Michelsen (1978) of a deeper-water environment, with progressively reducing conditions in the bottom waters. One level of the Stenlille-2 borehole, sample St-15,w (1234m b.r.t.) assigned an Early Toarcian age, showed a kerogen assemblage indicating severe oxygen-deficiency. A corresponding, but less oxygen-deficient level, was recorded from Fjerritslev-2, sample Fj-15,c (1561m b.r.t.).

In contradiction, the kerogen assemblages from Frederikshavn-2 clearly indicate that neither oxygen deficiency nor special palynomorph assemblages developed in this area during the deposition of F-III member.

The transition from the F-III member to the F-IV member is represented in the Fjerritslev-2 and, accord-

Fig. 16. Palynofacies results from the Stenlille-2 borehole. For further explanation, see text to fig. 12. →

THE STENLILLE No. 2 BOREHOLE



ing to the interpretation given here, the Stenlille-2 boreholes, where it is clearly reflected by changes in the kerogen assemblages. Marked increases in PhytOC-values and decreases in AmexOC-values (fig. 19) indicate an increased input of terrestrially-derived organic matter, and increasing oxygen levels in the bottom waters. In addition the ratios of saccate pollen/spores and (Polygonomorphitae + Netromorphitae)/Acanthomorphitae decrease, indicating shallower water and a shorter distance to the shoreline.

The F-IV member:

The F-IV member is represented by one sample from the Fjerritslev-2 and one sample from the Stenlille-2 borehole (see discussion on p. 52). The kerogen assemblages are dominated by brown wood, and show higher PhytOC-values than in the F-III member, indicating a higher input of terrestrially-derived organic matter. The AmexOC-values are clearly lower than in the F-III member, but generally higher than in the F-Ia, F-Ib and F-II members. These observations indicate mildly reducing conditions in the bottom waters, as supported by fairly good palynomorph preservation (figs 12 and 16). Non-saccate pollen dominate the terrestrial palynomorphs. The relative abundance of spores is, however, higher than in the F-III member. The two species of non-saccate pollen, *Spheripollenites psilatus* and especially *Corollina torosus,* show significantly lower relative abundances than in the F-III member. The marine palynomorphs show a low relative abundance, especially in Stenlille-2, where this group consists exclusively of acanthomorph acritarchs, strongly indicating a shallow water regime. In Fjerritslev-2, a more diverse aquatic palyno-flora was recorded. A maximum in the relative abundance of freshwater algae indicates proximity to a freshwater source. The associated maximum of Tasmanites is suggestive of brackish water conditions.

Michelsen (1978) proposed a "lagoonal environment" with "strongly reducing conditions" for the deposition of F-IV member. The kerogen assemblages of the F-IV member could very well reflect a lagoonal environment, but with only slightly reducing conditions in the bottom waters.

Variations in kerogen-assemblages from Gassum-1

Slides used for biostratigraphical counting by Dybkjær (1988) were also utilized for kerogen particle counting in this study. Some additional slides (of which several were more or less barren of palynomorphs) were included so as to cover as much lithological variation as possible. In contrast to the other boreholes, the Gassum-1 sequence was extensively cored, allowing more systematic sampling. Samples from the Fjerritslev Formation are lithologically very homogenous, consisting of claystone or silt-streaked claystone. Samples from the Gassum and Bream Formations are generally more coarse-grained.

Variations in the kerogen assemblages from Gassum-1 support neither the lithostratigraphical subdivision indicated by Pedersen (1986, fig. 6) (see fig. 18) nor the general environmental interpretations of the lithological units (fig. 19). Only with respect to the transition from the Gassum Formation to the Fjerritslev Formation do the kerogen assemblages indicate environmental changes that are comparable with earlier interpretations.

Fig. 17. Relative abundance of the main morphological groups of palynomorphs in the Stenlille-2 borehole. For further explanation, see text to fig. 13. No specimens referred to foraminiferal test-linings (IVf) were recorded from this borehole. →

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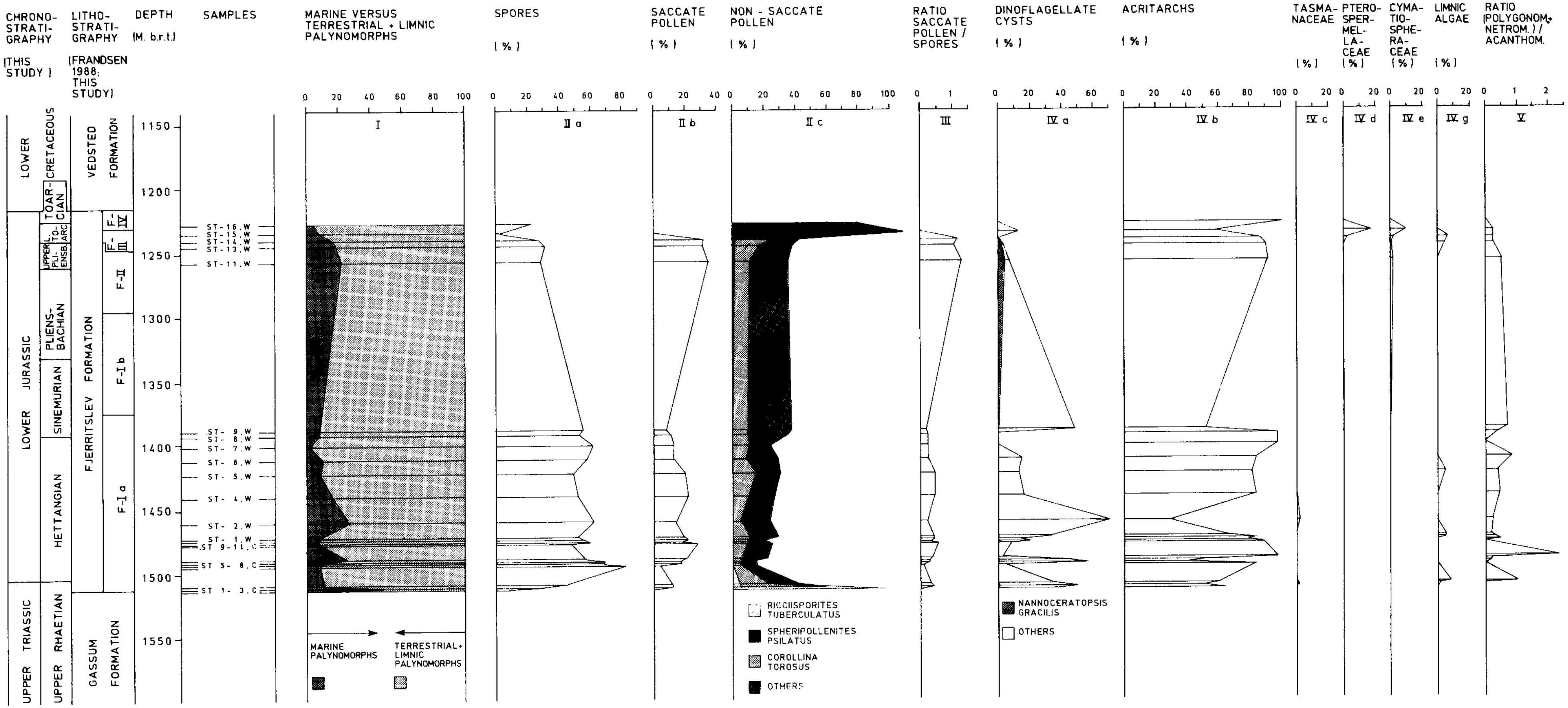
THE STENLILLE No. 2 BOREHOLE



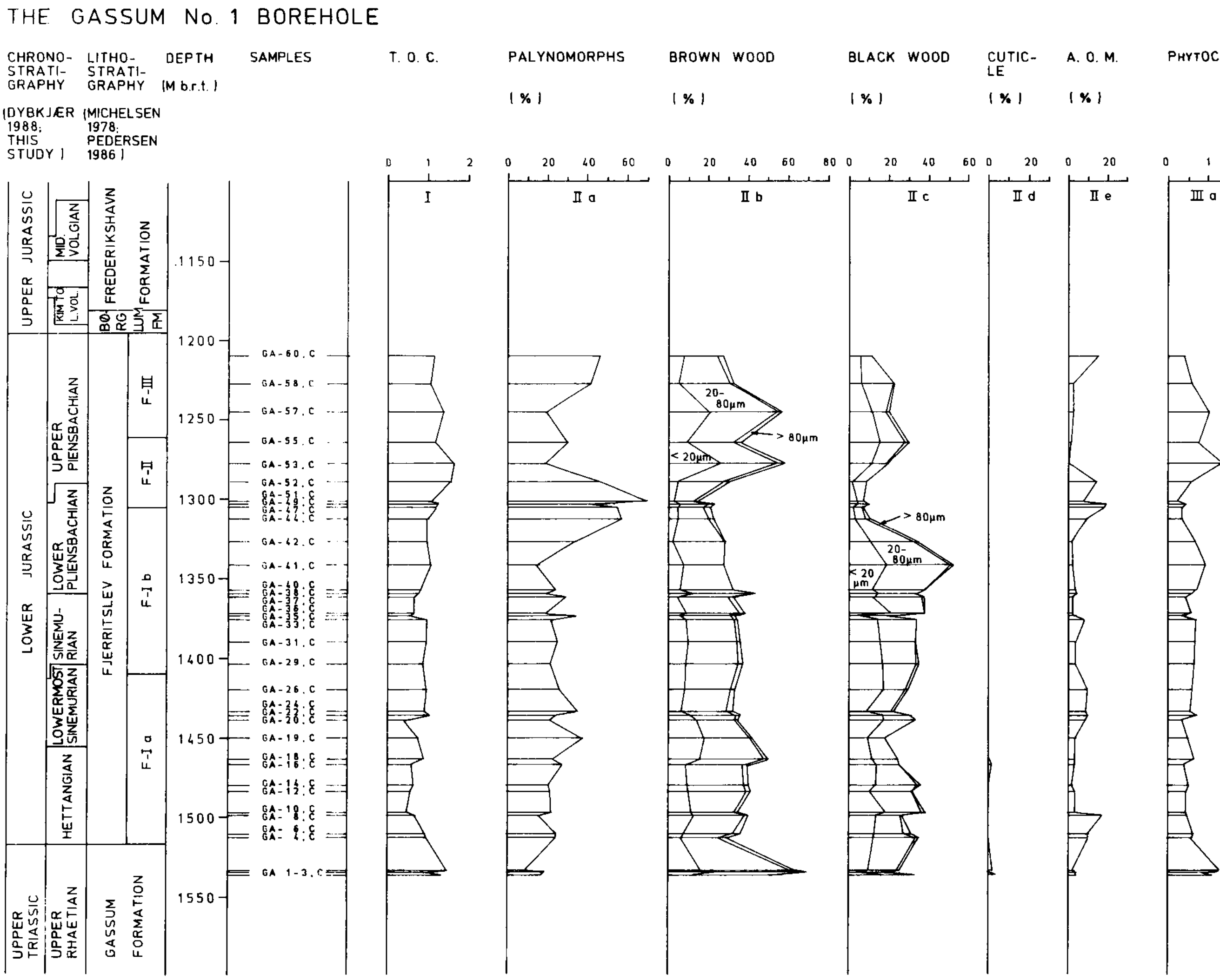


Fig. 18. Palynofacies results from the Gassum-1 borehole.

IV: After Dybkjær (1988).

VI a,b: After Michelsen (1975). The diversity curve shown here is the reverse of that presented by Michelsen (1975, fig. 22), redrawn such that high values indicate high diversity.

VI c: After Pedersen (1986).

VI d: After Nørvang (1957) and Pedersen (1986).

For further explanation, see text to fig. 12.

The kerogen curves show two overall patterns (fig. 18):

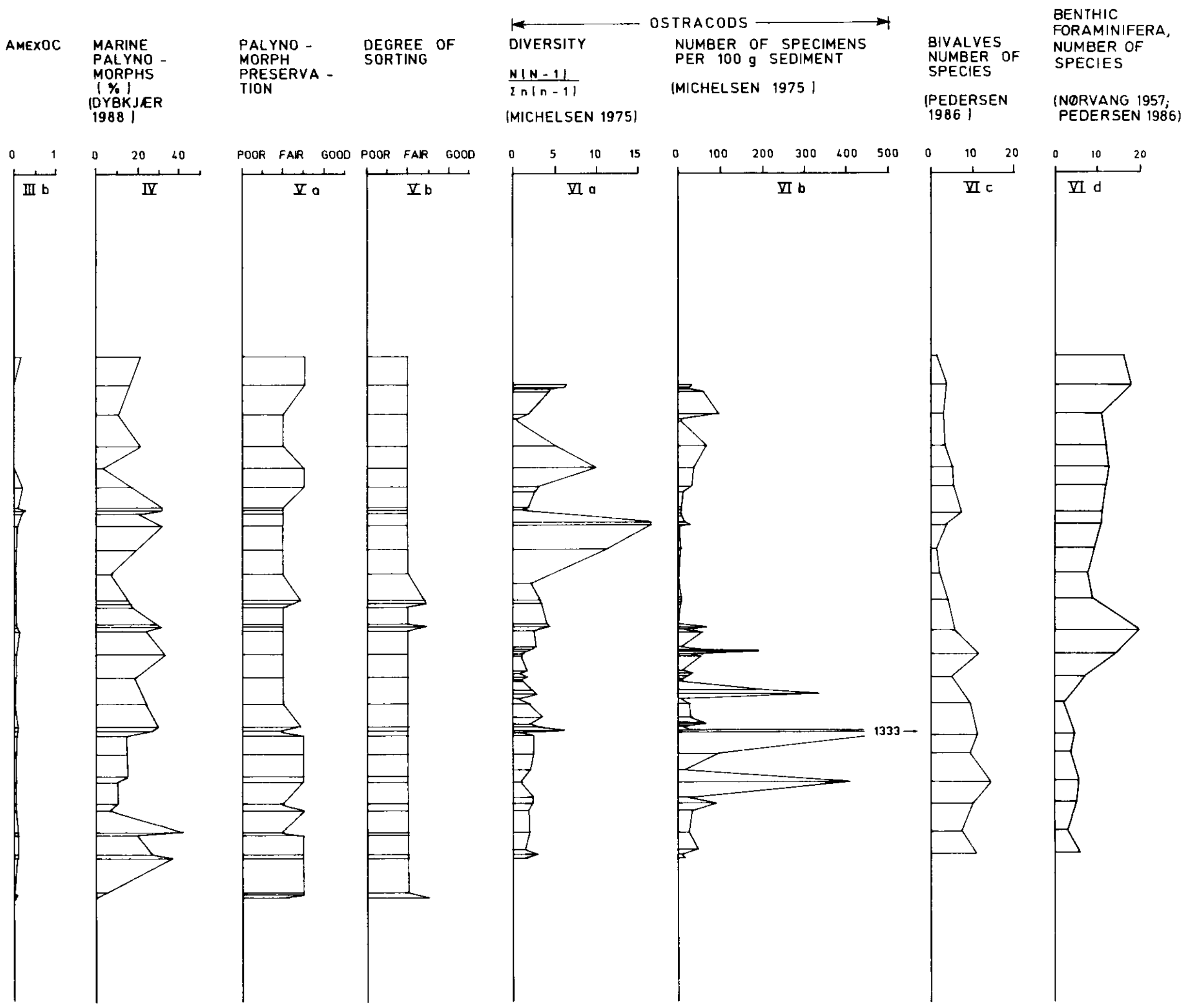
a) The curves for palynomorphs, brown wood, black wood, and PhytOC comprise a lower part, with relatively constant values, and an upper part with more variable values.

b) The curves for AmexOC (and relative percentage of A.O.M.) and marine palynomorphs generally correlate very well, showing minor variations throughout the investigated sequence. These minor variations are generally reflected in the patterns shown by the palynomorphs and, inversely, by the brown wood and PhytOC. Furthermore, these trends correlate with the relative abundance of saccate pollen, and show an inverse relationship with the curve for trilete spores (see Dybkjær 1988, fig. 10).

The variations within the kerogen assemblages, and the environmental indications of these changes, are discussed below. The results of the biostratigraphical investigation (Dybkjær 1988) have been included to support the interpretations.

The kerogen assemblages in the samples referred to the Gassum Formation are strongly dominated by phytoclasts, particularly brown wood, indicating a high influx of terrestrially-derived organic matter. Significant terrestrial influence is further supported by the low relative abundances of marine palynomorphs, and the dominance of spores among the terrestrial palynomorphs. Low AmexOC-values indicate well-oxygenated bottom waters.

A marked decrease in the influx of terrestrially-derived organic matter at the transition from the Gassum Formation to the Fjerritslev Formation is indicated by a significant decrease in the PhytOC-values, and an increase in the relative abundance of marine palynomorphs (fig. 19). An increase in AmexOC-values indicates a relative drop in oxygen content of bottom waters. Furthermore, distinct increases in the ratios of saccate pollen/spores and (Polygonomorphitae + Netromorphitae)/Acanthomorphitae indicate increased



distance to the shoreline, and increased water depths, respectively.

Above this level, in the F-Ia and F-Ib members, up to about sample GA-40 (1358m b.r.t.), the palynomorph-category, as well as the categories of brown wood, black wood, and PhytOC, only show minor variations. Brown wood generally shows a weak dominance over palynomorphs and black wood.

Above sample GA-40 the kerogen-curves for palynomorphs, brown wood and black wood show significantly greater oscillations. Generally higher T.O.C.-values were recorded above this level.

In the lower half of F-II member (GA-44 to GA-52) (1313m-1289m b.r.t.), a minimum of PhytOC was recorded, indicating a significant decrease in the supply of terrestrially derived organic matter. Relatively high AmexOC-values, high relative abundances of saccate pollen, and the dominance of saccate pollen among the terrestrial palynomorphs support this interpretation.

The upper part of the F-II member and most of the F-III member (samples GA-53 to GA-58) (1277m-1227m b.r.t.) are characterized by relatively high PhytOC-values, indicating a relatively high influx of terrestrially-derived organic matter. This is supported by generally low abundances of marine palynomorphs and low AmexOC-values. The palynomorph assemblage in sample GA-53 is dominated by *Ricciisporites tuberculatus* (presumed to be reworked); high relative abundances of limnic algae were also recorded. These observations may indicate a short-lived regressive phase resulting in erosion and reworking of older sediments in the marginal areas of the basin (Dybkjær 1988).

A decrease in PhytOC was recorded immediately below the top of the Fjerritslev Formation (sample GA-60)(1210m b.r.t.), in the upper part of the F-III member. At the same level, palynomorphs (mainly the genera *Spheripollenites* and *Corollina*) show a high relative abundance. These observations indicate a renewed reduction in the supply of terrestrially-derived organic matter, a conclusion supported by an increase in both the abundance of marine palynomorphs and in AmexOC.

Eventual relations between the observed variations in the kerogen assemblages and previous recorded variations of the bottom fauna from the Gassum-1 borehole (Michelsen 1975, Pedersen 1986), are discussed in the following.

The distinct change in the curve-patterns near the boundary between the F-Ib member and the F-II member (sample GA-40, 1358m b.r.t.) probably corresponds to the marked drop in diversity and density of both ostracods (Michelsen 1978) (see fig. 18) and bivalves (Pedersen 1986, fig. 6), immediately below this level. This event represents a "turnover" in the ostracod fauna with the appearance of several new species. The bivalve assemblage changes from a "normal shale facies fauna" to a "restricted shale facies fauna" (Morris 1979, Pedersen 1986). The changes in the kerogen curve pattern could thus be due, in part, to a decrease in bioturbation as a result of the dramatic decrease in benthonic fauna. Intensive bioturbation in the lower part of the sequence (Pedersen 1986) probably homogenized the organic matter. Larger changes in the kerogen assemblages would, however, be expected to be preserved despite intensive bioturbation. The kerogen assemblage in the lower part of the sequence thus seems to have been relatively constant. Abrupt and significant variations in the kerogen assemblages were recorded in the sequence with a restricted benthonic fauna, probably in part because of significantly reduced bioturbation. However, the full implications of this marked shift in kerogen assemblages is not clear.

Pedersen (1986) related the decrease in the benthonic fauna to a decrease in oxygen in the bottom waters, presumably in response to the Late Sinemurian-Early Pliensbachian sea-level rise (Hallam 1981). Such a decrease in oxygenation is not supported by the AmexOC-values.

The almost total absence of a benthonic fauna in the uppermost sample of the Fjerritslev Formation (F-III member) was suggested by Pedersen (1986) to indicate the initiation of the Early Toarcian anoxic event. Increases in AmexOC and in the relative abundance of marine palynomorphs, combined with increasing relative abundances of *Spheripollenites* and *Corollina* (Dybkjær 1988), support this suggestion.

Correlation with eustatic sea-level changes

Significant variation in lithology and in the kerogen assemblages, in the four boreholes, possibly resulted from "pulses" in the Early Jurassic sea-level rise, as shown in the sea-level curve of Hallam (1981) (see fig. 19).

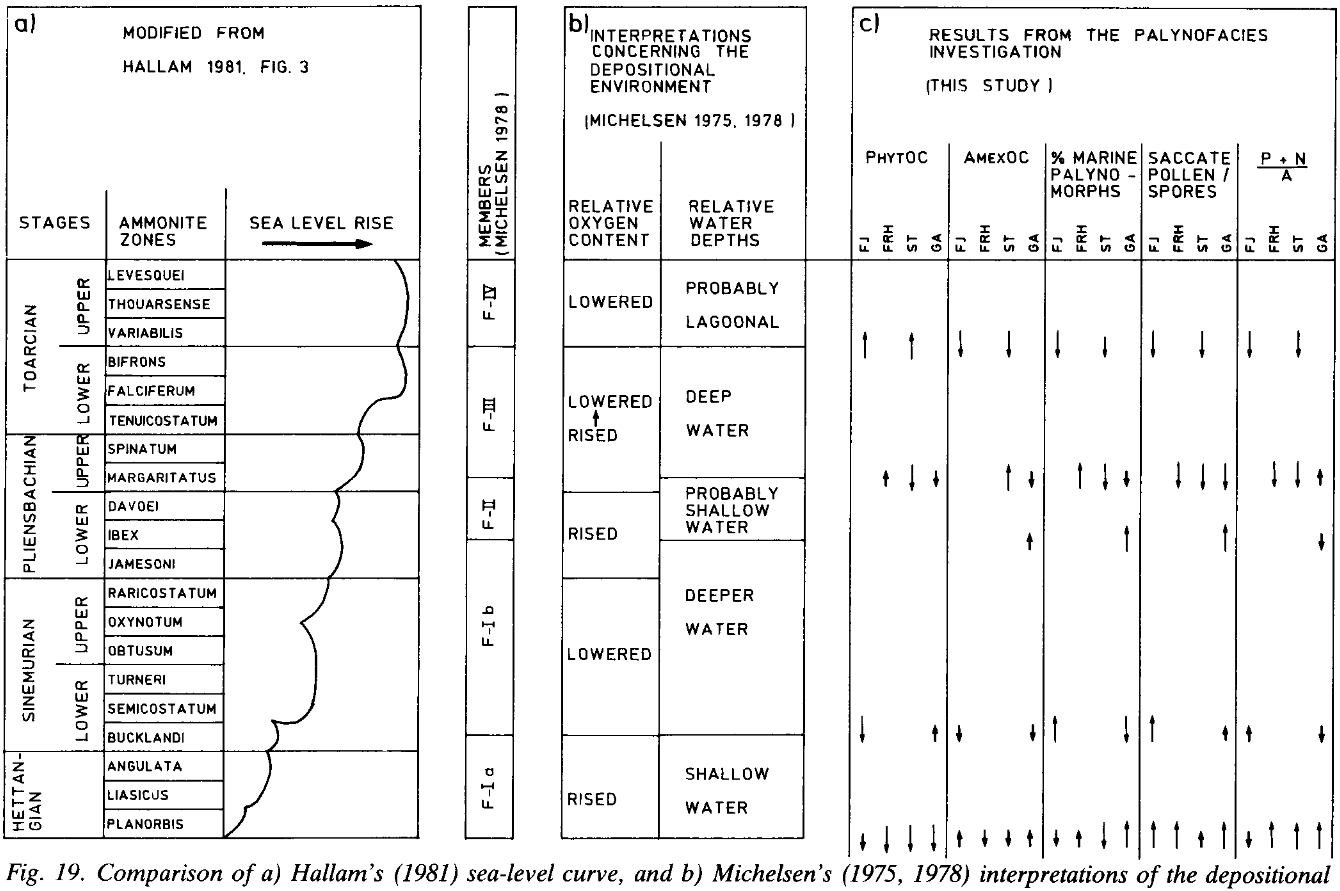


Fig. 19. *Comparison of a) Hallam's (1981) sea-level curve, and b) Michelsen's (1975, 1978) interpretations of the depositional environment of the lithostratigraphical units, with c) the results from the palynofacies investigation presented here. The arrows in (c) indicate whether there is a tendency for the parameters to increase or decrease passing from one lithostratigraphic unit to the other; these are based on comparisons of the mean values for each unit. The exact numbers are presented in Appendix E. Where there is no arrow either one of the lithostratigraphic units are not represented (or not defined) in the borehole, or no core samples exist from the unit.*

↑ : *distinct rise* ↑ : *weak rise*
↓ : *distinct fall* ↓ : *weak fall*

The basal Hettangian phase of sea-level rise was probably responsible for the change in sedimentation from the Gassum Formation to the Fjerritslev Formation in the distal to central parts of the subbasin – the Fjerritslev-2, Gassum-1, and Stenlille-2 boreholes. The transition from the Gassum Formation to the Fjerritslev Formation in Frederikshavn-2 is, according to Pedersen (1986), correlatable with the Late Sinemurian-Early Pliensbachian phase of sea-level rise. However, the biostratigraphic data presented here indicates an Early Sinemurian age for this event.

The Late Sinemurian-Early Pliensbachian sea-level rise could explain the significant changes in the benthonic fauna and in the curve-patterns of the kerogen categories in the Gassum-1 borehole (see discussion above).

According to Pedersen (1986) the transition from the F-II to the F-III member can possibly be related to a Late Pliensbachian rise in sea-level; the variable degrees of oxygen-deficiency in the middle to upper part of the F-III member, and in the F-IV member can be related to the Early Toarcian sea-level rise.

Indications of the major "pulses" of Early Jurassic sea-level rise, in the Gassum-1 borehole, have been studied by Pedersen (1986) and Dybkjær (1988).

Based on the idea that the initial phases of smaller transgressions induce oxygen deficiency on the sea-floor (Hallam & Bradshaw 1979), Pedersen proposed a relationship between the above mentioned major change in the bottom fauna and the Late Sinemurian-Early Pliensbachian phase of sea-level rise. Furthermore, it was suggested that the total absence of benthonic fossils in the uppermost sample referred to the Fjerritslev Formation, dated as Late Pliensbachian, could reflect the initiation of the Early Toarcian phase of sea-level rise.

Dybkjær (1988) investigated the palynomorph assemblages in the Lower Jurassic sequence in Gassum-1 and demonstrated a possible relationship between levels of maximum relative abundance of marine palynomorphs and the major "pulses" in sea-level rise during the Early Jurassic, as presented by Hallam (1981).

The relationship between the AmexOC-curve and the curve of marine versus terrestrial palynomorphs in Gassum-1 supports the correlation with Hallam's (1981) phases of sea-level rise.

Geographical variation

The four boreholes revealed some mutual differences in the kerogen assemblages that are probably related to their palaeogeographic situation within the Danish Subbasin.

A comparison of the composition of the organic matter from the four boreholes is given in fig. 20. In order to compare the results in this way, stage for stage, it has been necessary to make some assumptions concerning the age of some of the investigated samples. Sample Fj-11,c, from Fjerritslev-2, has been treated as being of Sinemurian age, and samples Fj-12,c and Fj-13,c as being of Pliensbachian age. Samples Frh-13,c and Frh-14,c, from Frederikshavn-2, have been assumed to be of Pliensbachian age while sample St-5,c from Stenlille-2, is regarded as the lowermost sample of Hettangian age. Furthermore, it should be noted that due to the sparse core coverage, samples within a broad stratigraphic interval are compared, e.g. samples from the Lower Pliensbachian in one borehole are compared with samples representing the Upper Pliensbachian from another borehole.

In the Hettangian stratigraphic interval, the mean values of the Gassum-1 borehole clearly indicate a more distal location than those of the Fjerritslev-2 and Stenlille-2 boreholes, showing a lower PhytOC mean value, a higher mean ratio of saccate pollen/spore, and a higher mean value of % marine palynomorphs.

In the Sinemurian, the most significant differences are seen between the distally located Gassum-1 borehole and the most marginally situated borehole, Frederikshavn-2. Gassum-1 clearly shows a lower mean PhytOC value, a higher mean ratio of saccate pollen/spores, and a significantly higher mean value of % marine palynomorphs than Frederikshavn-2. A slightly higher mean AmexOC value was also recorded from Gassum-1. The mean values from the two other boreholes show trends inbetween the Gassum-1 and Frederikshavn-2.

Also in the Pliensbachian interval, the mean values of the Frederikshavn-2 clearly reflect the marginal location of this borehole, compared to the others, showing the highest mean PhytOC values, the lowest ratio of saccate pollen/spores, and the lowest relative abundance of marine palynomorphs.

In the Toarcian interval the mean values in Frederikshavn-2 continuously reflect a more marginal position than the Fjerritslev-2 and Stenlille-2 boreholes, showing the highest mean PhytOC value and the lowest mean AmexOC value. The marginal position of Frederikshavn-2 is further reflected by the differences in the mean ratio of saccate pollen/spores and in the mean value of % marine palynomorphs compared to the Fjerritslev-2 borehole.

The palynomorph assemblages in the two samples representing the Toarcian in Stenlille-2 are, as mentioned earlier, totally dominated by a single species, here referred to *Spheripollenites psilatus*. The mean values based on palynomorphs (the ratio saccate pollen/spores, the ratio (P+N)/A, and % marine palynomorphs) are therefore not reliable and not comparable with the results from the other boreholes.

The mean values of the ratio (Polygonomorphitae +

		Frederikshavn-2 (A)	Fjerritslev-2 (B)	Gassum-1 (C)	Stenlille-2 (D)
HETTANGIAN	PhytOC		0.97 (n=1)	0.53 (n= 8)	0.75 (n=15)
	AmexOC		0.04 (n=1)	0.05 (n= 8)	0.04 (n=15)
	saccate pollen/spores		0.27 (n=1)	0.80 (n= 8)	0.30 (n=14)
	$\frac{P+N}{A}$		0.00 (n=1)	0.23 (n= 8)	0.40 (n=14)
	% marine palynomorphs		7% (n=1)	21% (n= 8)	11% (n=14)
SINEMURIAN	PhytOC	1.09 (n=11)	0.67 (n=7)	0.56 (n=10)	0.64 (n= 1)
	AmexOC	0.02 (n=11)	0.01 (n=7)	0.05 (n=10)	0.00 (n= 1)
	saccate pollen/spores	0.40 (n= 4)	0.56 (n=4)	0.88 (n= 8)	0.13 (n= 1)
	$\frac{P+N}{A}$	0.19 (n= 7)	0.02 (n=4)	0.14 (n= 8)	0.67 (n= 1)
	% marine palynomorphs	9% (n= 7)	10% (n=4)	26% (n= 8)	7% (n= 1)
PLIENSBACH	PhytOC	0.77 (n= 2)	0.58 (n=2)	0.63 (n=15)	0.41 (n= 4)
	AmexOC	0.03 (n= 2)	0.01 (n=2)	0.08 (n=15)	0.05 (n= 4)
	saccate pollen/spores	0.47 (n= 2)	1.47 (n=1)	1.08 (n=10	1.15 (n= 3)
	$\frac{P+N}{A}$	0.30 (n= 2)	0.11 (n=1)	0.09 (n=10)	0.32 (n= 3)
	% marine palynomorphs	10% (n= 2)	25% (n=1)	20% (n=10)	19% (n= 3)
TOARCIAN	PhytOC	0.66 (n= 8)	0.54 (n=2)		0.14 (n= 2)
	AmexOC	0.02 (n= 8)	0.27 (n=2)		0.75 (n= 2)
	saccate pollen/spores	0.43 (n= 5)	2.09 (n=1)		0.00 (n= 2)
	$\frac{P+N}{A}$	0.32 (n= 5)	0.16 (n=1)		0.09 (n= 2)
	% marine palynomorphs	16% (n= 5)	24% (n=1)		5% (n= 2)

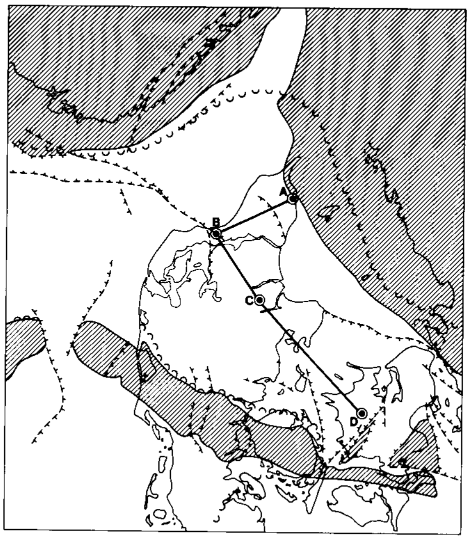
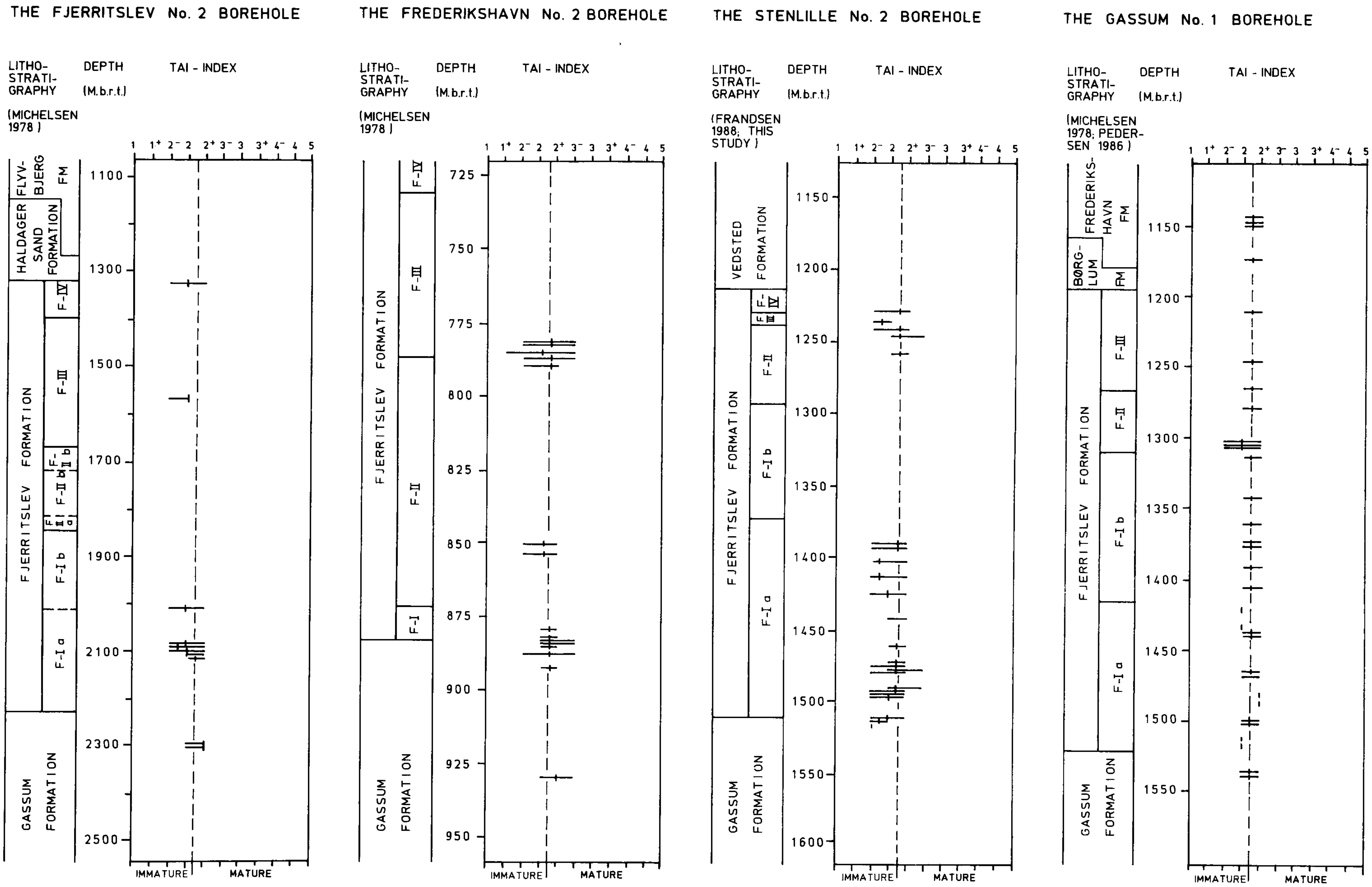


Fig. 20. This figure shows the overall differences in the kerogen assemblages from the four boreholes in relation to their location in the Danish Subbasin. The mean value for each stage is presented together with the number of samples responsible for the mean value (n). The Hettangian has not been investigated in the Frederikshavn-2 borehole, as these deposits are referred to the Gassum Formation.
No deposits of Toarcian age were recorded in the Gassum-1 borehole.

Fig. 21. Thermal Alteration Index (T.A.I.) related to depth. The recorded variations for each sample and the mean value are indicated. The boundary between immature and mature is also indicated. →


THE FJERRITSLEV No. 2 BOREHOLE
LITHO-STRATI-GRAPHY (MICHELSEN 1978)
DEPTH (M.b.r.t.)
TAI - INDEX
1 1+ 2- 2 2+ 3- 3 3+ 4- 4 5
FLYV-BJERG FM
HALDAGER SAND FORMATION
FJERRITSLEV FORMATION
F-IV
F-III
F-II b
F-II
F-II a
F-I b
F-I a
GASSUM FORMATION
1100
1300
1500
1700
1900
2100
2300
2500
IMMATURE
MATURE
THE FREDERIKSHAVN No. 2 BOREHOLE
LITHO-STRATI-GRAPHY (MICHELSEN 1978)
DEPTH (M.b.r.t.)
TAI - INDEX
1 1+ 2- 2 2+ 3- 3 3+ 4- 4 5
FJERRITSLEV FORMATION
F-IV
F-III
F-II
F-I
GASSUM FORMATION
725
750
775
800
825
850
875
900
925
950
IMMATURE
MATURE
THE STENLILLE No. 2 BOREHOLE
LITHO-STRATI-GRAPHY (FRANDSEN 1988; THIS STUDY)
DEPTH (M.b.r.t.)
TAI - INDEX
1 1+ 2- 2 2+ 3- 3 3+ 4- 4 5
VEDSTED FORMATION
FJERRITSLEV FORMATION
F-IV
F-III
F-II
F-I b
F-I a
GASSUM FORMATION
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
IMMATURE
MATURE
THE GASSUM No. 1 BOREHOLE
LITHO-STRATI-GRAPHY (MICHELSEN 1978; PEDERSEN 1986)
DEPTH (M.b.r.t.)
TAI - INDEX
1 1+ 2- 2 2+ 3- 3 3+ 4- 4 5
FREDERIKS-HAVN FM
BØRG-LUM FM
FJERRITSLEV FORMATION
F-III
F-II
F-I b
F-I a
GASSUM FORMATION
1150
1200
1250
1300
1350
1400
1450
1500
1550
IMMATURE
MATURE

Netromorphitae)/Acanthomorphitae generally show the trends opposite to those expected. Theoretically a high ratio indicates deposition in a relatively deep-water environment, while low ratios should indicate a shallow-water depositional environment. Here the mean values from Frederikshavn-2 are generally the highest. The usefulness of this ratio as an indication of water-depths should thus be investigated further.

With the exception of the ratio mentioned above, it can be concluded that the differences in the kerogen assemblages from the four boreholes are useful indication of their relative locations in the basin.

Amount, type and maturation of organic matter

According to Thomsen et al. (1987), the Fjerritslev Formation is the only Mesozoic sequence in the Norwegian-Danish Basin that qualifies as a potential source for oil.

A Total Organic Carbon (T.O.C.) value of 0.5% is the absolute minimum value for a marine shale to represent a potential source rock. Furthermore, the composition of the organic matter is critical for the hydrocarbon potential. The main distinction is made between terrestrial (non-aquatic) kerogen particles and particles derived from aquatic organisms. Kerogen comprising a large amount of terrestrial plant debris is generally only capable of generating a small amount of oil compared with kerogen made of marine or limnic organic matter. The terrestrially-derived kerogen could, however, provide a good source for hydrocarbon gas at greater depths (Tissot & Welte 1984).

The highest recorded T.O.C. values are from samples referred to the Gassum Formation where they vary from 0.9% to 4.7% (see Appendices A-D and figs 12, 14, 16 & 18); the maximum values were from the Frederikshavn-2 borehole. The kerogen assemblages in these samples are strongly dominated by terrestrial material. T.O.C. values in the Fjerritslev Formation vary between 0.4% and 1.9%; the highest values are from the F-III and F-IV members.

The kerogen assemblages in the F-Ia, F-Ib, and F-II members are strongly dominated by terrestrially-derived kerogen, especially brown wood. The composition of the kerogen assemblages in the F-III member varies a great deal from borehole to borehole, but shows a distinct decrease in the relative abundance of brown wood and a concurrent increase in A.O.M. and marine palynomorphs compared to the F-Ia, F-Ib, and F-II members. The kerogen assemblages in the F-IV member are dominated by terrestrially-derived particles, but the relative abundance of A.O.M. is higher than in the F-Ia, F-Ib, and F-II members.

The mean T.A.I.-values for each sample varies between 2- and 2+ (fig. 21). Maturity shows an overall increase with depth in Fjerritslev-2 and Frederikshavn-2, whereas no trends were recognized in Stenlille-2 and Gassum-1. Thomsen et al. (1983) recorded a general increase in rank with depth in all investigated boreholes, including Fjerritslev-2, Frederikshavn-1 and Gassum-1, although their investigation encompassed the full sequence from Rhaetian to Lower Cretaceous.

It can be concluded that the Fjerritslev Formation does not generally represent a potential source rock for oil. A few levels in the F-III member, however, show the characteristics of a fair to good source rock. The T.A.I. values indicate that the organic matter is generally immature, or only at the earliest stage of maturity. These results correspond very well with results from previous investigations (see p. 12–13).

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PLATES 1–22

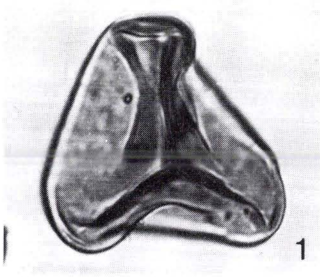
On plates 1–20 are shown specimens recorded in the present study. The number of the sample, from which the illustrated specimen was recorded, is given in the figure text. The slides containing the illustrated specimens are deposited at the Geological Survey of Denmark, together with a list of stage coordinates from the microscope. Plates 21 and 22 show new photos of the holotypes of some of the species erected by Nilsson (1958).

All magnifications are x1000, unless otherwise stated.

PLATE 1

Fig. 1. *Deltoidospora toralis* (Leschik 1955) Lund 1977. Sample St-5,c.
Fig. 2. *Deltoidospora minor* (Couper 1958) Pocock 1970. Sample Frh-13,s.
Fig. 3. *Deltoidospora* cf. *minor* (Couper 1958) Pocock 1970. Sample Frh-19,c.
Fig. 4. *Cibotiumspora jurienensis* (Balme 1957) Filatoff 1975. Sample Fj-9,c.
Fig. 5. *Tripartina variabilis* Malyavkina 1949. Sample Frh-17,c.
Fig. 6. *Intrapunctisporis toralis* (Leschik 1955) Lund 1977. Proximal side (high focus). Sample Frh-17,c.
Fig. 7. Same specimen as fig. 6. Proximal side (lower focus).
Fig. 8. *Punctatisporites globosus* (Leschik 1955) Lund 1977. Sample Frh-12,c.
Fig. 9. *Retusotriletes* cf. *mesozoicus* Klaus 1960. NOTICE: Magnification x500. Sample St-11,c.
Fig. 10. *Calamospora tener* (Leschik 1955) Mädler 1964. Sample Frh-1,c.
Fig. 11. *Stereisporites stereoides* (Potonié & Vernitz 1934) Thomson & Pflug 1953. Sample St-6,c.
Fig. 12. *Stereisporites antiquasporites* (Wilson & Webster 1946) Dettmann 1963. Sample St-6,c.
Fig. 13. *Stereisporites punctus* (Klaus 1960) Krutzsch 1963. Proximal side (high focus). Sample Frh-9,c.
Fig. 14. Same specimen as fig. 13. Distal side (low focus).

Plate 1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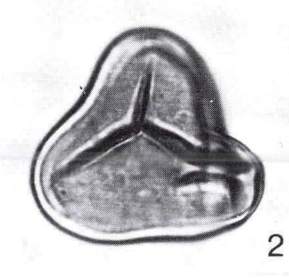
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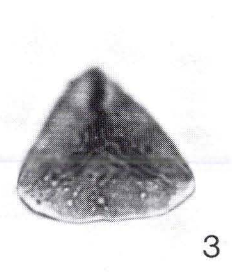
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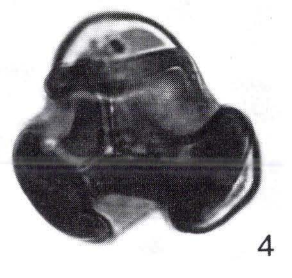
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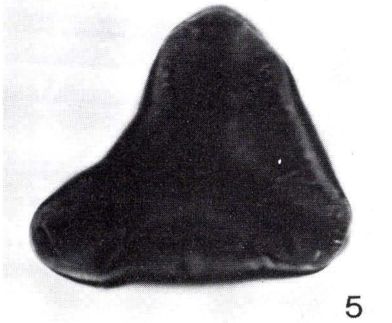
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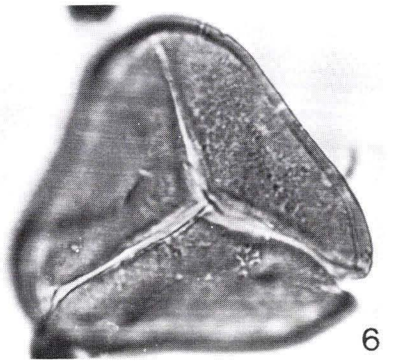
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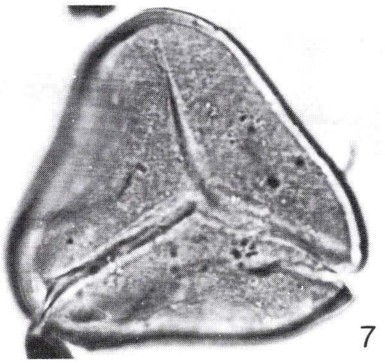
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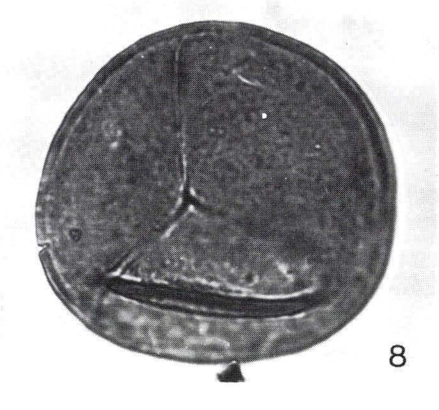
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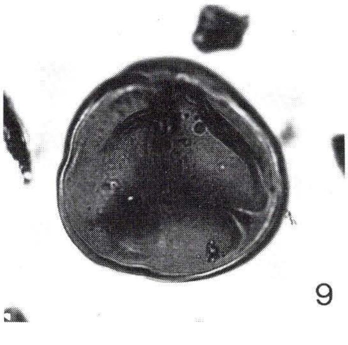
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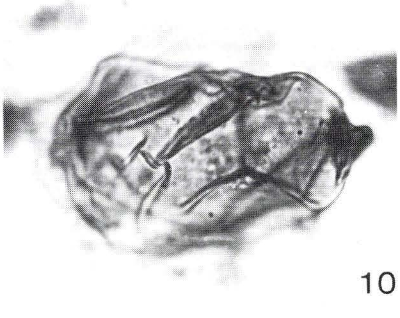
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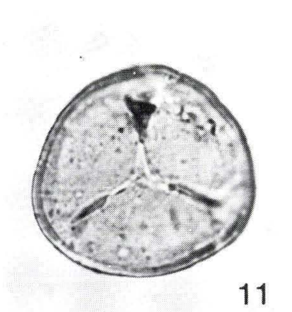
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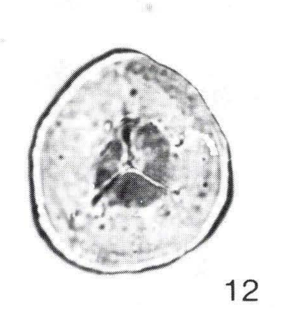
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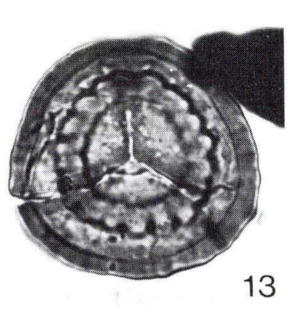
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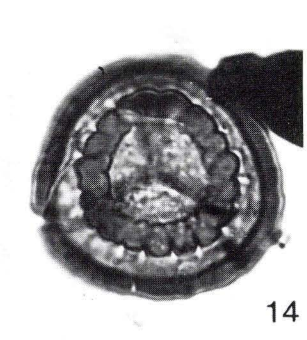
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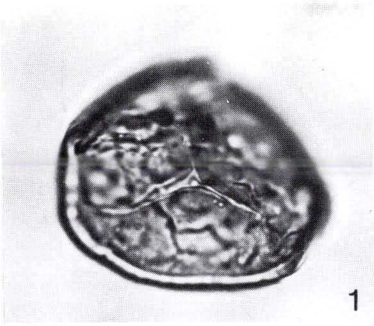
PLATE 2

Fig. 1. *Stereisporites aulosenensis* (Schulz 1967) Schulz 1966. Sample Fj-16,c.
Fig. 2. *Stereisporites* cf. *seebergensis* Schulz 1966. Sample Fj-16,c.
Fig. 3. *Stereisporites hauterivensis* Döring 1966. Sample St-9,w.
Fig. 4. *Trachysporites fuscus* Nilsson 1958. Proximal side (high focus). Sample St-7,c.
Fig. 5. Same specimen as fig. 4. Distal side (low focus).
Fig. 6. *Trachysporites asper* Nilsson 1958. Sample Frh-12,c.
Fig. 7. *Trachysporites sparsus* (Bharadwaj & Singh 1964) Lund 1977. Sample St-5,c.
Fig. 8. *Trachysporites sparsus* (Bharadwaj & Singh 1964) Lund 1977. Sample St-3,c.
Fig. 9. *Conbaculatisporites mesozoicus* Klaus 1960. Sample St-11,c.
Fig. 10. *Conbaculatisporites spinosus* (Mädler 1964) Lund 1977. Sample St-14,w.
Fig. 11. *Baculatisporites wellmanii* (Couper 1953) Krutzsch 1959. Proximal side (high focus). Sample St-7,c.
Fig. 12. Same specimen as fig. 11. Distal side (low focus).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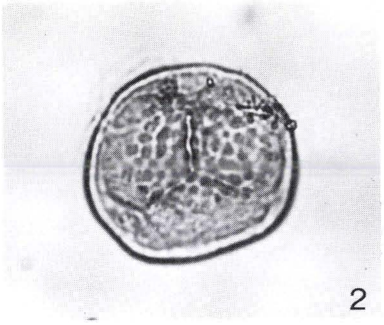
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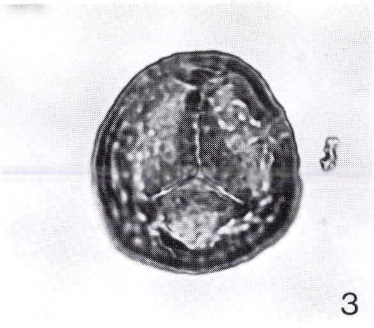
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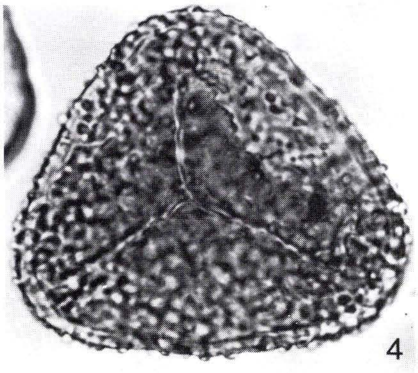
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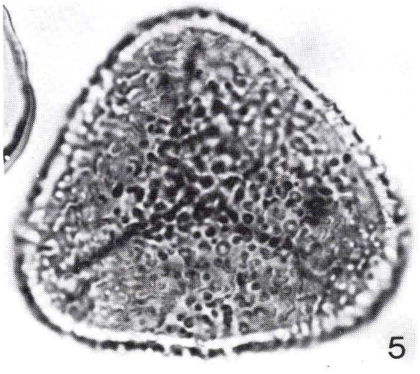
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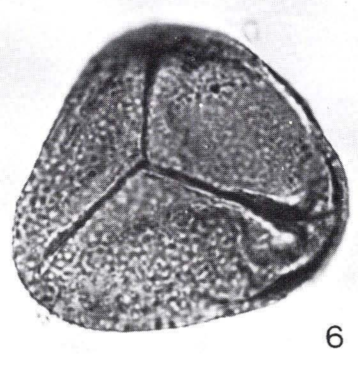
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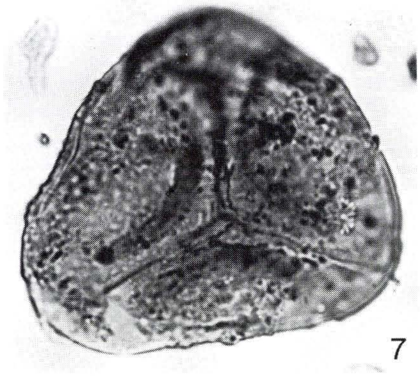
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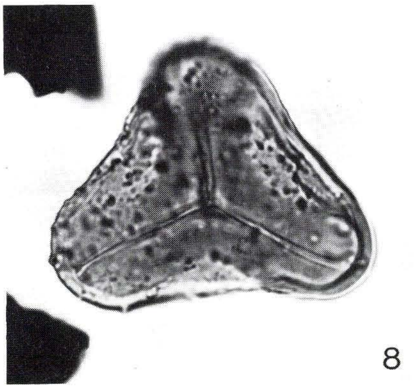
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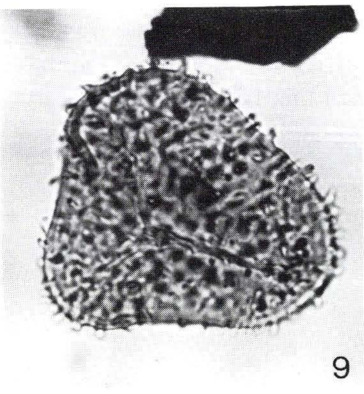
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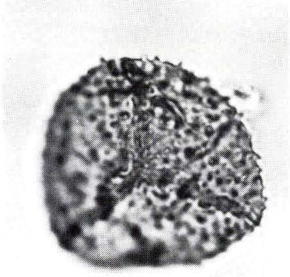
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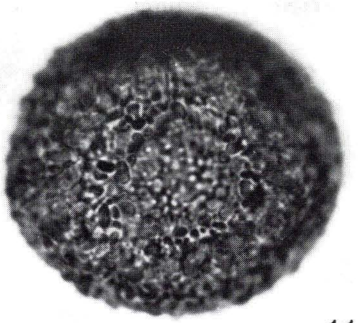
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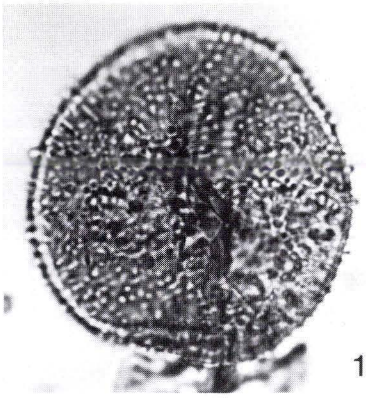
PLATE 3

Fig. 1. *Apiculatisporites ovalis* (Nilsson 1958) Norris 1964. Proximal side (high focus). Sample St-7,c.
Fig. 2. Same specimen as fig. 1. Proximal side (lower focus).
Fig. 3. *Baculatisporites oppressus* (Leschik 1955) Lund 1977. Sample St-11,w.
Fig. 4. *Apiculatisporites ovalis* (Nilsson 1958) Norris 1964. Proximal side (high focus). Sample Frh-9,c.
Fig. 5. Same specimen as fig. 4. Distal side (low focus).
Fig. 6. *Baculatisporites comaumensis* (Cookson 1953) Potonié 1956. Sample Frh-18,c.
Fig. 7. *Conbaculatisporites* sp. 1. Sample Frh-16,c.
Fig. 8. *Anapiculatisporites telephorus* (Pautsch 1958) Klaus 1960. Distal side (high focus). Sample St-8,w.
Fig. 9. Same specimen as fig. 8. Distal side (lower focus).
Fig. 10. *Taurocusporites verrucatus* Schulz 1967. Proximal side (high focus). Sample St-17,w.
Fig. 11. Same specimen as fig. 10. Proximal side (lower focus).
Fig. 12. *Foraminisporis jurassicus* Schulz 1967. Sample Frh-17,c.

Plate 3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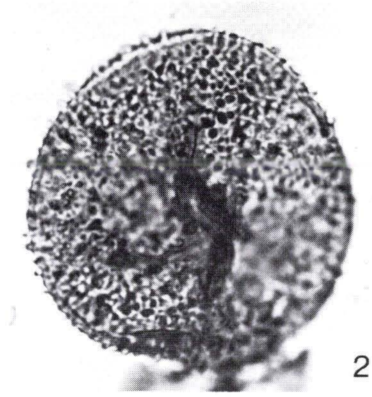
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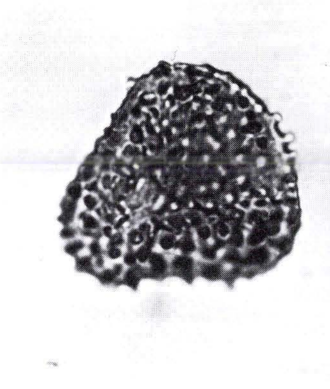
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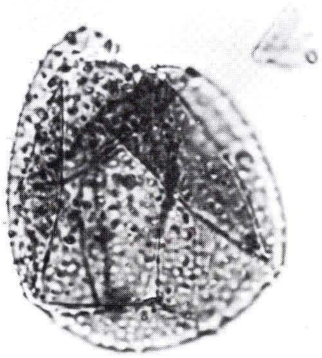
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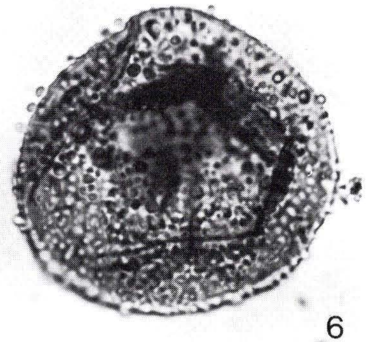
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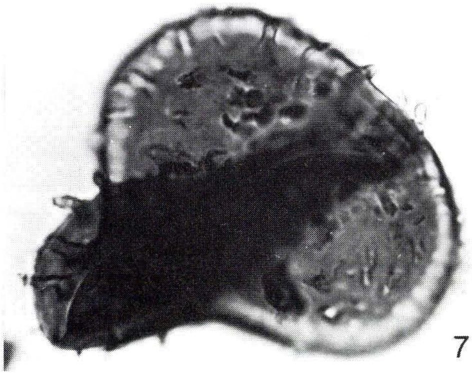
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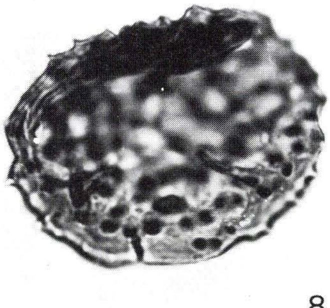
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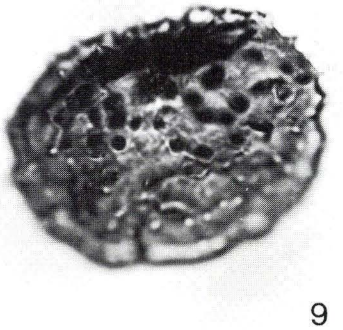
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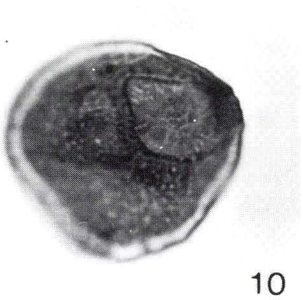
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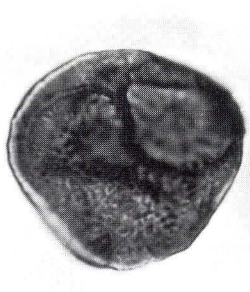
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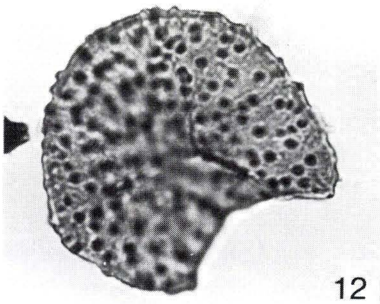
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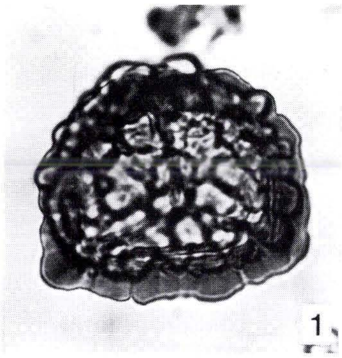
PLATE 4

Fig. 1. *Uvaesporites argenteaeformis* (Bolchovitina 1953) Schulz 1967. Proximal side (low focus). Sample Frh-23,s.
Fig. 2. Same specimen as fig. 1. Distal side (higher focus).
Fig. 3. Same specimen as fig. 1. Distal side (high focus).
Fig. 4. *Uvaesporites argenteaeformis* (Bolchovitina 1953) Schulz 1967. Proximal side (high focus). Sample Frh-24,s.
Fig. 5. *Manumia delcourtii* (Pocock 1970) comb. nov. et emend. Sample Fj-30,s.
Fig. 6. Cf. *Manumia* sp. 1. Sample Fj-32,s.
Fig. 7. Same specimen as fig. 4. Distal side (low focus).
Fig. 8. *Polypodiisporites polymicroforatus* (Orlowska-Zwolinska 1966) Lund 1977. Sample Fj-3,c.
Fig. 9. *Polypodiisporites polymicroforatus* (Orlowska-Zwolinska (1966) Lund 1977. Sample Fj-2,c.
Fig. 10. *Polypodiisporites ipsviciensis* (de Jersey 1962) Playford & Dettmann 1965. Sample Frh-10,c.
Fig. 11. *Leptolepidites major* Couper 1958. Proximal side (low focus). Sample St-16,w.
Fig. 12. Same specimen as fig. 11. Distal side (high focus).

Plate 4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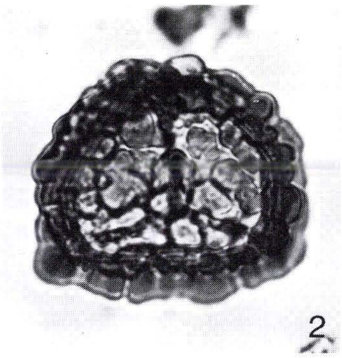
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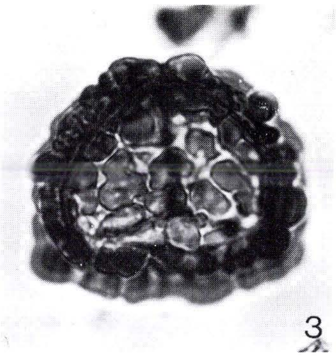
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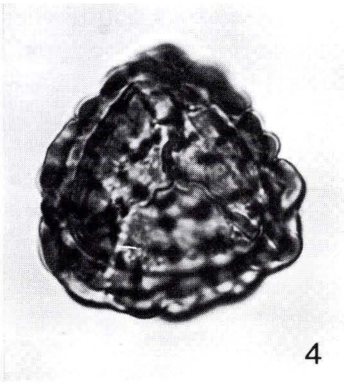
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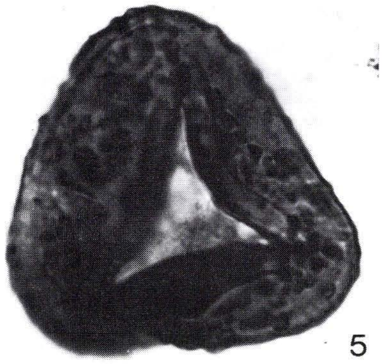
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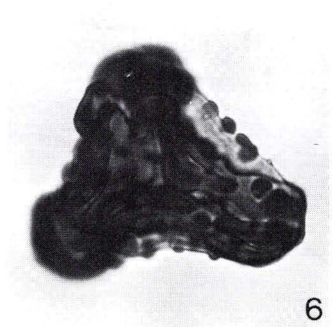
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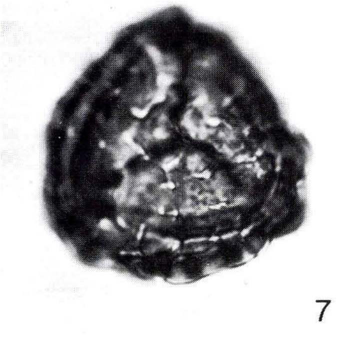
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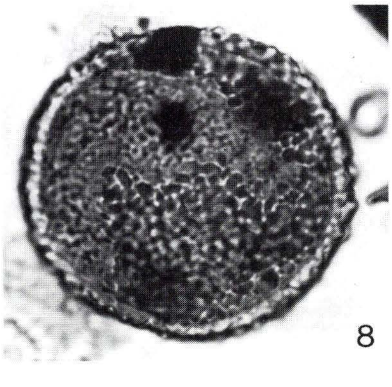
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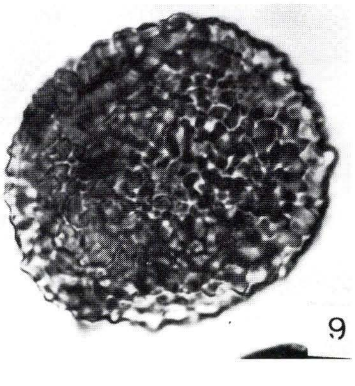
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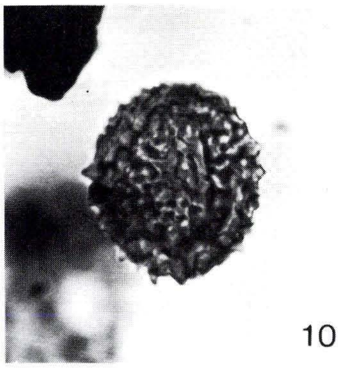
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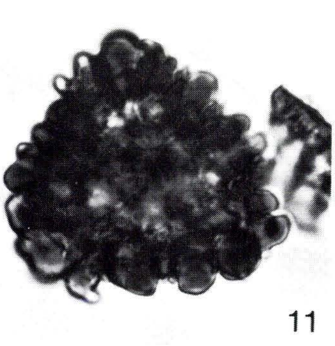
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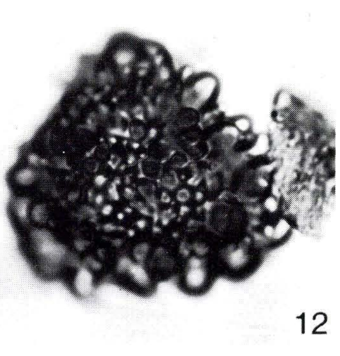
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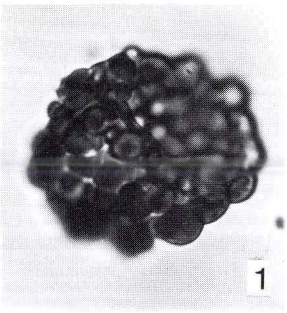
PLATE 5

Fig. 1. *Leptolepidites major* Couper 1958. Sample Fj-14,c.
Fig. 2. *Leptolepidites major* Couper 1958. Sample St-16,w.
Fig. 3. *Leptolepidites* sp. 1. Proximal side (low focus). Sample St-16,w.
Fig. 4. Same specimen as fig. 3. Distal side (high focus).
Fig. 5. *Leptolepidites* sp. 2. Proximal side (low focus). Sample Frh-22,s.
Fig. 6. Same specimen as fig. 5. Distal side (high focus).
Fig. 7. *Concavissimisporites variverrucatus* (Couper 1958) Brenner 1963. Presumed caved. Sample Frh-20,s.
Fig. 8. Cf. *Baculatisporites* sp. Sample Fj-16,c.
Fig. 9. *Lycopodiumsporites semimuris* Danzé-Corsin & Laveine 1963. Proximal side (high focus). Sample Fj-12,c.
Fig. 10. Same specimen as fig. 9. Distal side (low focus).
Fig. 11. *Lycopodiumsporites gracilis* (Nilsson 1958) Döring, Krutzsch, Mai & Schulz 1963. Proximal side (high focus). Sample Fj-34,s.
Fig. 12. *Lycopodiumsporites austroclavatidites* (Cookson 1953) Potonié 1956. Proximal side (low focus). Sample St-14,w.
Fig. 13. Same specimen as fig. 12. Distal side (high focus).
Fig. 14. Same specimen as fig. 11. Distal side (low focus).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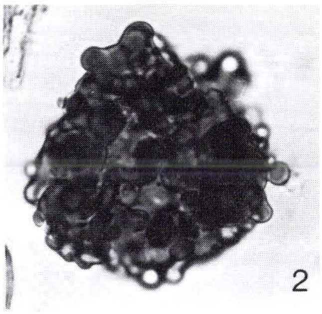
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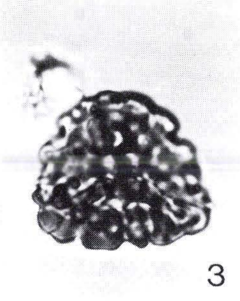
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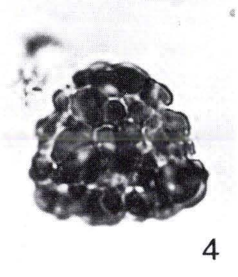
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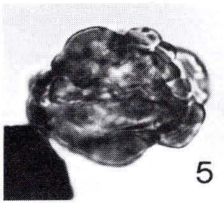
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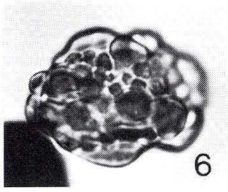
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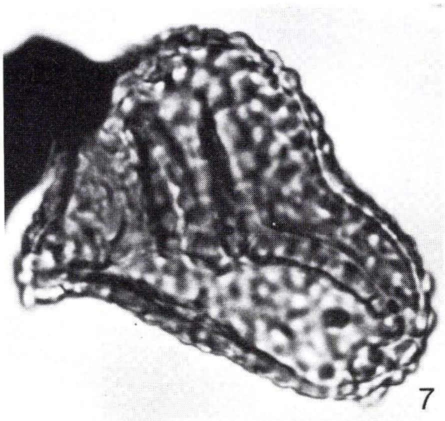
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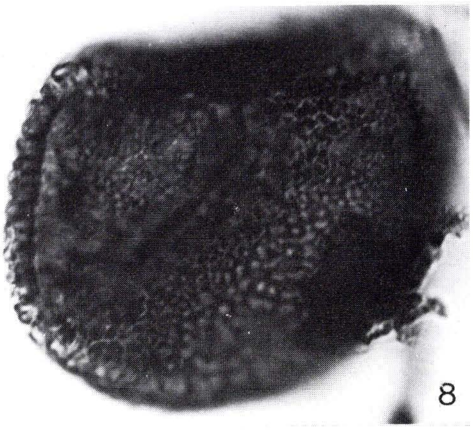
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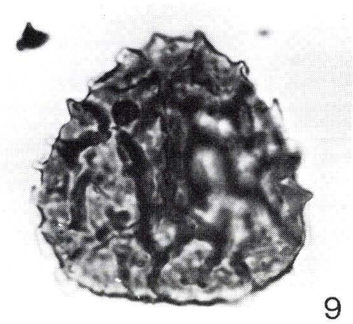
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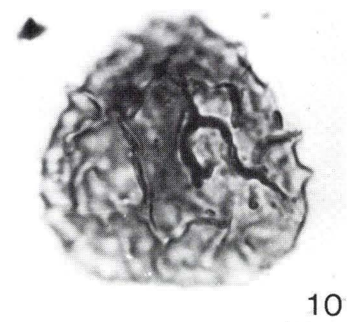
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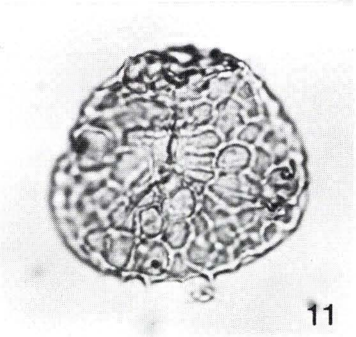
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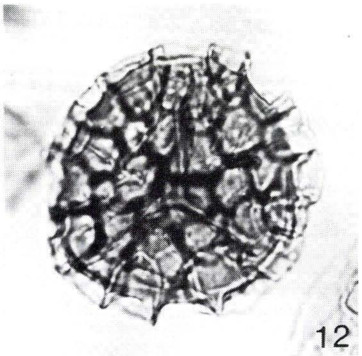
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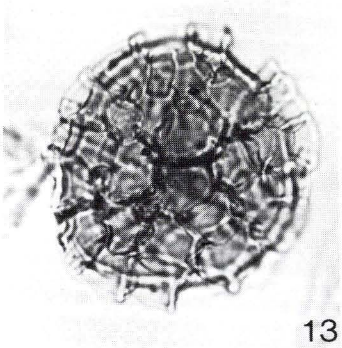
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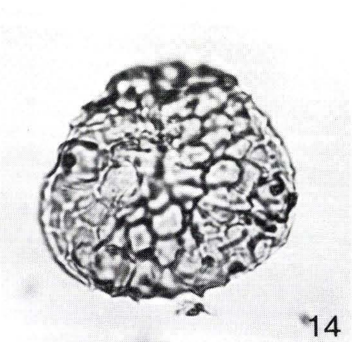
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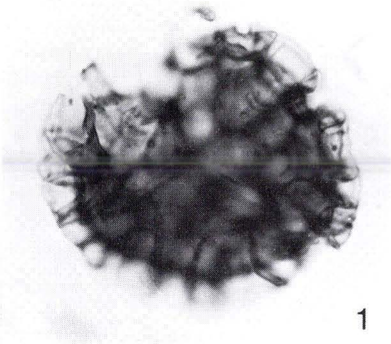
PLATE 6

Fig. 1. *Lycopodiumsporites* sp.1. Proximal side (low focus). Sample Fj-16,c.
Fig. 2. Same specimen as fig. 1. Distal side (higher focus).
Fig. 3. Same specimen as figs 1 and 2. Distal side (high focus).
Fig. 4. *Semiretisporis gothae* Reinhardt 1962. NOTICE: Magnification x500. Sample St-3,c.
Fig. 5. *Costatisulcites* cf. *ovatus* Scheuring 3978. Sample Fj-4,c.
Fig. 6. *Tigrisporites scurrandus* Norris 1967. Proximal side (high focus). Sample Frh-9,c.
Fig. 7. *Ischyosporites variegatus* Couper 1958. Sample Frh-17,c.
Fig. 8. Same specimen as figs 6. Proximal side (lower focus). Sample Frh-17,s.
Fig. 9. *Cicatricosisporites hallei* Delcourt & Sprumont 1955. Presumed caved. Proximal side (high focus). Sample Frh-17,s.
Fig. 10. Same specimen as fig. 9. Distal side (low focus).
Fig. 11. Same specimen as fig. 6 and 8. Distal side (low focus).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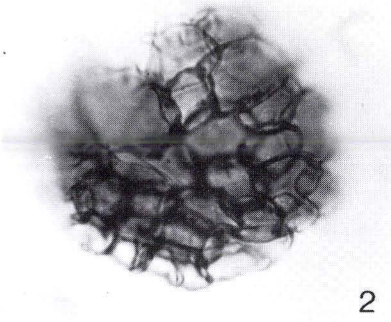
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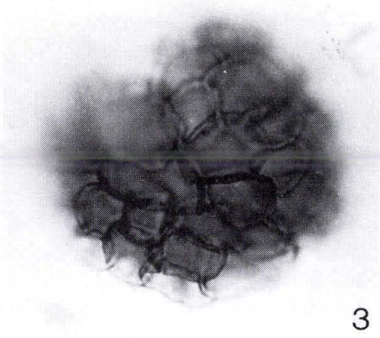
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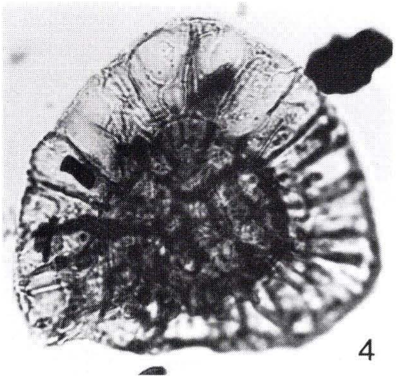
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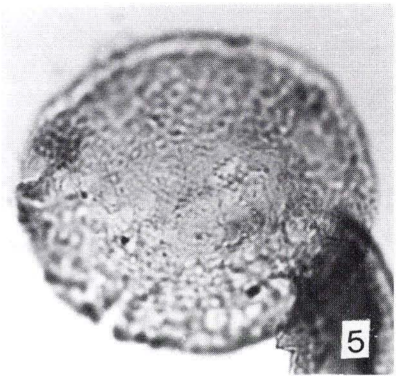
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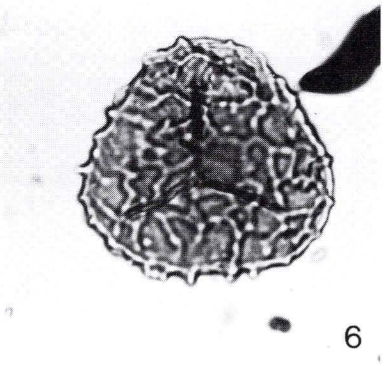
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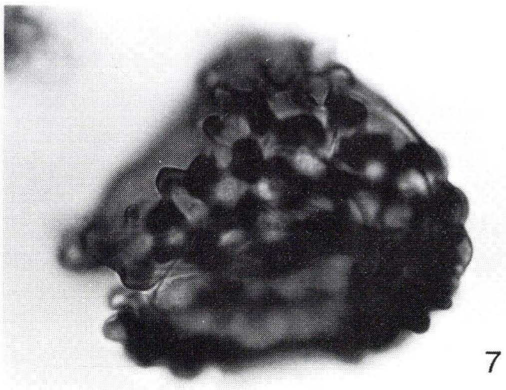
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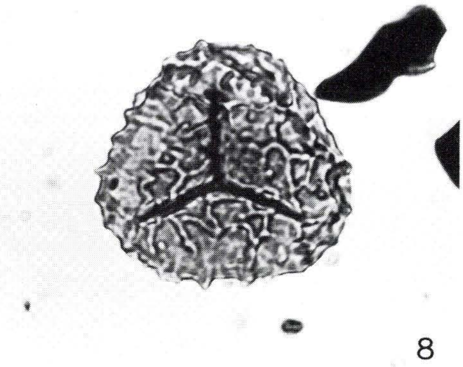
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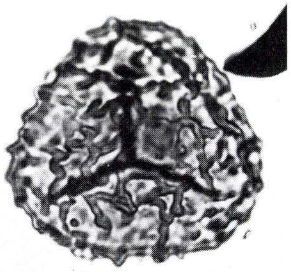
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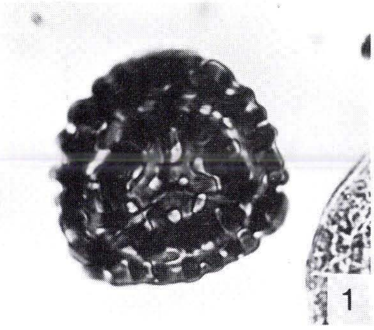
PLATE 7

Fig. 1. *Klukisporites lacunus* Filatoff 1975. Sample Frh-19,c.
Fig. 2. *Foveosporites labiosus* Singh 1971. Presumed caved. Proximal side (high focus). Sample Fj-22,s.
Fig. 3. Same specimen as fig. 2. Distal side (low focus).
Fig. 4. *Triancoraesporites ancorae* (Reinhardt 1962) Schulz 1967. Sample St-3,c.
Fig. 5. *Triancoraesporites ancorae* (Reinhardt 1962) Schulz 1967. Sample St-3,c.
Fig. 6. *Triancoraesporites reticulatus* Schulz 1967. Sample St-3,c.
Fig. 7. *Gleicheniidites senonicus* Ross 1949. Could be caved. Proximal side (high focus). Sample Frh-23,s.
Fig. 8. Same specimen as fig. 7. Equatorial view (lower focus).
Fig. 9. *Gleicheniidites* cf. *bulbosus* Kemp 1970. Presumed caved. Sample Frh-20,s.
Fig. 10. *Clavifera triplex* (Bolchovitina 1953) Bolchovitina 1966. Presumed caved. Sample Frh-20,s.
Fig. 11. *Zebrasporites interscriptus* (Thiergart 1949) Klaus 1960. Sample St-8,c.
Fig. 12. *Zebrasporites laevigatus* (Schulz 1962) Schulz 1967. Sample St-3,c.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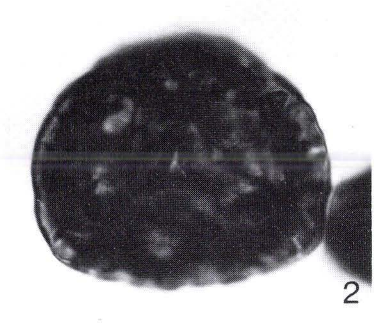
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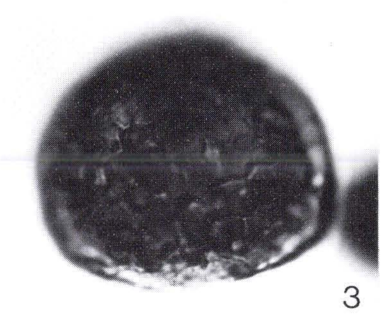
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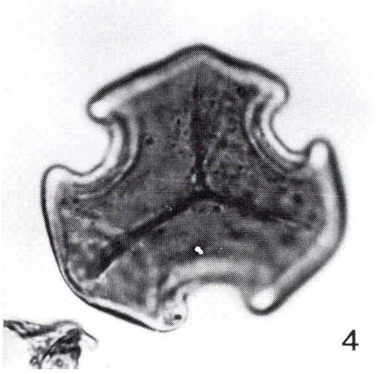
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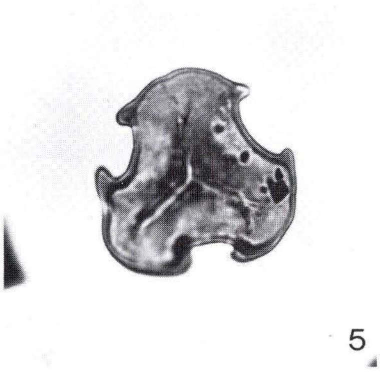
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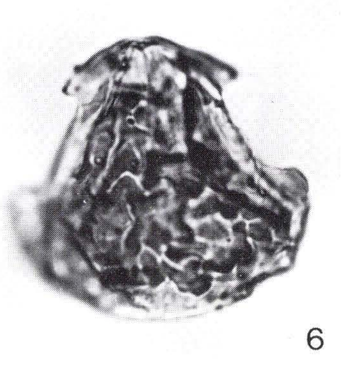
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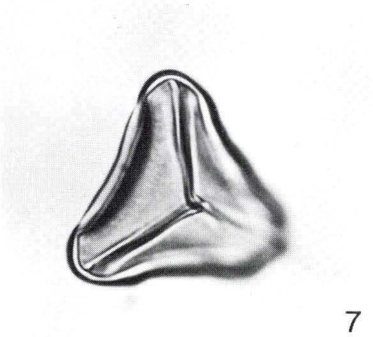
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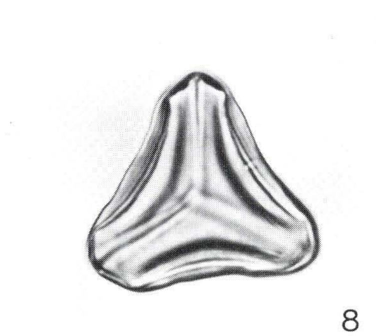
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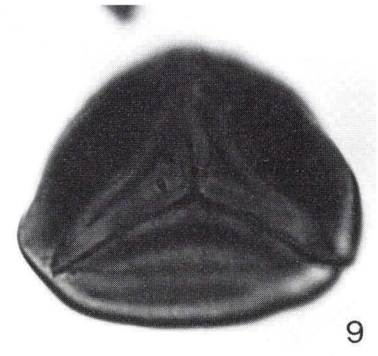
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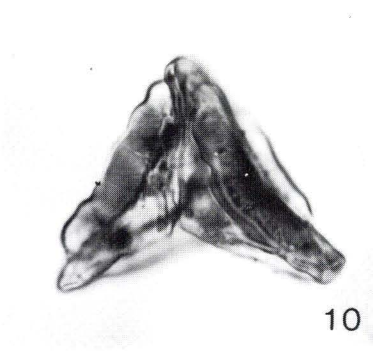
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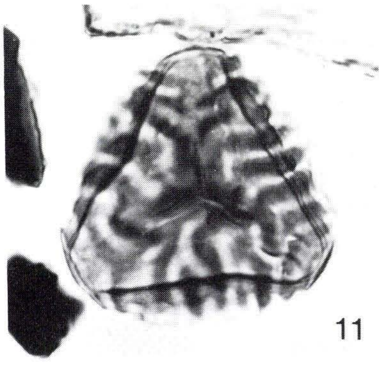
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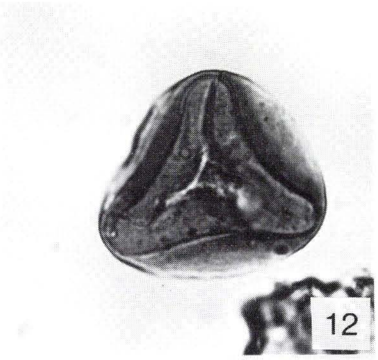
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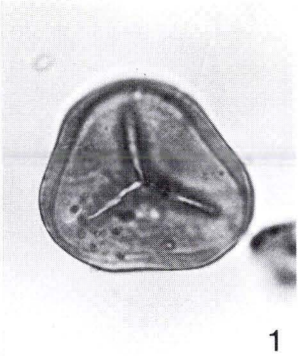
PLATE 8

Fig. 1. *Camarozonosporites laevigatus* Schulz 1967. Sample St-2,c.
Fig. 2. *Perinosporites thuringiacus* Schulz 1962. Proximal side (high focus). Sample St-3,c.
Fig. 3. Same specimen as fig. 2. Distal side (low focus).
Fig. 4. *Camarozonosporites rudis* Klaus 1960. Sample St-2,c.
Fig. 5. *Lycospora salebrosacea* (Maljavkina 1949) Schulz 1967. Could be reworked. Proximal side (high focus). Sample Fj-16,c.
Fig. 6. Same specimen as fig. 5. Distal side (low focus).
Fig. 7. *Lycospora salebrosacea* (Maljavkina 1949) Schulz 1967. Presumed reworked. Sample Fj-12,c.
Fig. 8. *Densosporites fissus* (Reinhardt 1962) Schulz 1967. Sample St-3,c.
Fig. 9. *Densosporites cavernatus* Orlowska-Zwolinska 1966. Proximal side (high focus). Sample St-3,c.
Fig. 10. Same specimen as fig. 9. Distal side (low focus).
Fig. 11. Cf. *Densosporites* ssp. Presumed reworked. Sample St-11,w.
Fig. 12. Cf. *Densosporites* ssp. Presumed reworked. Sample St-13,w.
Fig. 13. Cf. *Densosporites* ssp. Presumed reworked. Sample Fj-23,s.

Plate 8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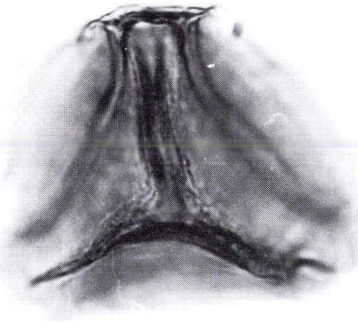
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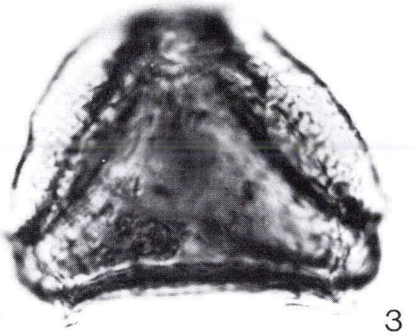
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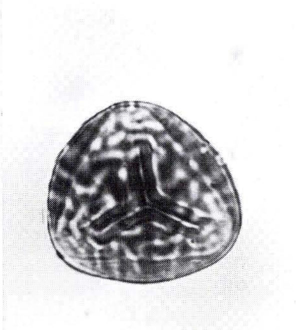
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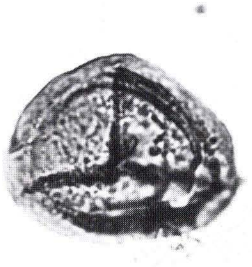
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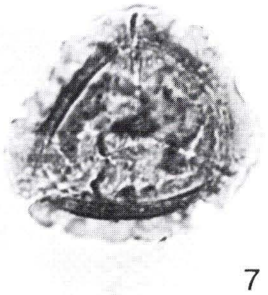
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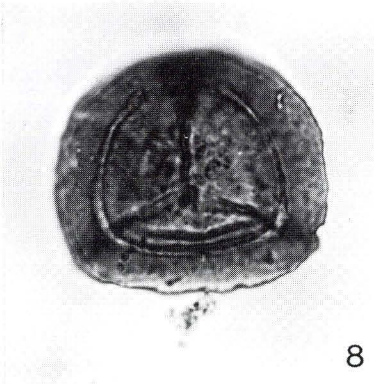
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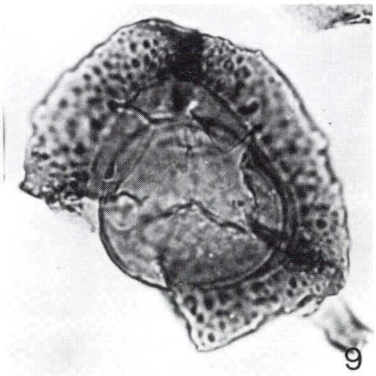
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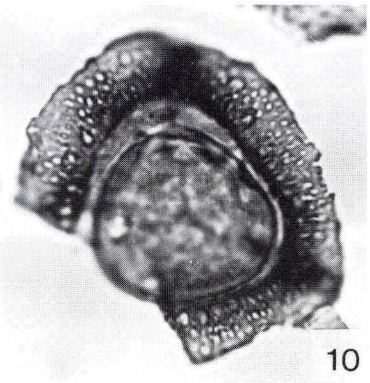
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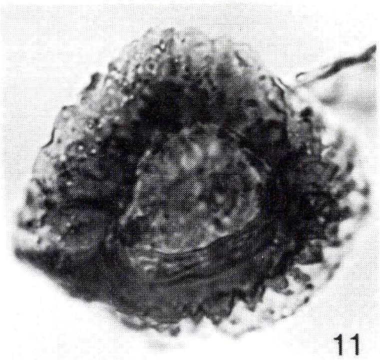
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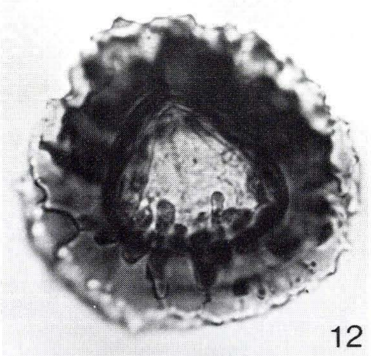
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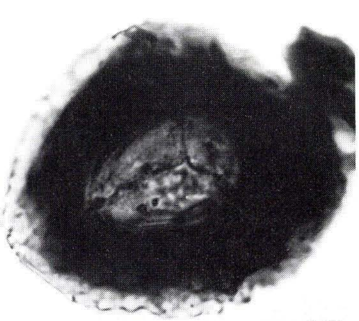
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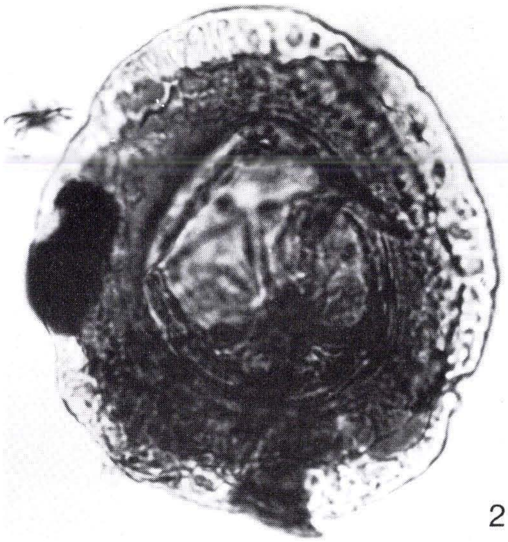
PLATE 9

Fig. 1. *Cf. Crassispora* sp. Presumed reworked. Sample Frh-21,c.
Fig. 2. *Cingulizonates rhaeticus* (Reinhardt 1961) Schulz 1967. Sample St-7,c.
Fig. 3. *Cingutriletes infrapunctus* (Schulz 1970) Morbey 1975. Sample Frh-2,c.
Fig. 4. *Limbosporites lundbladii* Nilsson 1958. Proximal side (low focus). Sample St-2,c.
Fig. 5. Same specimen as fig. 4. Distal side (high focus).
Fig. 6. *Iraquispora laevigata* (Mädler 1964) Lund 1977. Sample Frh-10,c.
Fig. 7. *Murospora florida* (Balme 1957) Pocock 1961. Sample Fj-8,s.
Fig. 8. *Heliosporites altmarkensis* Schulz 1962. Sample St-7,c.
Fig. 9. Cf. *Murospora* sp. Presumed reworked. Sample Fj-23,s.

Plate 9


1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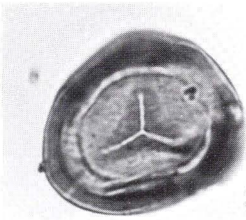
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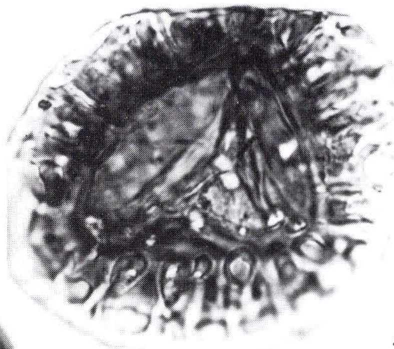
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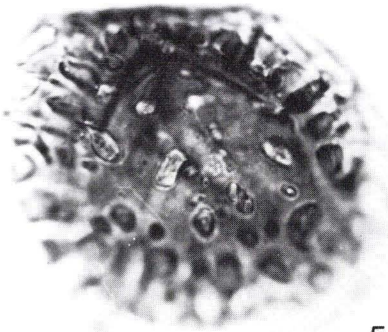
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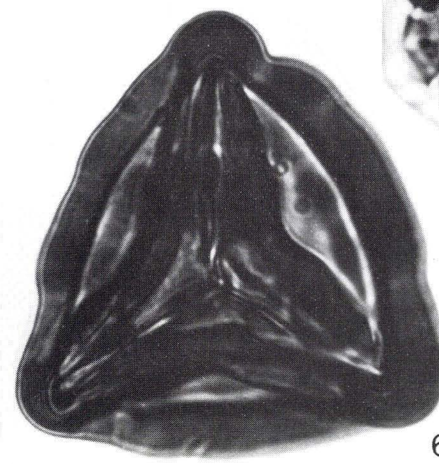
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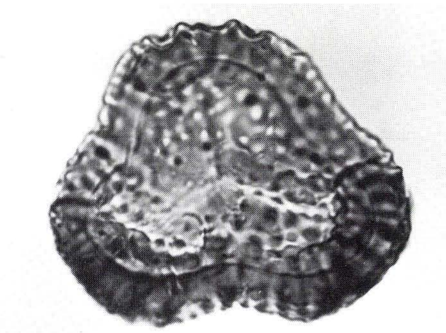
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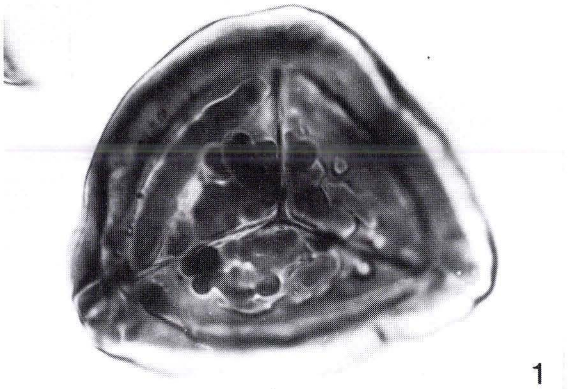
PLATE 10

Fig. 1. *Contignisporites glebulentus* Dettmann 1963 emend. Filatoff & Price 1988. Presumed caved. Proximal side (high focus). Sample Frh-10,s.
Fig. 2. Same specimen as fig. 1. Distal side (low focus).
Fig. 3. *Striatella jurassica* Mädler 1964. Proximal side (low focus). Sample Frh-25,s.
Fig. 4. Same specimen as fig. 3. Distal side (high focus).
Fig. 5. *Striatella seebergensis* Mädler 1964 emend. Filatoff & Price 1988. Sample St-10,c.
Fig. 6. *Polycingulatisporites liassicus* Schulz 1967. Proximal side (low focus). Sample St-18,w.
Fig. 7. *Polycingulatisporites triangularis* Playford & Dettmann 1965. Proximal side (high focus). Sample St-5,c.
Fig. 8. Same specimen as fig. 7. Distal side (low focus).
Fig. 9. Same specimen as fig. 6. Distal side (high focus).
Fig. 10. *Marattisporites scabratus* Couper 1958. Sample Frh-8,c.
Fig. 11. Cf. *Marattisporites* sp. 1. Sample St-6,c.

Plate 10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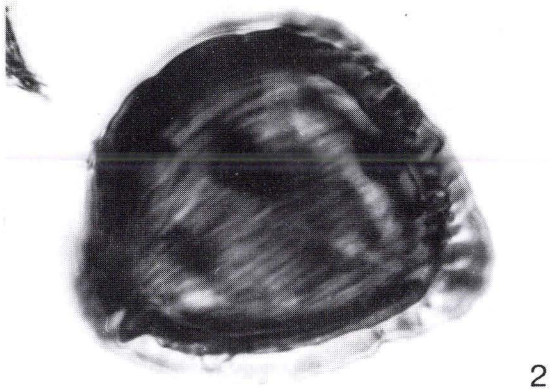
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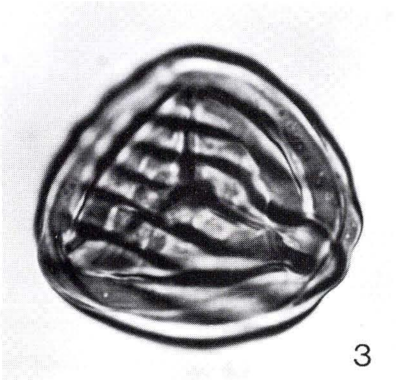
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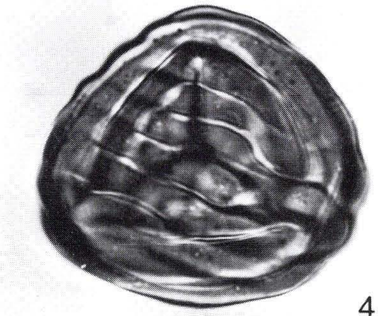
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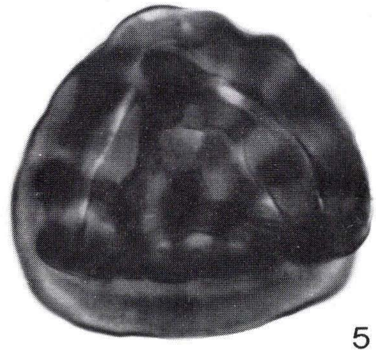
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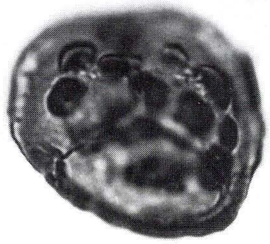
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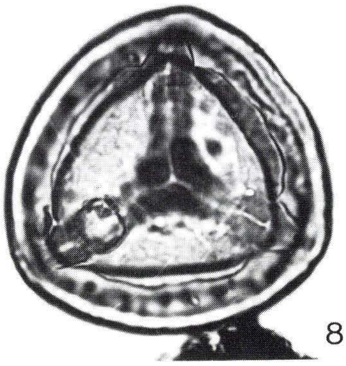
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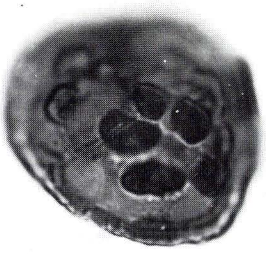
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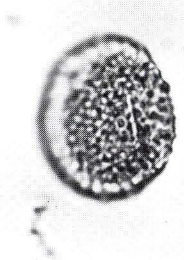
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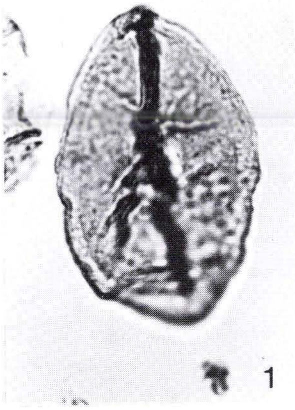
PLATE 11

Fig. 1. *Aratrisporites minimus* (Leschik 1955) Playford & Dettmann 1965. Sample St-9,w.
Fig. 2. *Aratrisporites fimbriatus* (Klaus 1960) Playford & Dettmann 1965. Sample St-3,c.
Fig. 3. *Vitreisporites pallidus* (Reissinger 1950) Nilsson 1958. Sample St-9,c.
Fig. 4. *Vitreisporites bjuvensis* Nilsson 1958. Sample St-3,c.
Fig. 5. *Pinuspollenites minimus* (Couper 1958) Kemp 1970. Sample St-7,c.
Fig. 6. *Protopinus scanicus* Nilsson 1958. Sample Frh-11,c.
Fig. 7. *Pinuspollenites minimus* (Couper 1958) Kemp 1970. Sample St-7,c.
Fig. 8. *Alisporites robustus* Nilsson 1958. Sample St-9,c.
Fig. 9. *Parvisaccites radiatus* Couper 1958. Presumed caved. Sample Frh-20,s.
Fig. 10. *Ovalipollis ovalis* Krutzsch 1955. Sample St-2,c.

Plate 11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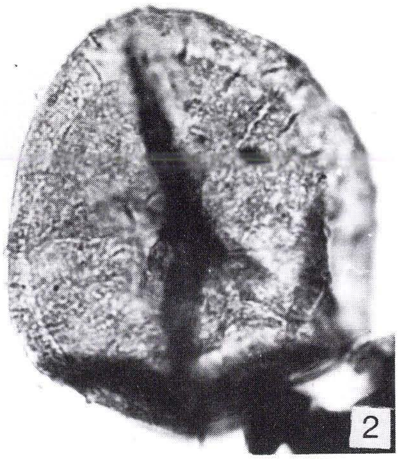
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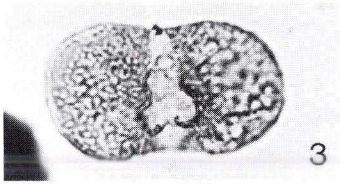
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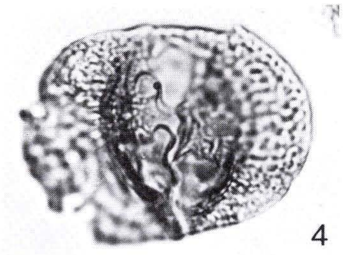
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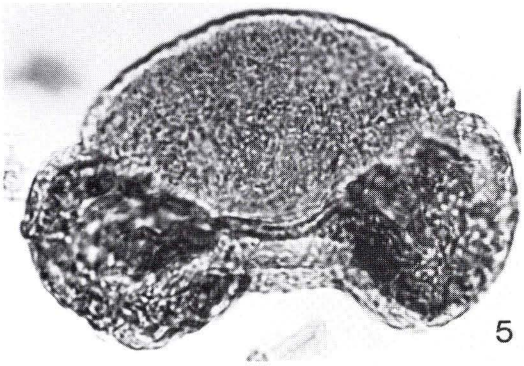
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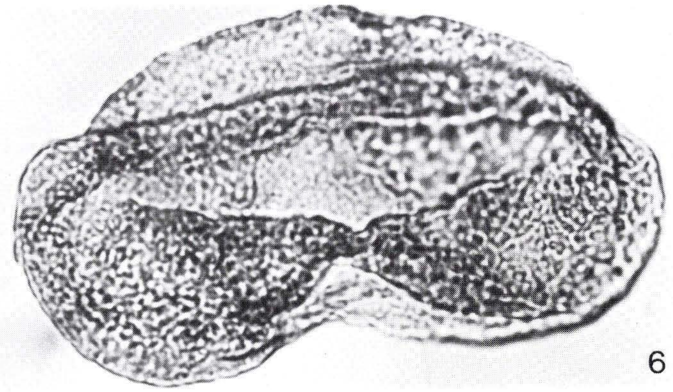
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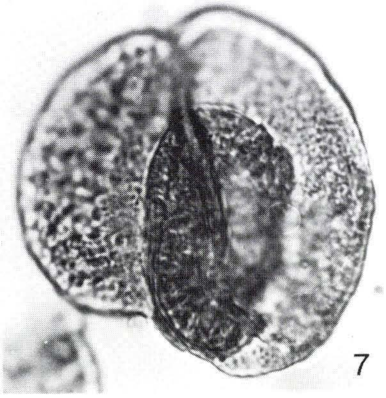
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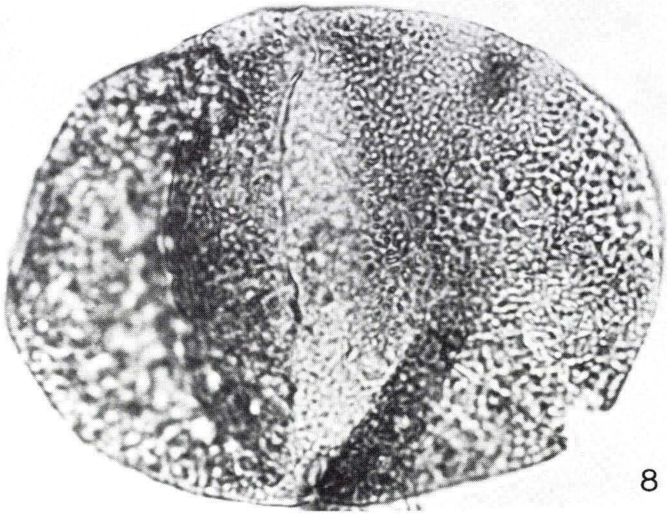
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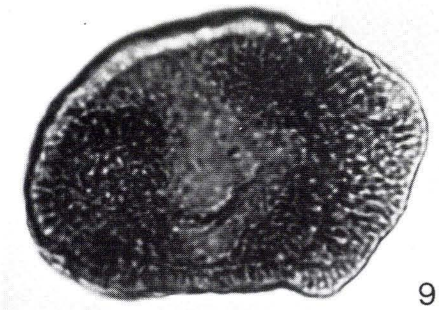
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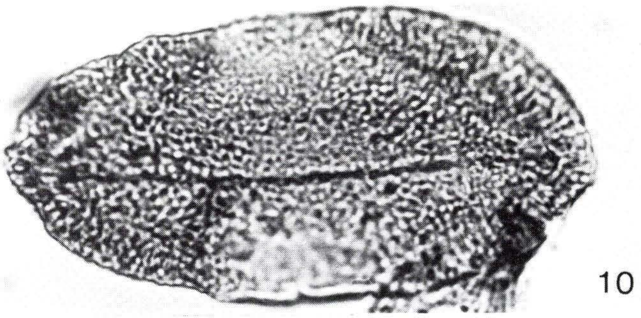
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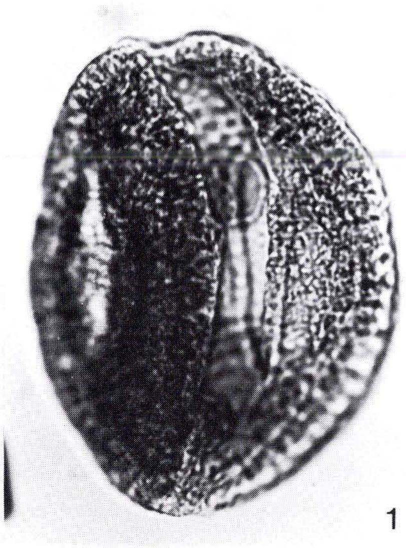
PLATE 12

Fig. 1. *Quadraeculina anellaeformis* Maljavkina 1949. Sample Frh-10,c.
Fig. 2. *Umbrososaccus keuperianus* Mädler 1964. Sample St-14,w.
Fig. 3. *Taeneaesporites* sp. Sample Fj-3,c.
Fig. 4. *Perinopollenites elatoides* Couper 1958. Sample Frh-9,c.
Fig. 5. *Perinopollenites elatoides* Couper 1958. Sample Frh-9,c.
Fig. 6. *Perinopollenites elatoides* Couper 1958. Loose innerbody. Sample Frh-8,c.
Fig. 7. *Perinopollenites* cf. *elatoides* Couper 1958. Sample Frh-9,c.
Fig. 8. *Perinopollenites* cf. *elatoides* Couper 1958. Broken velum. Sample Frh-12,c.
Fig. 9. *Perinopollenites* cf. *elatoides* Couper 1958. Loose innerbody. Sample Frh-9,c.

Plate 12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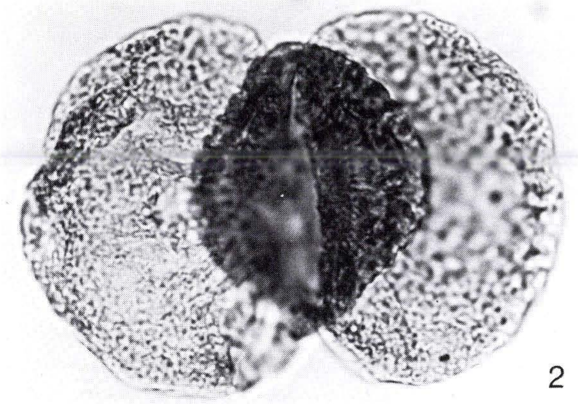
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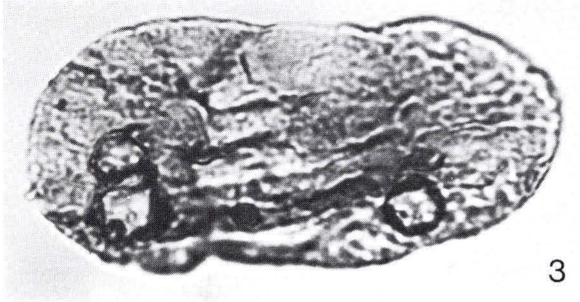
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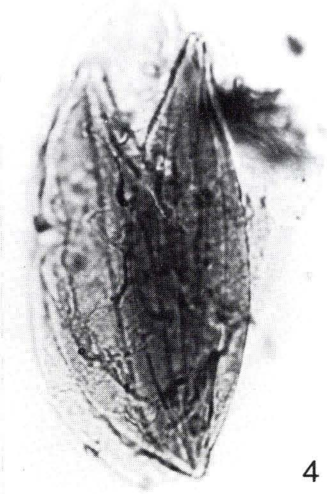
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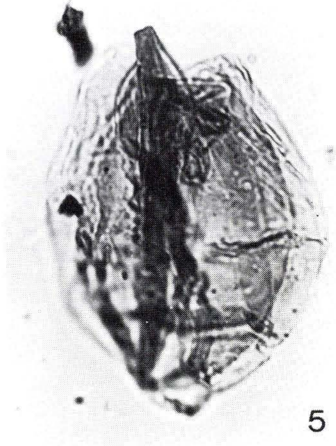
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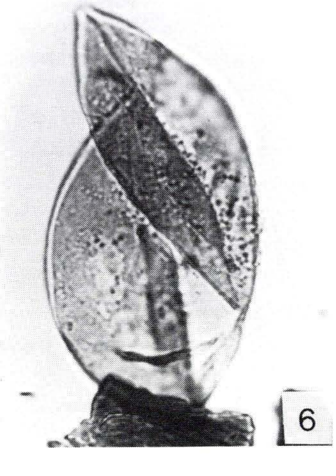
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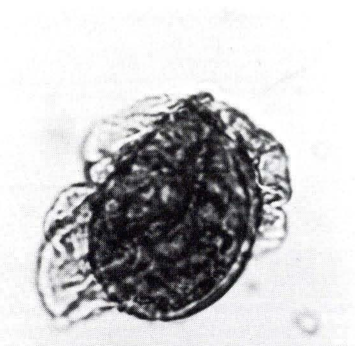
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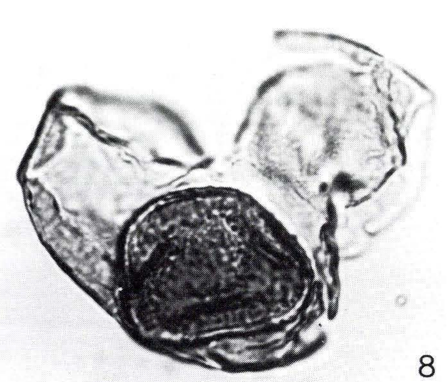
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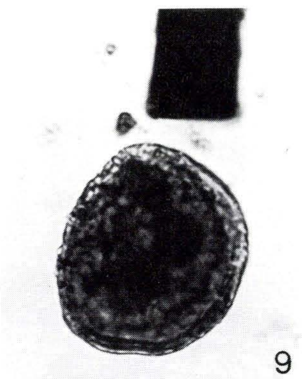
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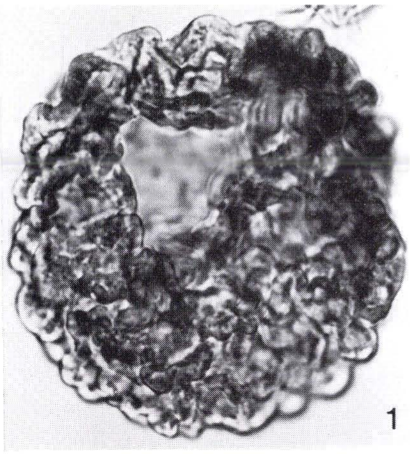
PLATE 13

Fig. 1. *Cerebropollenites macroverrucosus* (Thiergart 1949) Schulz 1967. Sample Fj-25,s.
Fig. 2. *Cerebropollenites thiergartii* Schulz 1967. Sample Frh-12,c.
Fig. 3. *Cerebropollenites thiergartii* Schulz 1967. Sample St-2,w.
Fig. 4. *Cerebropollenites thiergartii* Schulz 1967. Distinct sulcus. Proximal side (high focus). Sample Frh-17,c.
Fig. 5. Same specimen as fig. 4. Proximal side (low focus).
Fig. 6. *Cerebropollenites thiergartii* Schulz 1967. Distinct sulcus. Sample Frh-11,c.
Fig. 7. *Spheripollenites psilatus* Couper 1958. Cluster. NOTICE: Magnification x500. Sample Fj-31,s.
Fig. 8. *Exesipollenites tumulus* Balme 1957. Sample Fj-16,c.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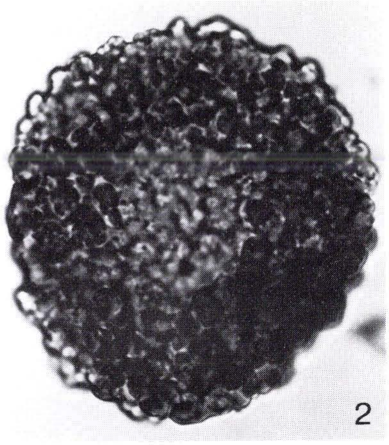
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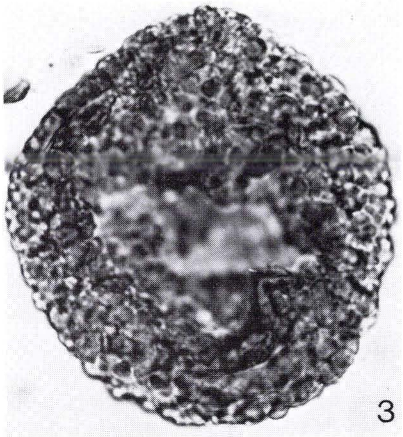
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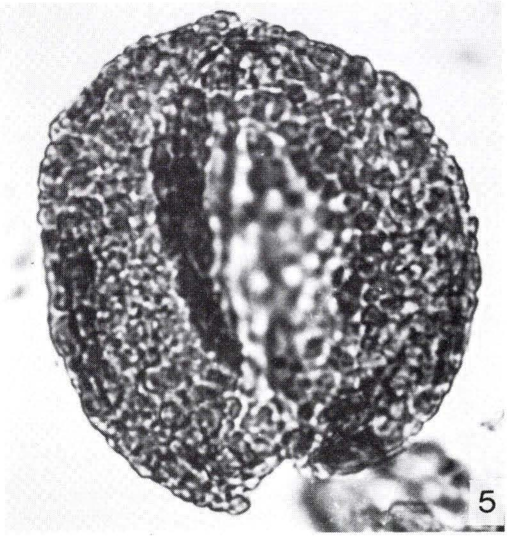
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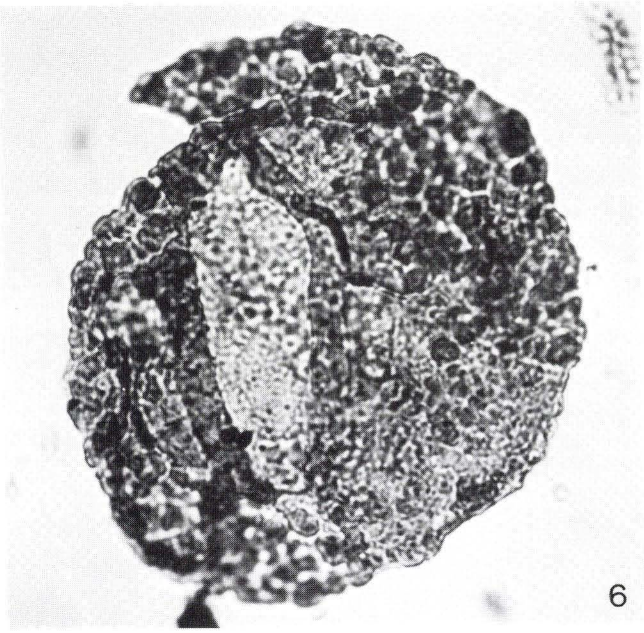
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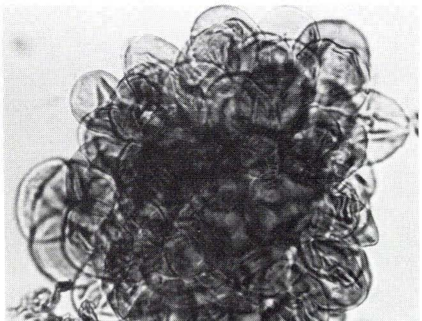
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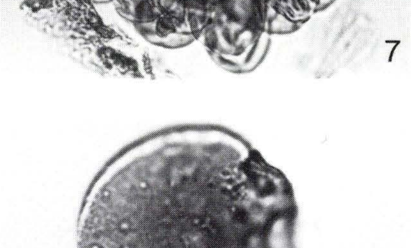
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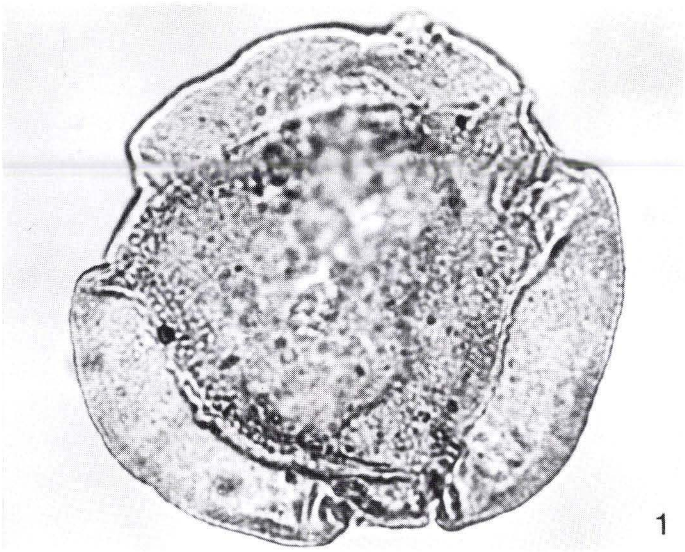
PLATE 14

Fig. 1. *Callialasporites trilobatus* (Balme 1957) Dev 1961. Sample Frh-13,s.
Fig. 2. *Callialasporites dampieri* (Balme 1957) Dev 1961. Sample Frh-24,s.
Fig. 3. *Chasmatosporites apertus* (Rogalska 1954) Nilsson 1958. Sample Fj-30,s.
Fig. 4. *Chasmatosporites hians* Nilsson 1958. Proximal side (high focus). Sample Frh-7,c.
Fig. 5. Same specimen as fig. 4. Distal side (low focus).
Fig. 6. *Chasmatosporites elegans* Nilsson 1958. Sample St-7,w.
Fig. 7. *Chasmatosporites major* Nilsson 1958. Sample St-14,w.
Fig. 8. *Ricciisporites tuberculatus* Lundblad 1954. Tetrad. NOTICE: Magnification x500. Sample St-2,c.
Fig. 9. *Riccisporites tuberculatus* Lundblad 1954. Single grain. Sample St-3,c.

Plate 14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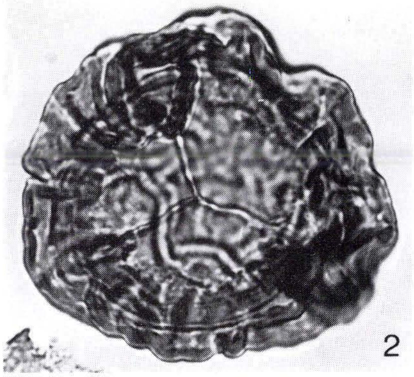
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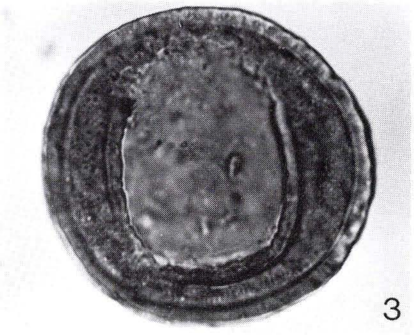
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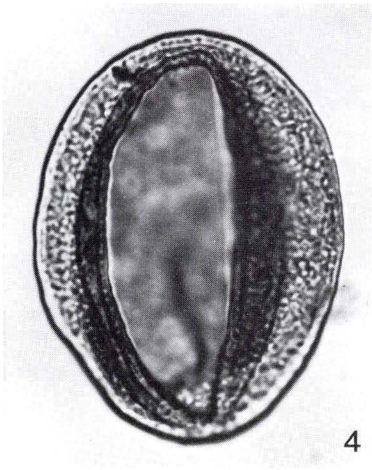
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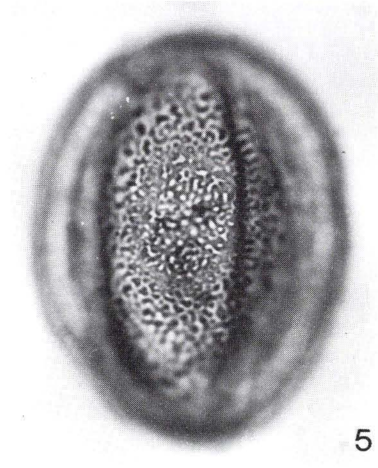
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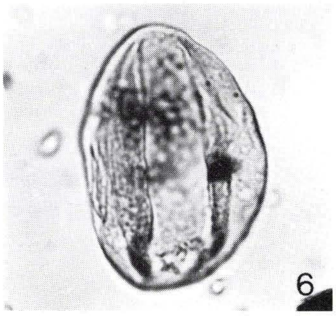
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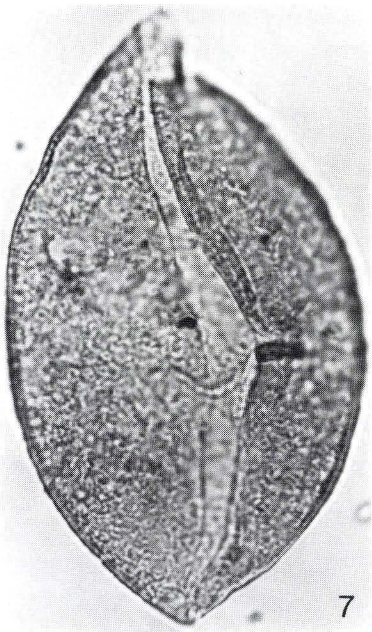
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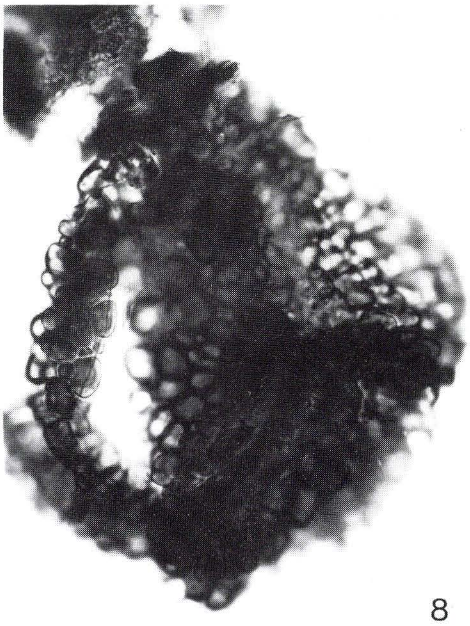
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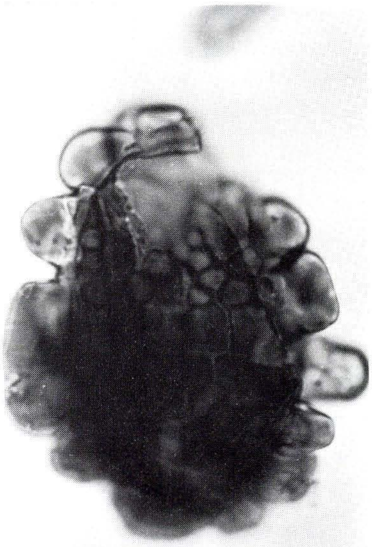
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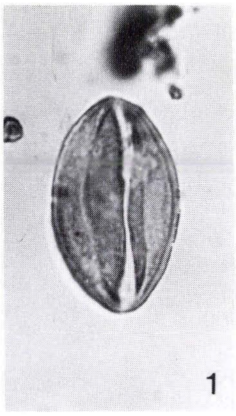
PLATE 15

Fig. 1. *Monosulcites minimus* Couper 1958. Sample Fj-21,s.
Fig. 2. *Corollina torosus* (Reissinger 1950) Klaus 1960. Tetrad. High focus. Sample Fj-33,s.
Fig. 3. Same specimen as fig. 2. Low focus.
Fig. 4. *Corollina torosus* (Reissinger 1950) Klaus 1960. Single grain. Sample St-11,c.
Fig. 5. *Corollina torosus* (Reissinger 1950) Klaus 1960. Single grain. Sample Fj-2,c.
Fig. 6. *Corollina* cf. *meyeriana* (Klaus 1960) Venkatachala & Góznan 1964. Sample Frh-12,c.
Fig. 7. *Corollina* cf. *meyeriana* (Klaus 1960) Venkatachala & Góznan 1964. Sample St-13,w.
Fig. 8. *Nannoceratopsis gracilis* (Alberti 1961) van Helden 1977. Sample Frh-22,c.
Fig. 9. *Nannoceratopsis* cf. *senex* van Helden 1977. Sample Frh-22,c.
Fig. 10. *Nannoceratopsis* sp. 1. Sample St-14,w.
Fig. 11. *Nannoceratopsis* cf. *pellucida* (Deflandre 1938) Evitt 1961. High focus. Sample Fj-15,c.
Fig. 12. Same specimen as fig. 11. Low focus.
Fig. 13. *Dapcodinium priscum* (Evitt 1961) Below 1987. Sample Fj-5,c.

Plate 15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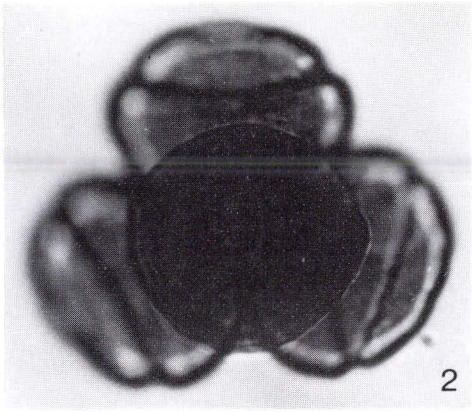
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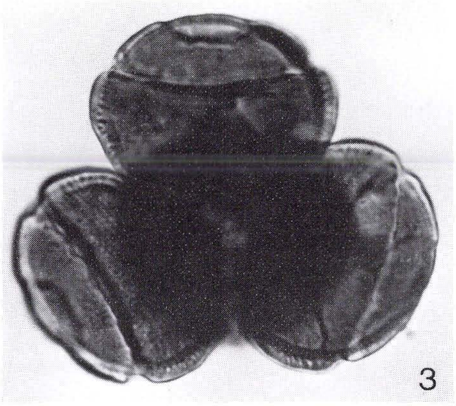
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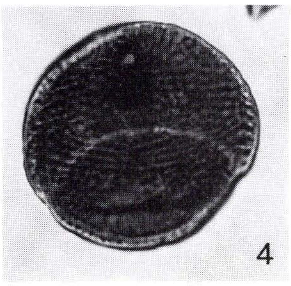
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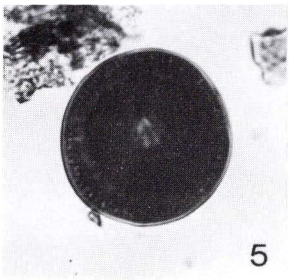
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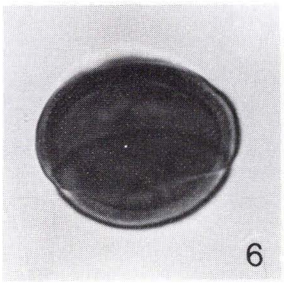
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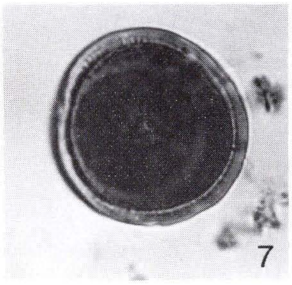
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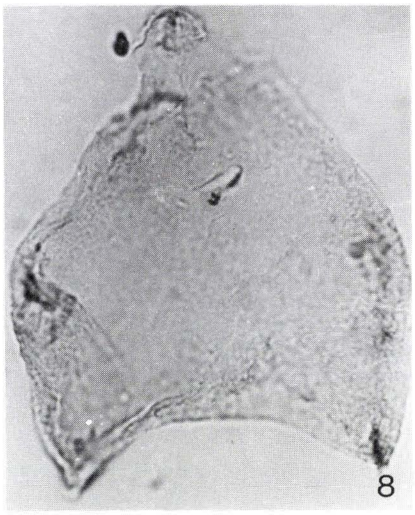
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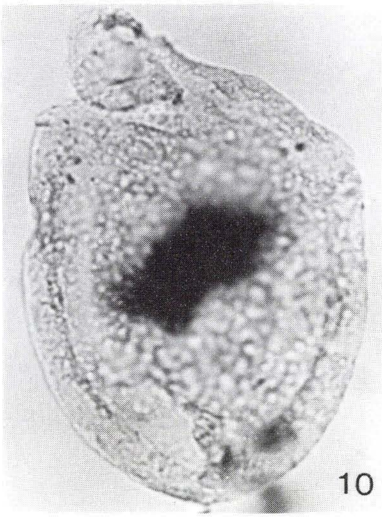
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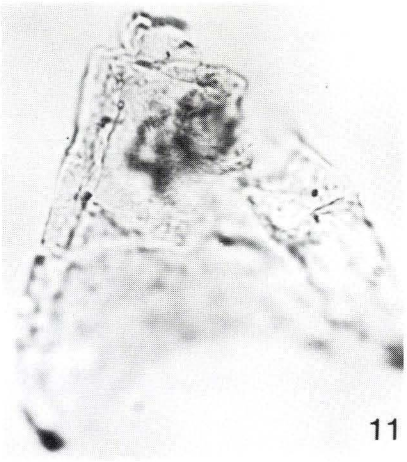
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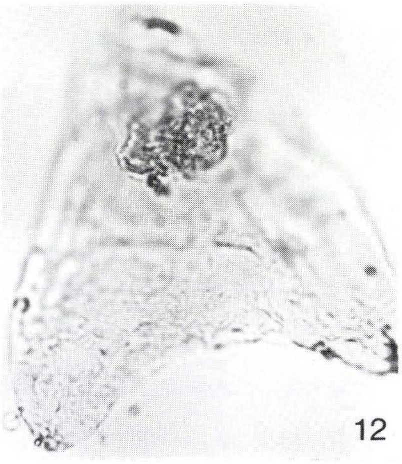
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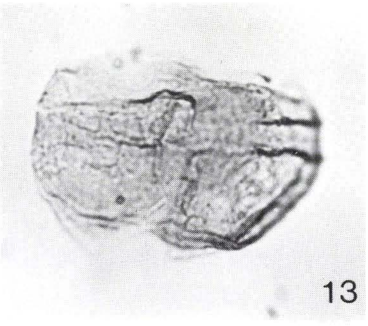
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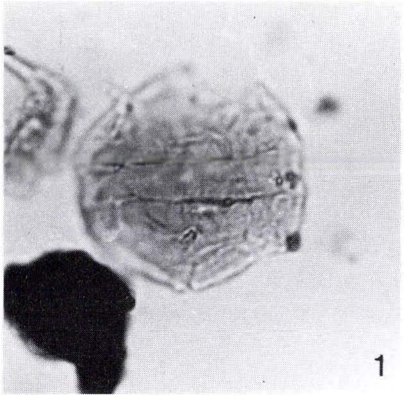
PLATE 16

Fig. 1. *Dapcodinium priscum* (Evitt 1961) Below 1987. High focus. Sample St-6,c.
Fig. 2. Same specimen as fig. 1. Low focus.
Fig. 3. *Liasidium variabile* Drugg 1978. Sample Fj-9,s.
Fig. 4. *Rhaetogonyaulax rhaetica* (Sarjeant 1963) Below 1987. Sample Fj-2,c.
Fig. 5. *Rhaetogonyaulax rhaetica* (Sarjeant 1963) Below 1987. Sample St-2,c.
Fig. 6. *Liasidium variabile* Drugg 1978. Sample Fj-9,s.
Fig. 7. *Escharisphaeridia pococki* (Sarjeant 1968) Erkman & Sarjeant 1980. High focus. Sample Fj-16,c.
Fig. 8. Same specimen as fig. 7. Low focus.
Fig. 9. *Escharisphaeridia* sp. Sample St-13,w.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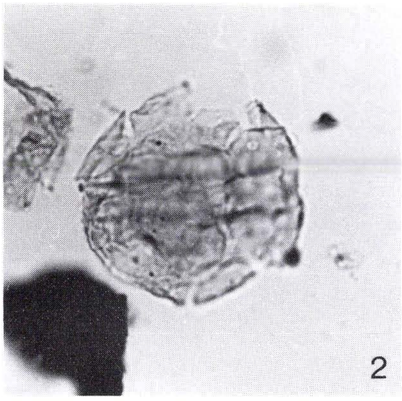
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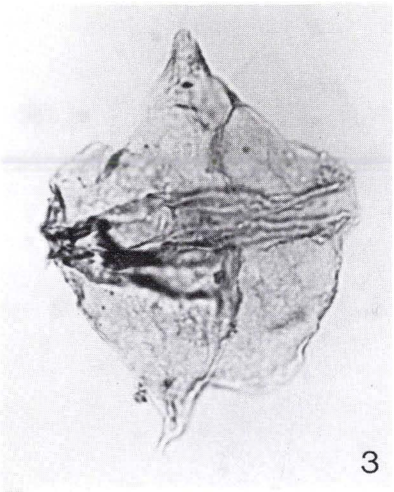
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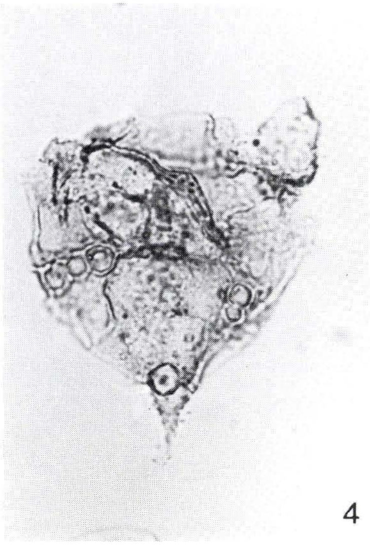
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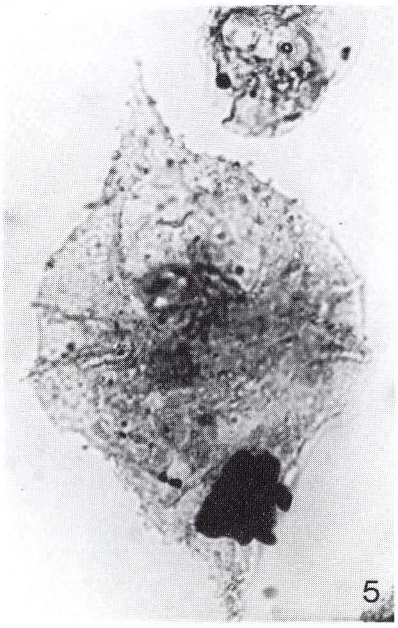
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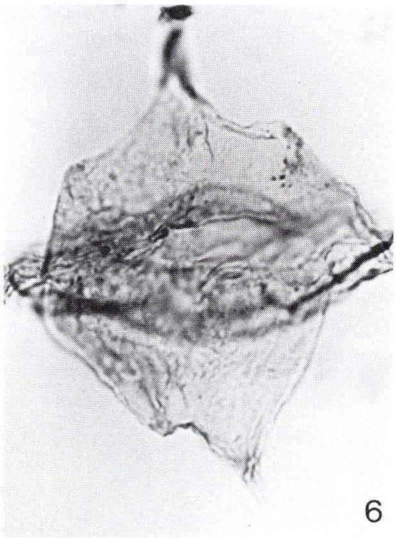
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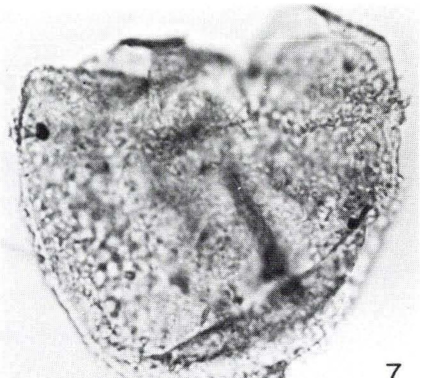
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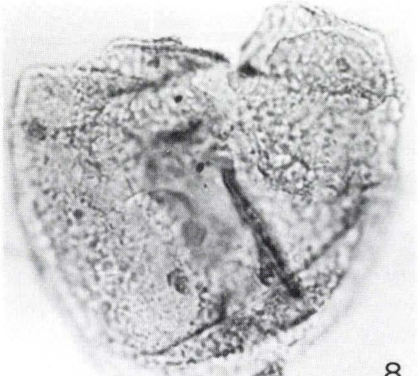
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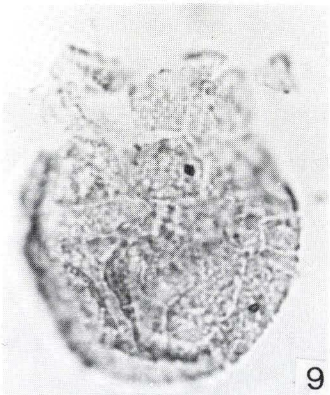
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PLATE 17

Fig. 1. *Dinocyst* sp. 1. Sample Frh-19,c.
Fig. 2. *Prolixosphaeridium* sp. Sample Frh-14,c.
Fig. 3. *Odontochitina* cf. *operculata* Deflandre 1947. Presumed caved. NOTICE: Magnification x500. Sample Frh-11,s.
Fig. 4. *Sirmiodinium grossii* Alberti 1961. Presumed caved. High focus. Sample Frh-11,s.
Fig. 5. Same specimen as fig. 4. Low focus.


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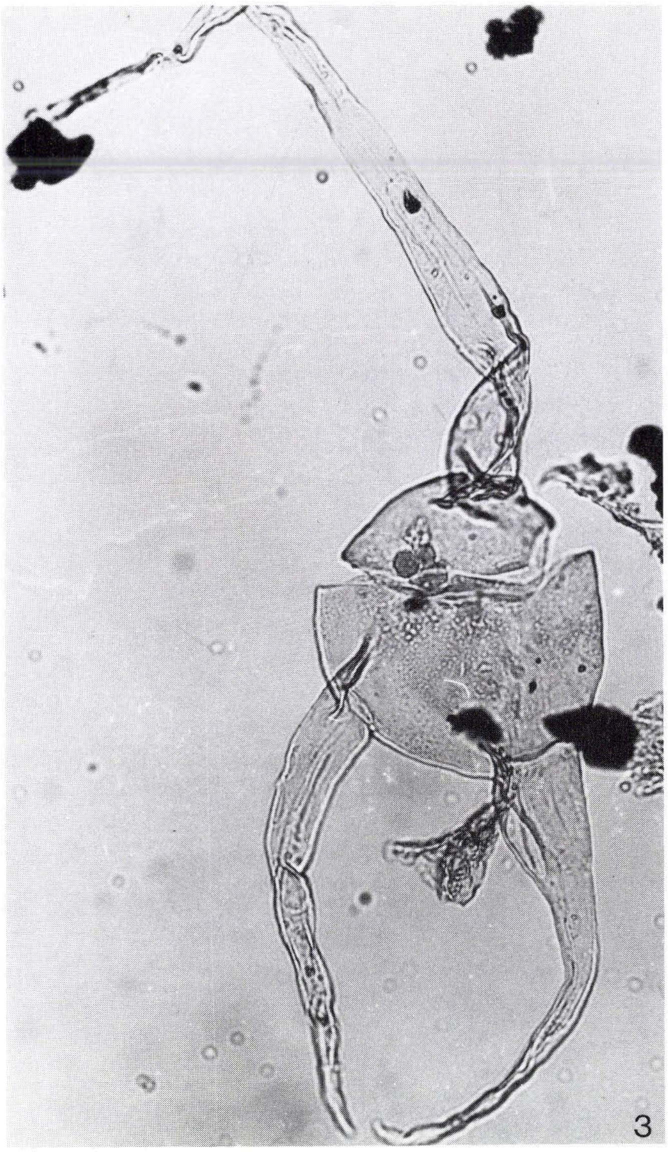
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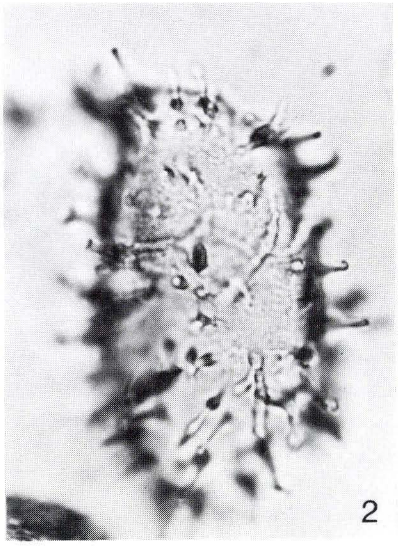
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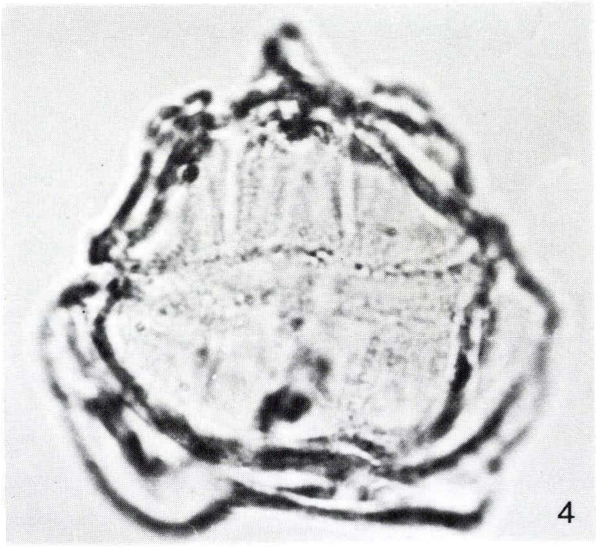
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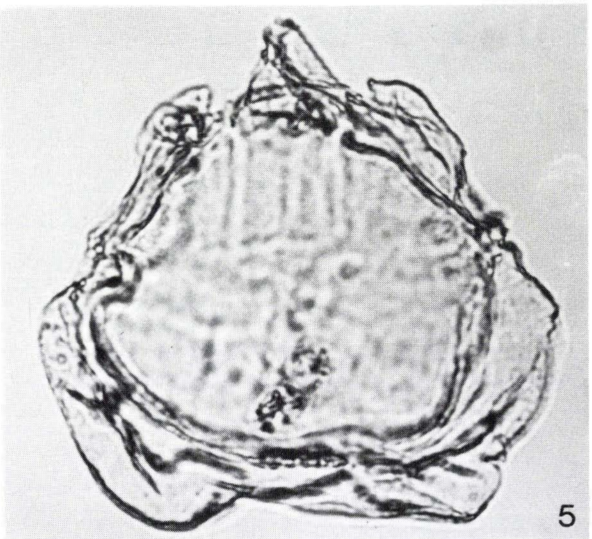
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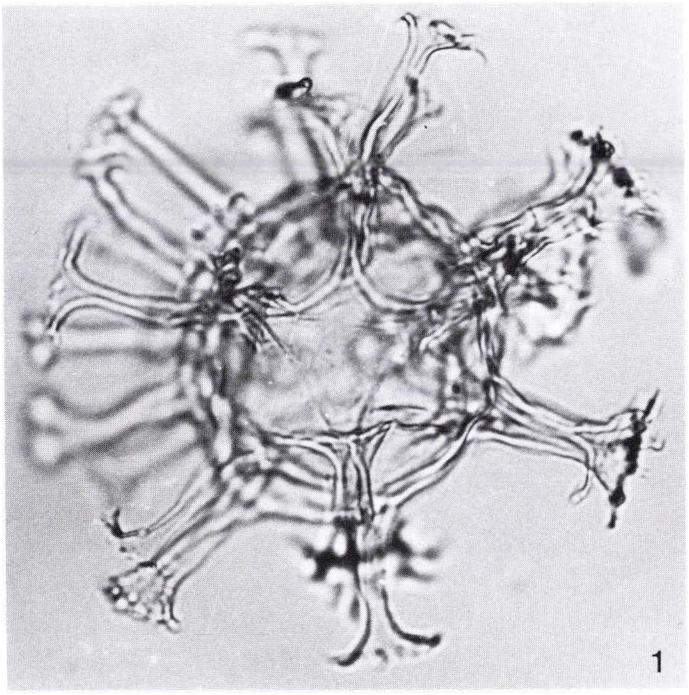
PLATE 18

Fig. 1. *Kleithriasphaeridium* cf. *readei* (Davey & Williams 1966) Davey & Verdier 1976. Presumed caved. Sample Frh-10,s.
Fig. 2. *Protoellipsodinium spinosum* Davey & Verdier 1971. Presumed caved. High focus. Sample Frh-20,s.
Fig. 3. Same specimen as fig. 2. Low focus.
Fig. 4. *Spiniferites ramosus* (Ehrenberg 1838) Loeblich & Loeblich 1966. Presumed caved. Sample Frh-20,s.
Fig. 5. *Sphaeromorphitae,* type 1. Sample St-2,c.
Fig. 6. *Sphaeromorphitae,* type 2. Sample St-2,w.
Fig. 7. *Acanthomorphitae,* type 1. Sample Fj-19,s.
Fig. 8. *Acanthomorphitae,* type 2. Sample St-11,w.
Fig. 9. *Acanthomorphitae,* type 3. Sample St-11,w.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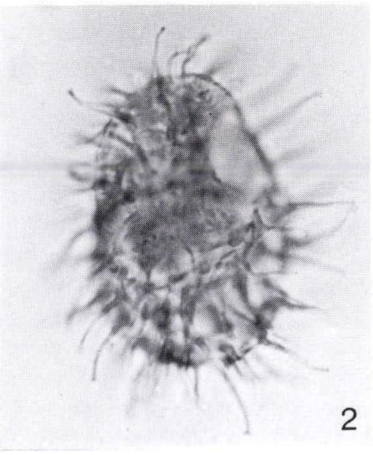
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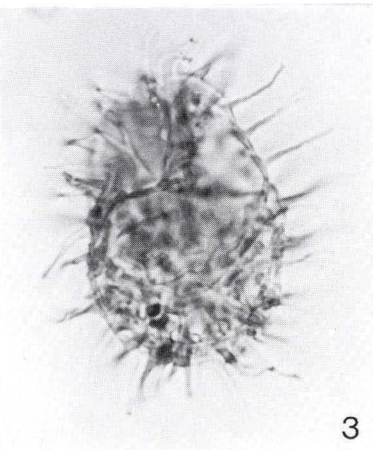
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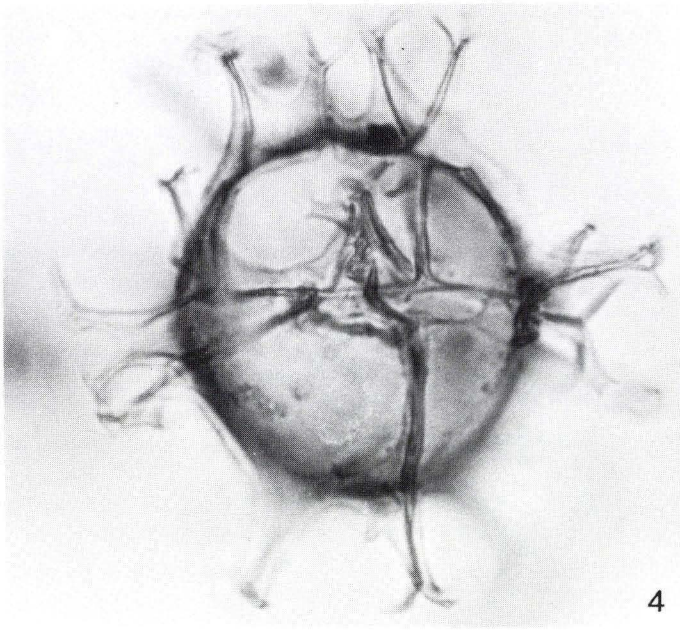
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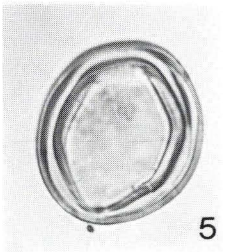
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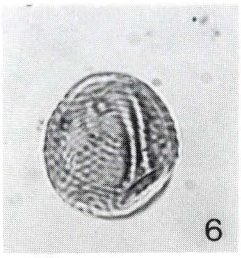
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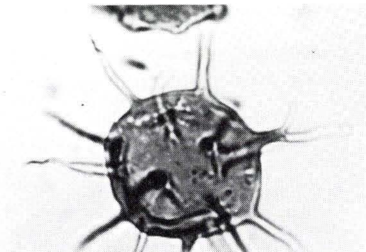
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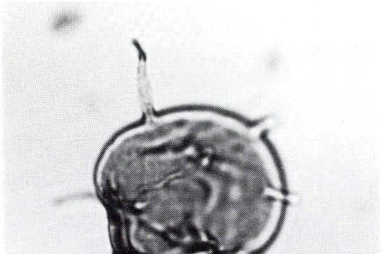
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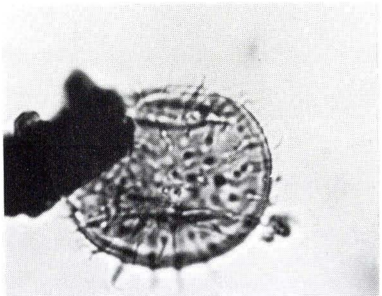
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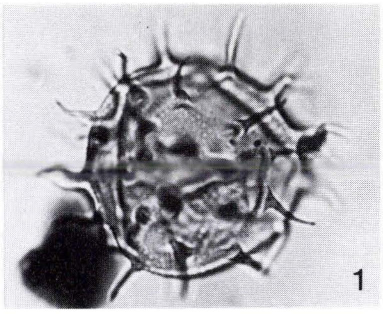
PLATE 19

Fig. 1. *Acanthomorphitae,* type 4. Sample Fj-21,s.
Fig. 2. *Veryhachium* sp. Sample Fj-16,c.
Fig. 3. *Leiofusa jurassica* Cookson & Eisenack 1958. Sample St-8,c.
Fig. 4. *Polygonomorphitae,* type 1. Sample Fj-5,s.
Fig. 5. *Polygonomorphitae,* type 2. Sample St-7,c.
Fig. 6. *Polygonomorphitae,* type 3. Sample St-7,c.
Fig. 7. *Cymatiosphaera,* type 1. Sample St-11,w.
Fig. 8. *Diexallophasis denticulata* (Stockmans & Williére 1963) Loeblich 1970. Presumed reworked. Sample St-17,w.
Fig. 9. *Multiplicisphaeridium* sp. Presumed reworked. Sample Frh-19,c.
Fig. 10. Species indet, type 1. Sample Frh-13,c.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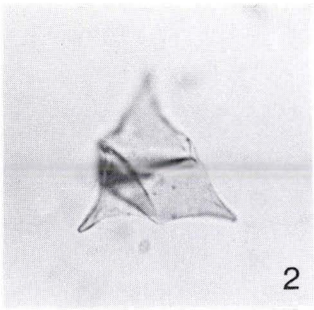
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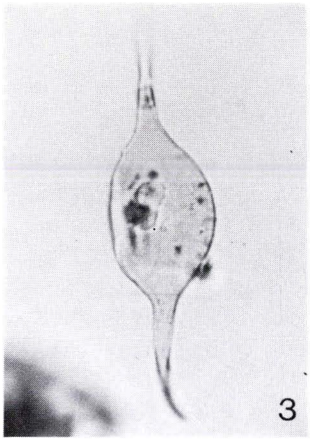
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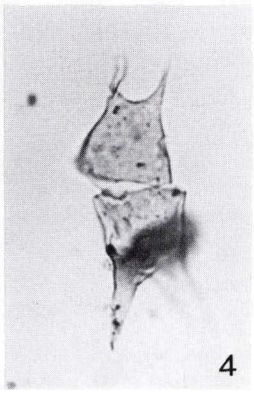
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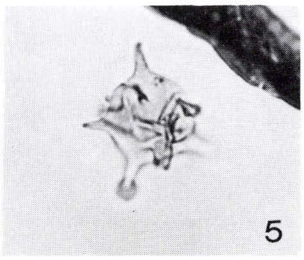
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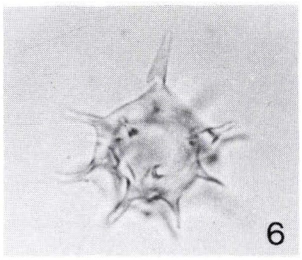
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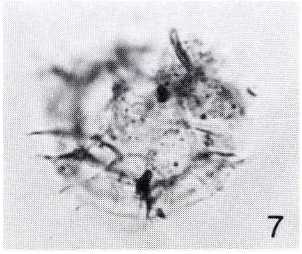
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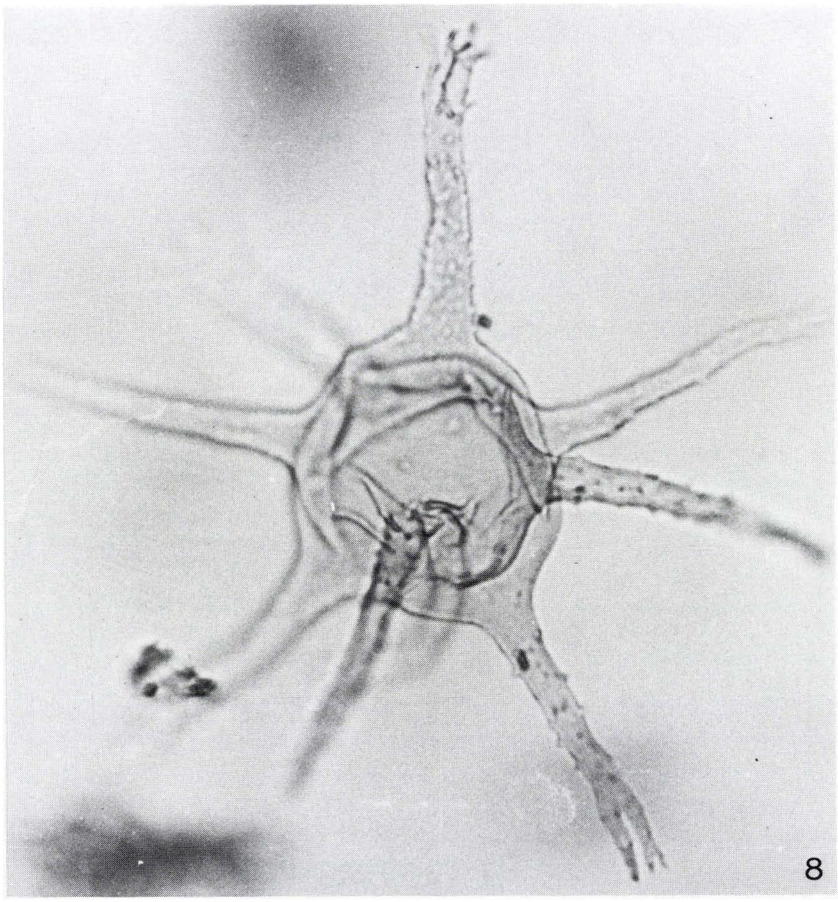
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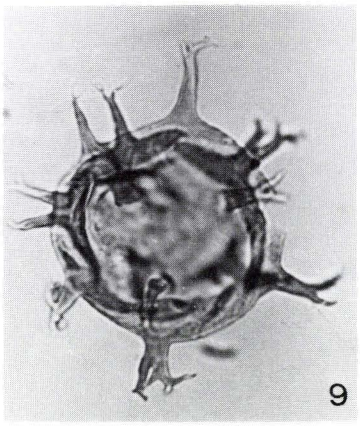
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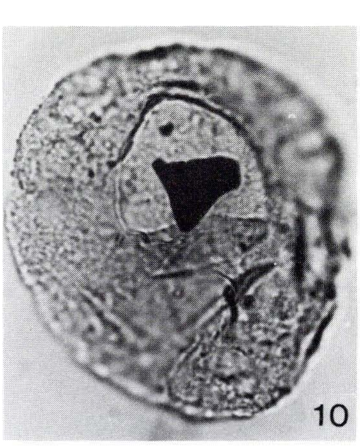
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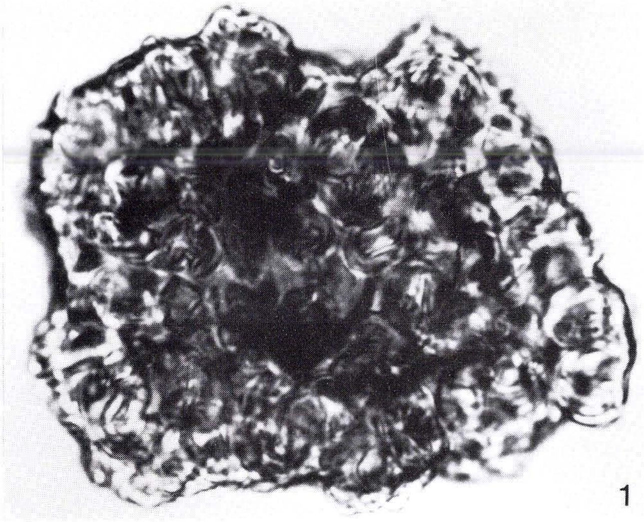
PLATE 20

Fig. 1. *Botryococcus* sp. Sample St-14,w.
Fig. 2. *Cymatiosphaera,* type 2. Sample Fj-32,s.
Fig. 3. *Schizocystia rara* Playford & Dettmann 1965. Sample Frh-15,c.
Fig. 4. *Schizosporis reticulatus* Cookson & Dettmann 1959. NOTICE: Magnification x250. Sample Frh-18,c.
Fig. 5. Foraminiferal test-lining. Sample Fj-31,s.
Fig. 6. Fungal spores. Sample St-9,w.
Fig. 7. Species indet., type 2. High focus. Sample Frh-16,c.
Fig. 8. Same specimen as fig. 7. Low focus.

Plate 20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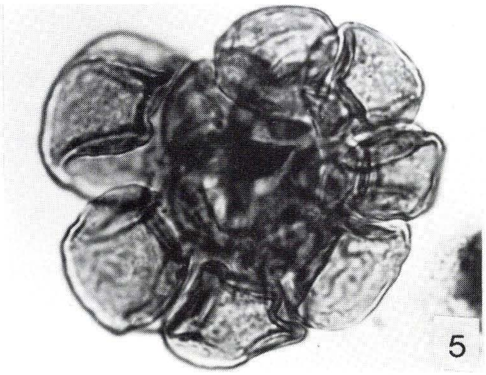
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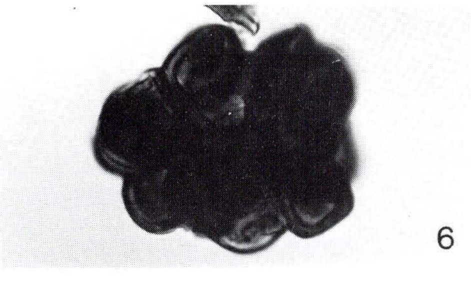
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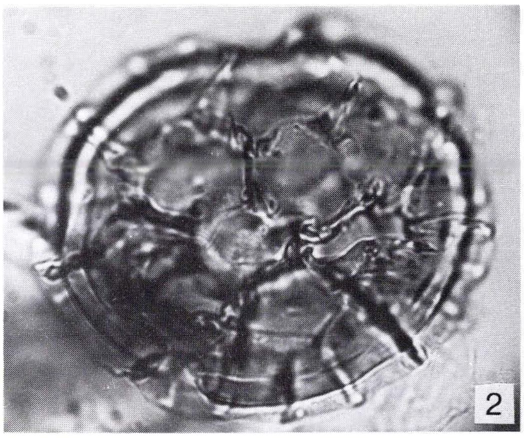
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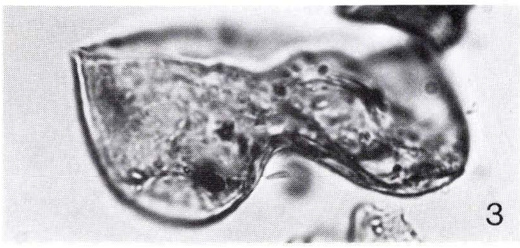
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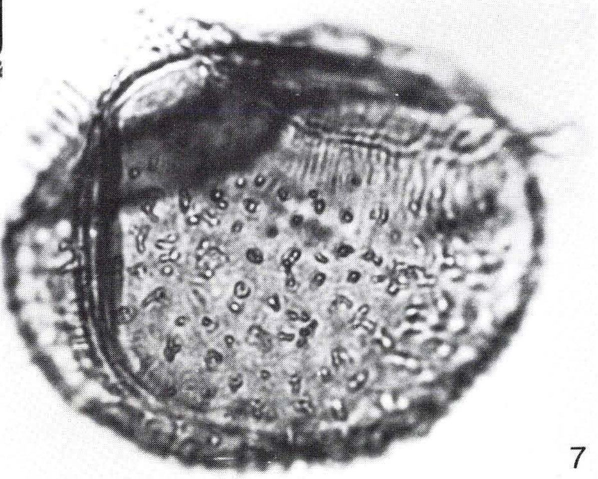
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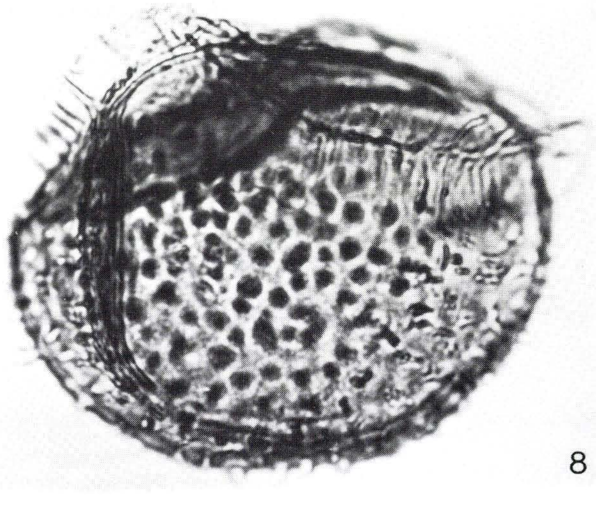
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PLATE 21

Fig. 1. *Trachysporites fuscus* Nilsson 1958. The holotype. Proximal side (high focus).

Fig. 2. *Trachysporites tuberosum* Nilsson 1958. The holotype. Junior synonym to *Trachysporites fuscus* Nilsson 1958.

Fig. 3. *Trachysporites asper* Nilsson 1958. The holotype.

Fig. 4. Same specimen as fig. 1. Proximal side (lower focus).

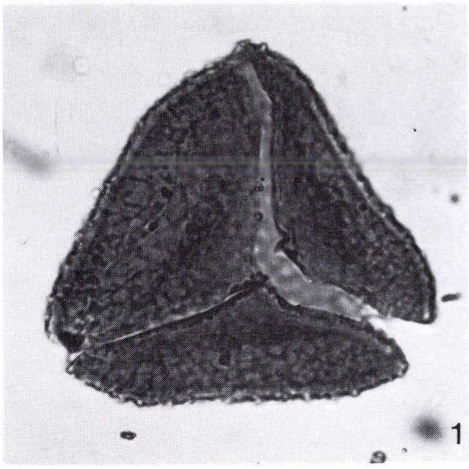
Fig. 5. *Apiculatisporites ovalis* (Nilsson 1958) Norris 1964. The holotype. (Formerly *Acanthotriletes ovalis* Nilsson 1958). Proximal side (high focus).

Fig. 6. Same specimen as fig. 5. Proximal side (lower focus).

Fig. 7. Same specimen as figs 1 and 4. Distal side (low focus).

Fig. 8. *Acanthotriletes trigonus* Nilsson 1958. The holotype. Junior synonym to *Apiculatisporites ovalis* (Nilsson 1958) Norris 1964.

Plate 21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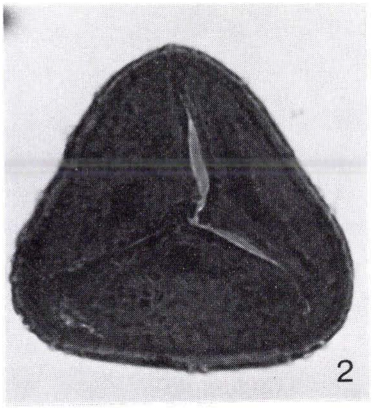
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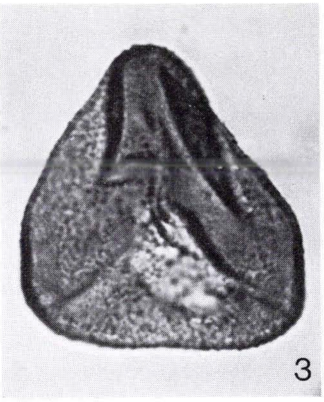
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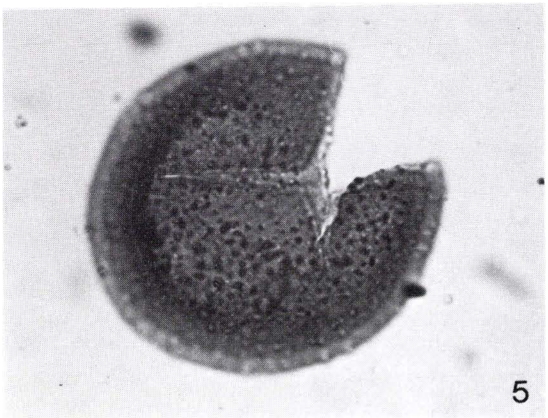
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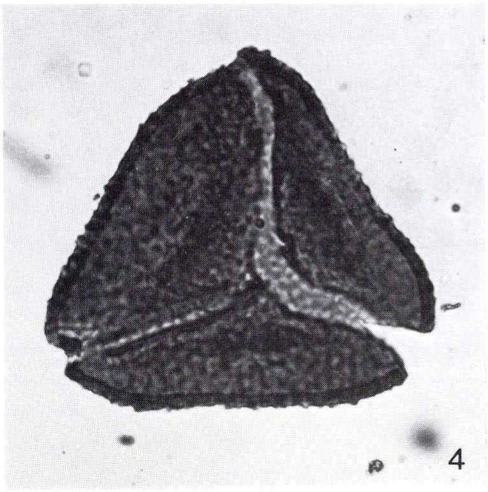
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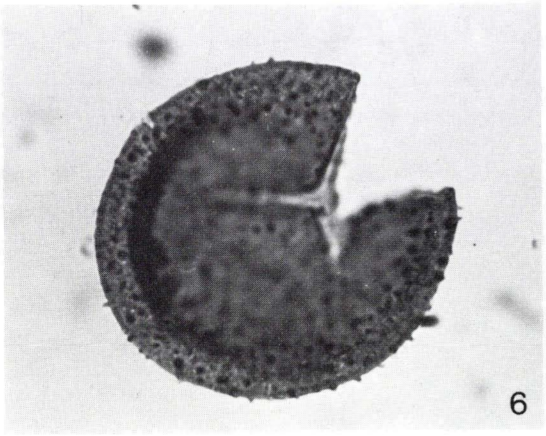
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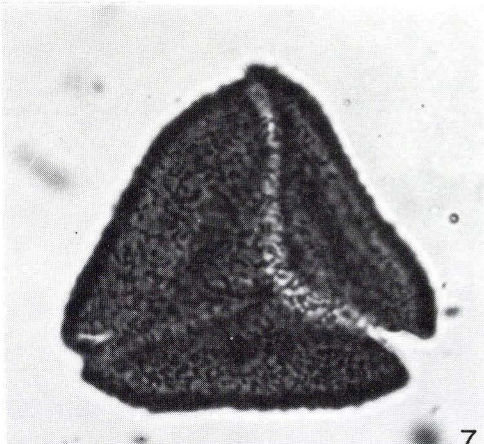
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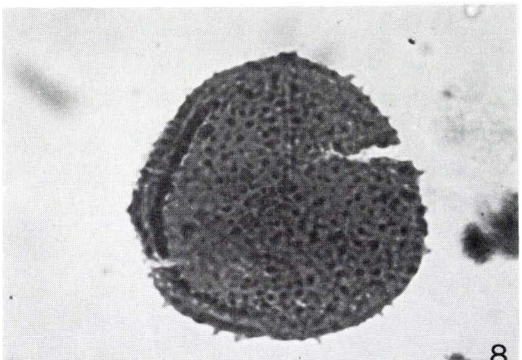
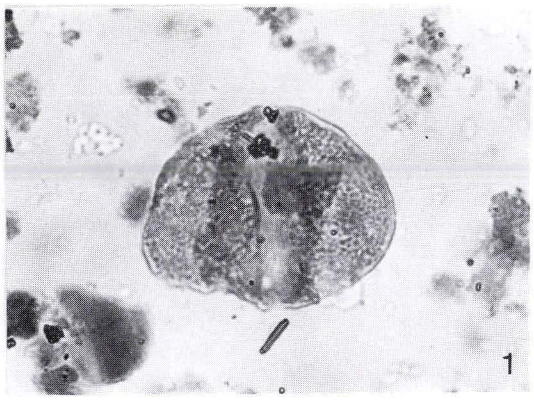

8

PLATE 22

Fig. 1. *Vitreisporites bjuvensis* Nilsson 1958. The holotype. Distal side (high focus).
Fig. 2. Same specimen as fig. 1. Distal side (lower focus).
Fig. 3. *Alisporites robustus* Nilsson 1958. The holotype. Proximal side (high focus).
Fig. 4. Same specimen as fig. 3. Distal side (low focus).
Fig. 5. *Schismatosporites ovalis* Nilsson 1958. The holotype. Lateral view. NOTICE: Magnification x800.
Fig. 6. *Chasmatosporites elegans* Nilsson 1958. The holotype.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3


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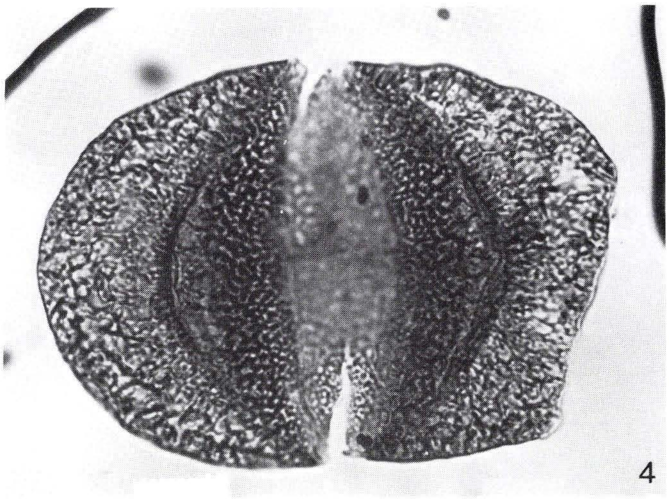
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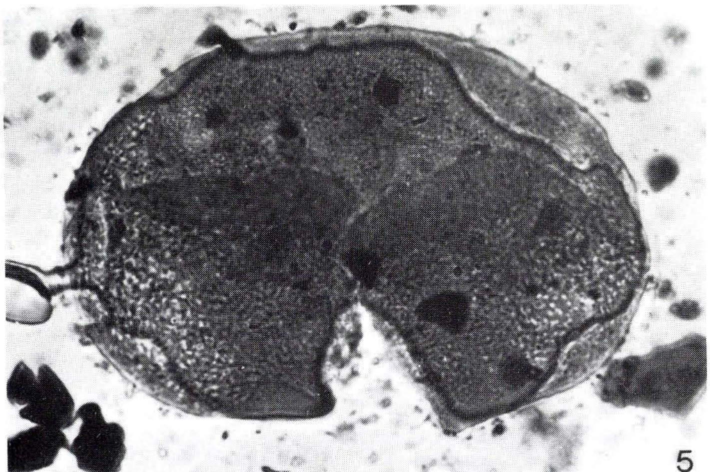
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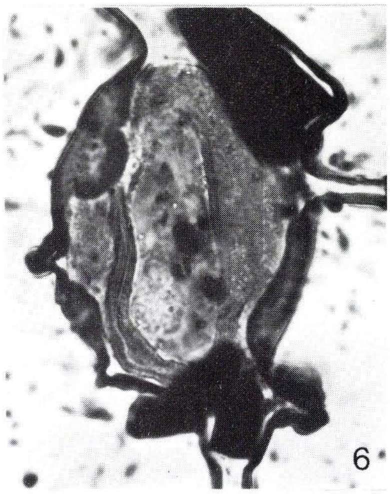
6

Appendix A
The Fjerritslev-2 borehole

Sample litholgy

Lithostrat. units	Sample no.	Depth (m.b.r.t.)	Sample lithology	T.O.C.
F-IV Mb.	FJ-16,c	1329	si.cl.st.ξ	1.5
F-III Mb.	FJ-15,c	1561	si.cl.st.	1.5
	FJ-14,c	1563	si.cl.st.	1.4
F-Ib Mb.	FJ-13,c	2001	si.cl.st.	0.9
	FJ-12,c	2003	si.cl.st.	0.6
F-Ia Mb.	FJ-11,c	2084	si.cl.st.ξ	0.7
	FJ-10,c	2085	si.cl.st.	0.7
	FJ- 9,c	2087	si.cl.st.	0.8
	FJ- 8,c	2102	si.cl.st.	0.8
	FJ- 7,c	2103	si.cl.st.	0.8
	FJ- 6,c	2104	si.cl.st.	0.9
	FJ- 5,c	2105	clayst.	1.0
	FJ- 4,c	2106	clayst.	1.1
Gassum Fm.	FJ- 3,c	2303	cl.sa.st.	0.9
	FJ- 2,c	2304	sa.cl.st.	1.0
	FJ- 1,c	2305	cl.sa.st.	0.9

ξ: burrows
claysт.: claystone
si.cl.st.: silt-streaked claystone
sa.cl.st.: sand-streaked claystone
cl.sa.st.: clay-streaked sandstone

Kerogen categories
Relative abundances

Sample no.	Paly-nom. %	Br. wood %	Bl. wood %	Cuticle %	A.O.M. %	Total %
FJ-16,c	23	56	13	1	7	100
FJ-15,c	43	32	7	0	18	100
FJ-14,c	43	31	5	0	20	100
FJ-13,c	25	55	18	0	2	100
FJ-12,c	21	55	23	1	1	100
FJ-11,c	22	66	12	0	0	100
FJ-10,c	18	69	13	0	0	100
FJ- 9,c	12	71	16	0	1	100
FJ- 8,c	18	73	8	0	2	100
FJ- 7,c	15	75	8	0	2	100
FJ- 6,c	13	72	12	0	3	100
FJ- 5,c	17	74	8	0	1	100
FJ- 4,c	4	83	9	0	3	100
FJ- 3,c	8	67	23	0	1	100
FJ- 2,c	11	76	11	0	2	100
FJ- 1,c	0	77	23	0	0	100

Brown wood, size groups, relative abundances
100% = total of brown wood

Sample no.	<20 microns %	20–80 microns %	>80 microns %	Total %
FJ-16,c	36	61	3	100
FJ-15,c	30	67	3	100
FJ-14,c	31	66	3	100
FJ-13,c	11	84	5	100
FJ-12,c	23	74	3	100
FJ-11,c	30	68	2	100
FJ-10,c	24	74	2	100
FJ- 9,c	34	63	3	100
FJ- 8,c	25	72	3	100
FJ- 7,c	29	69	3	100
FJ- 6,c	25	70	4	100
FJ- 5,c	23	74	3	100
FJ- 4,c	25	71	4	100
FJ- 3,c	22	75	3	100
FJ- 2,c	9	86	5	100
FJ- 1,c	34	65	1	100

Black wood, size groups, relative abundances
100% = total of black wood

Sample no.	<20 microns %	20–80 microns %	>80 microns %	Total %
FJ-16,c	22	78	0	100
FJ-15,c	43	52	5	100
FJ-14,c	20	80	0	100
FJ-13,c	14	80	6	100
FJ-12,c	13	86	1	100
FJ-11,c	11	86	3	100
FJ-10,c	21	79	0	100
FJ- 9,c	26	73	1	100
FJ- 8,c	25	73	2	100
FJ- 7,c	38	63	0	100
FJ- 6,c	30	68	1	100
FJ- 5,c	11	89	0	100
FJ- 4,c	38	56	6	100
FJ- 3,c	26	70	4	100
FJ- 2,c	8	90	2	100
FJ- 1,c	38	61	1	100

Kerogen categories
Absolute abundance

Sample no.	Palyno-morphs	Brown wood	<20 microns	20–80 microns	>80 microns	Black wood	<20 microns	20–80 microns	>80 microns	Cuticle	A.O.M	n
FJ-16,c	139	329	119	201	9	77	17	60	0	4	43	592
FJ-15,c	252	189	56	127	6	44	19	23	2	0	104	589
FJ-14,c	242	176	55	116	5	30	6	24	0	1	110	559
FJ-13,c	137	294	32	246	16	95	13	76	6	1	12	539
FJ-12,c	111	297	68	219	10	125	16	108	1	3	3	539
FJ-11,c	113	346	104	235	7	63	7	54	2	0	1	523
FJ-10,c	111	419	102	310	7	78	16	62	0	1	1	610
FJ- 9,c	67	393	134	248	11	89	23	65	1	0	3	552
FJ- 8,c	97	401	99	288	14	44	11	32	1	0	11	553
FJ- 7,c	83	424	122	291	11	48	18	30	0	0	14	569
FJ- 6,c	75	420	106	296	18	69	21	47	1	2	18	584
FJ- 5,c	94	421	97	312	12	44	5	39	0	1	6	566
FJ- 4,c	24	461	114	327	20	52	20	29	3	0	19	556
FJ- 3,c	45	359	79	268	12	123	32	86	5	1	7	535
FJ- 2,c	62	414	37	358	19	60	5	54	1	0	11	547
FJ- 1,c	0	398	134	259	5	122	46	75	1	0	0	520

Sample no.	PhytOC	AmexOC	Marine palynom. %
FJ-16,c	1.03	0.11	11
FJ-15,c	0.57	0.26	24
FJ-14,c	0.50	0.27	–
FJ-13,c	0.66	0.02	–
FJ-12,c	0.50	0.00	25
FJ-11,c	0.54	0.00	14
FJ-10,c	0.56	0.00	–
FJ- 9,c	0.72	0.00	20
FJ- 8,c	0.64	0.02	–
FJ- 7,c	0.66	0.02	5
FJ- 6,c	0.72	0.03	–
FJ- 5,c	0.83	0.01	1
FJ- 4,c	0.97	0.04	7
FJ- 3,c	0.82	0.01	9
FJ- 2,c	0.89	0.02	22
FJ- 1,c	0.85	0.00	–

PhytOC = (% brown wood + % black wood + % cuticle) × T.O.C.
AmexOC = % Amorphous Organic Matter (A.O.M.) × T.O.C.
% marine palynomorphs: 100% = total palynomorphs

Terrestrial palynomorphs
Relative abundances

Sample no.	Spores %	Saccate pollen %	Non-saccate pollen %	Total spores+ pollen %	Ratio: saccate pollen/ spores
FJ-16,c	20	14	66	100	0.71
FJ-15,c	8	17	75	100	2.09
FJ-14,c	–	–	–	–	–
FJ-13,c	–	–	–	–	–
FJ-12,c	23	34	42	100	1.47
FJ-11,c	33	26	41	100	0.78
FJ-10,c	–	–	–	–	–
FJ- 9,c	40	12	48	100	0.31
FJ- 8,c	–	–	–	–	–
FJ- 7,c	37	15	48	100	0.40
FJ- 6,c	–	–	–	–	–
FJ- 5,c	38	28	35	100	0.74
FJ- 4,c	56	15	29	100	0.27
FJ- 3,c	37	7	56	100	0.20
FJ- 2,c	33	8	59	100	0.23
FJ- 1,c	–	–	–	–	–

Aquatic palynomorphs
Relative abundances

Sample no.	Dinofl. cysts %	Acri- tarchs %	Tasma- naceae %	Ptero- sperm. %	Cymat. sphera. %	Foram. testl. %	Limnic algae %	Total aquat. palyn. %
FJ-16,c	13	75	9	0	0	0	3	100
FJ-15,c	8	86	0	2	3	0	1	100
FJ-14,c	–	–	–	–	–	–	–	–
FJ-13,c	–	–	–	–	–	–	–	–
FJ-12,c	20	80	0	0	0	0	0	0
FJ-11,c	0	100	0	0	0	0	0	0
FJ-10,c	–	–	–	–	–	–	–	–
FJ- 9,c	0	100	0	0	0	0	0	0
FJ- 8,c	–	–	–	–	–	–	–	–
FJ- 7,c	0	100	0	0	0	0	0	0
FJ- 6,c	–	–	–	–	–	–	–	–
FJ- 5,c	40	60	0	0	0	0	0	0
FJ- 4,c	5	84	0	0	0	5	5	11
FJ- 3,c	42	50	0	0	0	0	8	8
FJ- 2,c	68	32	0	0	0	0	0	0
FJ- 1,c	–	–	–	–	–	–	–	–

Acritarch groups
Ratio: (Polygonomorphitae + Netromorphitae) /Acanthomorphitae

Sample no.	Ratio: (P + N)/ A
FJ-16,c	0.04
FJ-15,c	0.16
FJ-14,c	–
FJ-13,c	–
FJ-12,c	0.11
FJ-11,c	0.05
FJ-10,c	–
FJ- 9,c	0.02
FJ- 8,c	–
FJ- 7,c	0.00
FJ- 6,c	–
FJ- 5,c	0.00
FJ- 4,c	0.00
FJ- 3,c	0.09
FJ- 2,c	0.00
FJ- 1,c	–

Mean values of the kerogen categories for each lithostratigraphical unit.

	Fj. F.		Ga. F.		F-Ia M.		F-Ib M.		F-III M.		F-IV M.	
	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n
T.O.C.	1.0	13	0.9	3	0.8	8	0.8	2	1.4	2	1.5	1
%palynomorphs	21	13	7	3	15	8	23	2	43	2	23	1
%brown wood	62	13	73	3	73	8	55	2	32	2	56	1
%black wood	12	13	19	3	11	8	20	2	6	2	13	1
%cuticle	0	13	0	3	0	8	0	2	0	2	1	1
%A.O.M.	5	13	1	3	2	8	1	2	19	2	7	1
PhytOC	0.68	13	0.85	3	0.71	8	0.58	2	0.54	2	1.03	1
AmexOC	0.06	13	0.01	3	0.02	8	0.01	2	0.27	2	0.11	1
%marine palynom.	13	8	15	2	9	5	25	1	24	1	11	1
%spores	32	8	35	2	41	5	23	1	8	1	20	1
%saccate pollen	20	8	8	2	19	5	34	1	17	1	14	1
%non-sac. pollen	48	8	58	2	40	5	42	1	75	1	66	1
sac. pollen/spores	0.52	8	0.22	2	0.55	5	1.47	1	2.09	1	0.71	1
%dinofl. cysts	11	8	55	2	9	5	20	1	8	1	13	1
%acritarchs	86	8	41	2	89	5	80	1	89	1	75	1
%Tasmanaceae	1	8	0	2	0	5	0	1	0	1	9	1
%Pterospermel.	0	8	0	2	0	5	0	1	2	1	0	1
%Cymatiosph.	0	8	0	2	0	5	0	1	3	1	0	1
%foram.testl.	1	8	0	2	1	5	0	1	0	1	0	1
%limnic algae	1	8	4	2	1	5	0	1	1	1	3	1
(P + N)/A	0.05	8	0.05	2	0.01	5	0.11	1	0.16	1	0.04	1

Appendix B
The Frederikshavn-2 borehole

Sample lithology

Lithostrat. units	Sample no.	Depth (m.b.r.t.)	Sample lithology	T.O.C.
	Frh-22,c	782	si.cl.st. ψθξ	1.0
F-III Mb.	Frh-21,c	783	cl.si.st. ψθ	0.9
	Frh-20,c	784	cl.si.st. ψθ	0.8
	Frh-19,c	785	si.cl.st. ψθ	0.9
	Frh-18,c	787	si.cl.st. ψθ	0.8
	Frh-17,c	787	clayst. ψ	0.7
F-II Mb.	Frh-16,c	788	cl.si.st. θξ	0.7
	Frh-15,c	789	cl.sa.st.	0.8
	Frh-14,c	851	siltst. ψθξ	1.0
	Frh-13,c	854	sa.cl.st. θ	0.9
	Frh-12,c	880	si.cl.st.	0.4
	Frh-11,c	881	si.cl.st.	1.2
F-I Mb.	Frh-10,c	883	si.cl.st.	0.4
	Frh- 9,c	884	si.cl.st.	1.1
	Frh- 8,c	885	cl.si.st.	0.8
	Frh- 7,c	886	clayst.	1.0
	Frh- 6,c	886	sandst. ψ	0.9
	Frh- 5,c	887	siltst. ψ	1.5
Gassum Fm.	Frh- 4,c	889	cl.si.st.	4.2
	Frh- 3,c	890	cl.si.st.	2.3
	Frh- 2,c	892	cl.si.st.	1.0
	Frh- 1,c	930	clayst. ■	4.7

ψ: plant remains
■: coal pieces
θ: shell remains
ξ: burrows
clayst.: claystone
si.cl.st.: silt-streaked claystone
sa.cl.st.: sand-streaked claystone
siltst.: siltstone
cl.si.st.: clay-streaked siltstone
sandst.: sandstone
cl.sa.st.: clay-streaked sandstone

Kerogen categories
Relative abundances

Sample no.	Paly-nom. %	Br. wood %	Bl. wood %	Cuticle %	A.O.M. %	Total %
Frh-22,c	23	71	3	0	2	100
Frh-21,c	15	81	2	1	1	100
Frh-20,c	19	78	1	1	1	100
Frh-19,c	17	77	2	0	4	100
Frh-18,c	19	76	2	1	3	100
Frh-17,c	26	70	1	1	2	100
Frh-16,c	18	77	3	1	1	100
Frh-15,c	11	86	2	0	1	100
Frh-14,c	22	68	7	0	3	100
Frh-13,c	15	78	4	0	3	100
Frh-12,c	18	77	2	0	3	100
Frh-11,c	21	66	11	0	2	100
Frh-10,c	18	75	5	0	2	100
Frh- 9,c	22	70	6	0	2	100
Frh- 8,c	30	64	6	0	1	100
Frh- 7,c	23	72	4	0	1	100
Frh- 6,c	4	92	3	0	0	100
Frh- 5,c	8	86	5	1	0	100
Frh- 4,c	22	45	31	0	2	100
Frh- 3,c	5	87	8	0	1	100
Frh- 2,c	17	71	11	0	1	100
Frh- 1,c	6	93	1	0	0	100

Brown wood, size groups, relative abundances
100% = total of brown wood

Sample no.	<20 microns %	20–80 microns %	>80 microns %	Total %
Frh-22,c	32	67	1	100
Frh-21,c	40	59	0	100
Frh-20,c	38	61	0	100
Frh-19,c	32	67	2	100
Frh-18,c	30	69	1	100
Frh-17,c	35	64	1	100
Frh-16,c	60	40	0	100
Frh-15,c	56	44	0	100
Frh-14,c	38	61	1	100
Frh-13,c	29	70	1	100
Frh-12,c	33	66	1	100
Frh-11,c	23	75	2	100
Frh-10,c	31	68	1	100
Frh- 9,c	40	60	0	100
Frh- 8,c	41	58	1	100
Frh- 7,c	42	56	2	100
Frh- 6,c	55	44	1	100
Frh- 5,c	30	70	0	100
Frh- 4,c	24	74	2	100
Frh- 3,c	51	49	0	100
Frh- 2,c	37	62	1	100
Frh- 1,c	49	50	1	100

Black wood, size groups, relative abundances
100% = total of black wood

Sample no.	<20 microns %	20–80 microns %	>80 microns %	Total %
Frh-22,c	50	44	6	100
Frh-21,c	50	40	10	100
Frh-20,c	67	33	0	100
Frh-19,c	69	23	8	100
Frh-18,c	67	33	0	100
Frh-17,c	50	38	13	100
Frh-16,c	44	56	0	100
Frh-15,c	38	54	8	100
Frh-14,c	17	83	0	100
Frh-13,c	10	85	5	100
Frh-12,c	15	85	0	100
Frh-11,c	36	64	0	100
Frh-10,c	42	58	0	100
Frh- 9,c	34	63	3	100
Frh- 8,c	48	52	0	100
Frh- 7,c	45	50	5	100
Frh- 6,c	47	47	6	100
Frh- 5,c	19	78	4	100
Frh- 4,c	49	50	1	100
Frh- 3,c	34	66	0	100
Frh- 2,c	32	66	2	100
Frh- 1,c	0	86	14	100

Kerogen categories
Absolute abundance

Sample no.	Palyno-morphs	Brown wood	<20 microns	20–80 microns	>80 microns	Black wood	<20 microns	20–80 microns	>80 microns	Cuticle	A.O.M	n
Frh-22,c	140	430	139	288	3	18	9	8	1	1	15	604
Frh-21,c	84	448	181	266	1	10	5	4	1	4	6	552
Frh-20,c	120	501	191	308	2	9	6	3	0	4	5	639
Frh-19,c	103	463	147	308	8	13	9	3	1	2	23	604
Frh-18,c	109	435	132	298	5	9	6	3	0	5	16	574
Frh-17,c	140	375	133	239	3	8	4	3	1	3	11	537
Frh-16,c	103	433	259	172	2	16	7	9	0	3	4	559
Frh-15,c	59	466	259	206	1	13	5	7	1	2	5	545
Frh-14,c	119	362	137	221	4	35	6	29	0	2	14	532
Frh-13,c	83	424	124	297	3	20	2	17	1	2	16	545
Frh-12,c	101	432	143	284	5	13	2	11	0	0	17	563
Frh-11,c	120	382	87	288	7	67	24	43	0	0	14	583
Frh-10,c	95	397	122	270	5	26	11	15	0	1	10	529
Frh- 9,c	129	401	159	240	2	32	11	20	1	0	12	574
Frh- 8,c	164	346	142	200	4	31	15	16	0	0	3	544
Frh- 7,c	126	392	166	220	6	20	9	10	1	1	4	543
Frh- 6,c	27	588	323	260	5	17	8	8	1	2	3	637
Frh- 5,c	45	467	138	327	2	27	5	21	1	3	0	542
Frh- 4,c	128	258	62	192	4	174	86	87	1	0	9	569
Frh- 3,c	27	516	262	252	2	47	16	31	0	1	4	595
Frh- 2,c	94	393	147	244	2	62	20	41	1	0	3	552
Frh- 1,c	33	537	261	270	6	7	0	6	1	0	0	577

Sample no.	PhytOC	AmexOC	Marine palynom. %
Frh-22,c	0.76	0.03	20
Frh-21,c	0.75	0.01	29
Frh-20,c	0.63	0.01	–
Frh-19,c	0.70	0.03	15
Frh-18,c	0.60	0.02	–
Frh-17,c	0.50	0.01	2
Frh-16,c	0.60	0.01	–
Frh-15,c	0.74	0.01	16
Frh-14,c	0.77	0.03	13
Frh-13,c	0.77	0.03	7
Frh-12,c	0.35	0.01	5
Frh-11,c	0.90	0.03	–
Frh-10,c	0.30	0.01	–
Frh- 9,c	0.86	0.02	16
Frh- 8,c	0.52	0.00	8
Frh- 7,c	0.72	0.01	5
Frh- 6,c	0.87	0.00	5
Frh- 5,c	1.40	0.00	–
Frh- 4,c	3.16	0.07	9
Frh- 3,c	2.18	0.02	–
Frh- 2,c	0.78	0.01	12
Frh- 1,c	4.42	0.00	15

PhytOC = (% brown wood + % black wood + % cuticle) × T.O.C.
AmexOC = % Amorphous Organic Matter (A.O.M.) × T.O.C.
% marine palynomorphs: 100% = total palynomorphs

Terrestrial palynomorphs
Relative abundances

Sample no.	Spores %	Saccate pollen %	Non-pollen pollen %	Total saccate pollen %	Ratio: pollen/ spores
Frh-22,c	38	11	51	100	0.28
Frh-21,c	40	12	48	100	0.31
Frh-20,c	–	–	–	–	–
Frh-19,c	34	15	50	100	0.45
Frh-18,c	–	–	–	–	–
Frh-17,c	34	13	53	100	0.37
Frh-16,c	–	–	–	–	–
Frh-15,c	30	21	49	100	0.72
Frh-14,c	36	15	49	100	0.41
Frh-13,c	38	20	42	100	0.53
Frh-12,c	45	18	37	100	0.40
Frh-11,c	–	–	–	–	–
Frh-10,c	–	–	–	–	–
Frh- 9,c	28	16	55	100	0.57
Frh- 8,c	41	17	42	100	0.42
Frh- 7,c	51	13	36	100	0.25
Frh- 6,c	45	16	39	100	0.36
Frh- 5,c	–	–	–	–	–
Frh- 4,c	43	14	43	100	0.33
Frh- 3,c	–	–	–	–	–
Frh- 2,c	46	20	34	100	0.44
Frh- 1,c	43	13	44	100	0.29

Aquatic palynomorphs
Relative abundances

Sample no.	Dinofl. cysts %	Acri-tarchs %	Tasma-naceae % %	Cymat. sphera. %	Foram. testl. %	Limnic algae %	Total aquat. palyn. %
Frh-22,c	57	28	0	0	0	15	100
Frh-21,c	76	13	1	0	0	10	100
Frh-20,c	–	–	–	–	–	–	–
Frh-19,c	59	16	0	0	0	25	100
Frh-18,c	–	–	–	–	–	–	–
Frh-17,c	23	15	0	0	0	62	100
Frh-16,c	–	–	–	–	–	–	–
Frh-15,c	12	82	0	2	0	4	100
Frh-14,c	0	98	0	0	0	2	100
Frh-13,c	4	91	0	0	4	0	100
Frh-12,c	40	53	0	0	0	7	100
Frh-11,c	–	–	–	–	–	–	–
Frh-10,c	–	–	–	–	–	–	–
Frh- 9,c	2	97	0	0	0	2	100
Frh- 8,c	0	100	0	0	0	0	100
Frh- 7,c	7	93	0	0	0	0	100
Frh- 6,c	0	100	0	0	0	0	100
Frh- 5,c	–	–	–	–	–	–	–
Frh- 4,c	3	84	3	0	0	9	100
Frh- 3,c	–	–	–	–	–	–	–
Frh- 2,c	0	100	0	0	0	0	100
Frh- 1,c	0	98	0	0	0	2	100

Acritarch groups
Ratio (Polygonomorphitae + Netromorphitae) /Acanthomorphitae

Sample no.	Ratio: (P + N)/A
Frh-22,c	0.10
Frh-21,c	0.13
Frh-20,c	–
Frh-19,c	0.25
Frh-18,c	–
Frh-17,c	1.00
Frh-16,c	–
Frh-15,c	0.12
Frh-14,c	0.19
Frh-13,c	0.40
Frh-12,c	0.14
Frh-11,c	–
Frh-10,c	–
Frh- 9,c	0.19
Frh- 8,c	0.47
Frh- 7,c	0.17
Frh- 6,c	0.27
Frh- 5,c	–
Frh- 4,c	0.04
Frh- 3,c	–
Frh- 2,c	0.05
Frh- 1,c	0.02

Mean values of the kerogen categories for each lithostratigraphical unit.

	Fj. F.		Ga. F.		F-I M.		F-II M.		F-III M.	
	mean	n	mean	n	mean	n	mean	n	mean	n
T.O.C.	0.8	15	2.2	7	0.8	5	0.8	6	0.9	4
%palynomorphs	20	15	12	7	22	5	19	6	19	4
%brown wood	74	15	78	7	70	5	6	6	77	4
%black wood	4	15	9	7	6	5	3	6	2	4
%cuticle	0	15	0	7	0	5	1	6	0	4
%A.O.M.	2	15	1	7	2	5	2	6	2	4
PhytOC	0.65	15	1.93	7	0.59	5	0.66	6	0.71	4
AmexOC	0.02	15	0.02	7	0.01	5	0.02	6	0.02	4
%marine palynom.	13	10	9	5	10	3	9	4	21	3
%spores	36	10	46	5	38	3	34	4	37	3
%saccate pollen	16	10	15	5	17	3	17	4	13	3
%non-sac. pollen	48	10	39	5	45	3	48	4	50	3
sac. pollen/spores	0.45	10	0.33	5	0.46	3	0.51	4	0.35	3
%dinofl. cysts	27	10	2	5	14	3	10	4	64	3
%acritarchs	60	10	95	5	83	3	72	4	19	3
%Tasmanaceae	0	10	1	5	0	3	0	4	0	3
%Pterospermel.	0	10	0	5	0	3	0	4	0	3
%Cymatiosph.	0	10	0	5	0	3	1	4	0	3
%foram.testl.	0	10	0	5	0	3	1	4	0	3
%limnic algae	13	10	2	5	3	3	17	4	17	3
(P + N)/A	0.30	10	0.11	5	0.27	3	0.42	4	0.16	3

Appendix C
The Stenlille-2 borehole

Lithostrat. units	Sample no.	Depth (m.b.r.t.)	Sample lithology	T.O.C.
F-IV Mb.	St-16,w	1228	si.cl.st.	0.4
F-III Mb.	St-15,w	1234	clayst.	1.9
	St-14,w	1240	sa.cl.st.	0.8
F-II Mb.	St-13,w	1246	sa.cl.st.	0.8
	St-12,w	1252	cl.si.st.	0.5
	St-11,w	1258	si.cl.st.	0.9
	St-10,w	1380	sa.cl.st.	0.8
	St- 9,w	1390	clayst.	0.8
	St- 8,w	1392	clayst.	1.0
	St- 7,w	1401	cl.sa.st.	0.4
	St- 6,w	1413	si.cl.st.	0.9
	St- 5,w	1424	sa.cl.st.	1.2
	St- 4,w	1441	clayst.	0.9
	St- 3,w	1452	cl.sa.st.	0.5
	St- 2,w	1460	clayst.	1.1
F-Ia Mb.	St- 1,w	1472	clayst.	0.7
	St-11,c	1476	si.cl.st.	0.8
	St-10,c	1477	clayst.	0.9
	St- 9,c	1478	clayst.	1.1
	St- 8,c	1491	clayst.	1.0
	St- 7,c	1493	cl.sa.st. ξ	1.4
	St- 6,c	1494	sa.cl.st.	1.5
	St- 5,c	1496	sa.cl.st.	1.7
	St- 4,c	1503	sandst.	0.4
	St- 3,c	1510	clayst.	1.5
Gassum Fm.	St- 2,c	1512	sa.cl.st.	2.7
	St- 1,c	1513	cl.sa.st. ■	2.6

■: coal pieces
ξ: burrows
clayst.: claystone
si.cl.st.: silt-streaked claystone
sa.cl.st.: sand-streaked claystone
cl.si.st.: clay-streaked siltstone
sandst.: sandstone
cl.sa.st.: clay-streaked sandstone

Kerogen categories
Relative abundances

Sample no.	Paly- nom. %	Br. wood %	Bl. wood %	Cuticle %	A.O.M. %	Total %
St-16,w	16	63	1	2	18	100
St-15,w	22	1	0	0	76	100
St-14,w	45	42	9	0	3	100
St-13,w	39	36	8	0	17	100
St-12,w	30	64	5	0	1	100
St-11,w	41	50	6	0	2	100
St-10,w	–	–	–	–	–	–
St- 9,w	24	69	7	0	0	100
St- 8,w	14	78	6	0	3	100
St- 7,w	3	90	7	0	0	100
St- 6,w	13	77	5	0	4	100
St- 5,w	16	77	6	0	1	100
St- 4,w	17	78	4	0	1	100
St- 3,w	1	97	2	0	0	100
St- 2,w	10	81	3	0	6	100
St- 1,w	11	65	3	0	20	100
St-11,c	18	73	7	0	2	100
St-10,c	14	79	4	0	2	100
St- 9,c	17	66	6	0	12	100
St- 8,c	22	66	6	0	7	100
St- 7,c	17	75	6	0	2	100
St- 6,c	14	79	6	0	1	100
St- 5,c	7	88	6	0	0	100
St- 4,c	1	70	29	0	0	100
St- 3,c	20	69	11	0	0	100
St- 2,c	18	68	6	0	8	100
St- 1,c	4	80	17	0	0	100

Brown wood, size groups, relative abundances
100% = total of brown wood

Sample no.	<20 microns %	20–80 microns %	>80 microns %	Total %
St-16,w	38	48	14	100
St-15,w	25	75	0	100
St-14,w	60	38	2	100
St-13,w	58	40	2	100
St-12,w	68	30	2	100
St-11,w	76	22	2	100
St-10,w	–	–	–	–
St- 9,w	78	22	0	100
St- 8,w	78	22	0	100
St- 7,w	90	10	0	100
St- 6,w	70	29	1	100
St- 5,w	78	21	1	100
St- 4,w	72	26	1	100
St- 3,w	80	20	0	100
St- 2,w	77	23	1	100
St- 1,w	72	27	1	100
St-11,c	70	29	1	100
St-10,c	79	21	0	100
St- 9,c	76	23	1	100
St- 8,c	79	21	0	100
St- 7,c	71	27	2	100
St- 6,c	68	30	2	100
St- 5,c	76	24	0	100
St- 4,c	76	23	0	100
St- 3,c	62	37	1	100
St- 2,c	64	35	1	100
St- 1,c	73	26	1	100

Black wood, size groups, relative abundances
100% = total of black wood

Sample no.	<20 microns %	20–80 microns %	>80 microns %	Total %
St-16,w	60	40	0	100
St-15,w	100	0	0	100
St-14,w	77	23	0	100
St-13,w	66	34	0	100
St-12,w	75	25	0	100
St-11,w	83	17	0	100
St-10,w	–	–	–	–
St- 9,w	92	8	0	100
St- 8,w	73	27	0	100
St- 7,w	54	46	0	100
St- 6,w	76	24	0	100
St- 5,w	62	38	0	100
St- 4,w	55	41	5	100
St- 3,w	46	54	0	100
St- 2,w	75	25	0	100
St- 1,w	83	17	0	100
St-11,c	61	36	3	100
St-10,c	86	9	5	100
St- 9,c	55	45	0	100
St- 8,c	77	23	0	100
St- 7,c	94	6	0	100
St- 6,c	55	41	3	100
St- 5,c	73	27	0	100
St- 4,c	65	34	1	100
St- 3,c	88	11	2	100
St- 2,c	86	14	0	100
St- 1,c	70	26	3	100

Kerogen categories
Absolute abundance

Sample no.	Palyno-morphs	Brown wood	<20 microns	20–80 microns	>80 microns	Black wood	<20 microns	20–80 microns	>80 microns	Cuticle	A.O.M	n
St-16,w	85	341	130	163	48	5	3	2	0	12	95	538
St-15,w	119	8	2	6	0	2	2	0	0	0	413	542
St-14,w	240	226	136	85	5	48	37	11	0	1	17	532
St-13,w	225	208	120	83	5	44	29	15	0	0	96	573
St-12,w	165	351	240	105	6	28	21	7	0	0	5	549
St-11,w	217	264	201	59	4	29	24	5	0	0	13	523
St-10,w	–	–	–	–	–	–	–	–	–	–	–	–
St- 9,w	126	362	284	78	0	36	33	3	0	2	0	526
St- 8,w	75	421	327	93	1	30	22	8	0	0	16	542
St- 7,w	17	469	423	45	1	37	20	17	0	1	0	524
St- 6,w	69	407	284	118	5	29	22	7	0	2	23	530
St- 5,w	85	406	318	85	3	29	18	11	0	2	4	526
St- 4,w	88	412	298	109	5	22	12	9	1	0	4	526
St- 3,w	4	517	414	101	2	13	6	7	0	0	0	534
St- 2,w	55	461	353	105	3	16	12	4	0	0	34	566
St- 1,w	62	355	256	96	3	18	15	3	0	1	109	545
St-11,c	101	400	281	116	3	36	22	13	1	1	12	550
St-10,c	76	416	328	87	1	22	19	2	1	0	13	527
St- 9,c	93	363	276	82	5	31	17	14	0	0	65	552
St- 8,c	119	361	285	76	0	31	24	7	0	0	36	547
St- 7,c	92	396	281	107	8	32	30	2	0	0	8	528
St- 6,c	75	413	281	124	8	29	16	12	1	1	5	523
St- 5,c	35	468	355	111	2	30	22	8	0	0	0	533
St- 4,c	7	367	280	86	1	151	98	52	1	0	1	526
St- 3,c	107	364	225	136	3	56	49	6	1	1	0	528
St- 2,c	100	377	242	131	4	36	31	5	0	0	44	557
St- 1,c	21	419	305	109	5	87	61	23	3	0	0	527

Sample no.	PhytOC	AmexOC	Marine palynom. %
St-16,w	0.25	0.07	3
St-15,w	0.03	1.42	7
St-14,w	0.41	0.03	17
St-13,w	0.37	0.14	19
St-12,w	0.33	0.00	–
St-11,w	0.53	0.02	22
St-10,w	0.00	0.00	–
St- 9,w	0.64	0.00	7
St- 8,w	0.83	0.03	7
St- 7,w	0.37	0.00	1
St- 6,w	0.72	0.04	10
St- 5,w	0.97	0.01	8
St- 4,w	0.76	0.01	16
St- 3,w	0.50	0.00	–
St- 2,w	0.92	0.07	27
St- 1,w	0.48	0.14	8
St-11,c	0.66	0.02	7
St-10,c	0.72	0.02	6
St- 9,c	0.79	0.13	10
St- 8,c	0.69	0.06	26
St- 7,c	0.00	0.00	10
St- 6,c	1.27	0.01	7
St- 5,c	1.58	0.00	7
St- 4,c	0.41	0.00	–
St- 3,c	1.19	0.00	11
St- 2,c	1.96	0.21	50
St- 1,c	2.51	0.00	1

PhytOC = (% brown wood + % black wood + % cuticle) × T.O.C.
AmexOC = % Amorphous Organic Matter (A.O.M.) × T.O.C.
% marine palynomorphs: 100% = total palynomorphs

Terrestrial palynomorphs
Relative abundances

Sample no.	Spores %	Saccate pollen %	Non-saccate pollen %	Total spores+ pollen %	Ratio: saccate pollen/ spores
St-16,w	22	0	78	100	0.00
St-15,w	1	0	99	100	0.00
St-14,w	26	31	43	100	1.20
St-13,w	31	31	39	100	1.00
St-12,w	–	–	–	–	–
St-11,w	28	35	37	100	1.26
St-10,w	–	–	–	–	–
St- 9,w	55	7	38	100	0.13
St- 8,w	53	11	37	100	0.20
St- 7,w	62	14	24	100	0.23
St- 6,w	58	13	29	100	0.22
St- 5,w	49	20	31	100	0.40
St- 4,w	52	22	26	100	0.43
St- 3,w	–	–	–	–	–
St- 2,w	63	14	23	100	0.21
St- 1,w	52	19	29	100	0.37
St-11,c	56	22	22	100	0.40
St-10,c	59	19	22	100	0.31
St- 9,c	47	28	25	100	0.58
St- 8,c	57	20	22	100	0.36
St- 7,c	69	16	15	100	0.24
St- 6,c	67	17	15	100	0.26
St- 5,c	82	4	15	100	0.04
St- 4,c	–	–	–	–	–
St- 3,c	45	12	43	100	0.25
St- 2,c	32	12	57	100	0.37
St- 1,c	5	0	95	100	0.08

Aquatic palynomorphs
Relative abundances

Sample no.	Dinofl. cysts %	Acri- tarchs %	Tasma- naceae %	Ptero- sperm. %	Cymatio- sphera. %	Limnic algae %	Total aquat. palyno. %
St-16,w	0	100	0	0	0	0	100
St-15,w	14	59	0	18	9	0	100
St-14,w	3	87	0	2	2	6	100
St-13,w	5	91	0	0	0	4	100
St-12,w	–	–	–	–	–	–	–
St-11,w	7	92	0	0	1	0	100
St-10,w	–	–	–	–	–	–	–
St- 9,w	48	52	0	0	0	0	100
St- 8,w	0	100	0	0	0	0	100
St- 7,w	0	100	0	0	0	0	100
St- 6,w	14	86	0	0	0	0	100
St- 5,w	13	83	0	0	0	4	100
St- 4,w	16	84	0	0	0	0	100
St- 3,w	–	–	–	–	–	–	–
St- 2,w	69	30	1.00	0	0	0	100
St- 1,w	30	65	0	0	0	4	100
St-11,c	13	83	0	0	0	4	100
St-10,c	19	81	0	0	0	0	100
St- 9,c	7	90	0	0	0	0	100
St- 8,c	1	99	0	0	0	0	100
St- 7,c	49	51	0	0	0	0	100
St- 6,c	57	43	0	0	0	0	100
St- 5,c	19	81	0	0	0	0	100
St- 4,c	–	–	–	–	–	–	–
St- 3,c	32	61	0	0	0	8	100
St- 2,c	50	48	1.00	0	0	1	100
St- 1,c	33	67	0	0	0	0	100

Acritarch groups Ratio:
(Polygonomorphitae + Netromorphitae) /Acanthomorphitae

Sample no.	Ratio: (P + N)/ A
St-16,w	0.00
St-15,w	0.18
St-14,w	0.23
St-13,w	0.21
St-12,w	–
St-11,w	0.52
St-10,w	–
St- 9,w	0.67
St- 8,w	0.40
St- 7,w	0.00
St- 6,w	0.85
St- 5,w	0.38
St- 4,w	0.41
St- 3,w	–
St- 2,w	0.18
St- 1,w	0.15
St-11,c	0.19
St-10,c	0.44
St- 9,c	0.00
St- 8,c	2.35
St- 7,c	0.13
St- 6,c	0.12
St- 5,c	0.00
St- 4,c	–
St- 3,c	0.92
St- 2,c	0.03
St- 1,c	0.00

Mean values of the kerogen categories for each lithostratigraphical unit.

	Fj. F.		Ga. F.		F-Ia M.		F-II M.		F-III M.		F-IV M.	
	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n
T.O.C.	1.0	25	2.6	2	1.0	19	0.8	4	1.9	1	0.4	1
%palynomorphs	18	24	11	2	13	18	39	4	22	1	16	1
%brown wood	68	24	74	2	76	18	48	4	1	1	63	1
%black wood	6	24	11	2	7	18	7	4	0	1	1	1
%cuticle	0	24	0	2	0	18	0	4	0	1	2	1
%A.O.M.	8	24	4	2	3	18	6	4	76	1	18	1
PhytOC	0.64	24	2.24	2	0.75	18	0.41	4	0.03	1	0.25	1
AmexOC	0.09	24	0.11	2	0.33	18	0.05	4	1.42	1	0.07	1
%marine palynom.	11	21	25	2	10	16	19	3	7	1	3	1
%spores	49	21	18	2	58	16	28	3	1	1	22	1
%saccate pollen	17	21	6	2	16	16	32	3	0	1	0	1
%non-sac. pollen	34	21	76	2	26	16	40	3	99	1	78	1
sac. pollen/spores	0.43	21	0.23	2	0.29	16	1.15	3	0.00	1	0.00	1
%dinofl. cysts	20	21	42	2	24	16	5	3	14	1	0	1
%acritarchs	78	21	57	2	74	16	91	3	68	1	100	1
%Tasmanaceae	0	21	0	2	0	16	0	3	0	1	0	1
%Pterospermel.	1	21	0	2	0	16	1	3	18	1	0	1
%Cymatiosph.	1	21	0	2	0	16	1	3	9	1	0	1
%foram.testl.	0	21	0	2	0	16	0	3	0	1	0	1
%limnic algae	1	21	1	2	1	16	3	3	0	1	0	1
(P + N)/A	0.26	21	0.02	2	0.28	16	0.32	3	0.00	1	0.00	1

Appendix D
The Gassum-1 borehole

Lithostrat. units	Sample no.	Depth (m.b.r.t.)	Sample lithology		T.O.C.
	GA-60,c	1210	si.cl.st.	ψ~	1.2
	GA-58,c	1227	si.cl.st.	ψ~	1.1
F-III Mb.	GA-57,c	1245	clayst.		1.4
	GA-55,c	1264	si.cl.st.		1.2
	GA-53,c	1277	si.cl.st.	ψ	1.7
	GA-52,c	1289	si.cl.st.	~	1.6
F-II Mb.	GA-51,c	1301	clayst.	~	1.1
	GA-49,c	1303	clayst.		1.3
	GA-47,c	1305	si.cl.st.	~	1.2
	GA-44,c	1313	clayst.	ψ~	1.0
	GA-42,c	1327	clayst.		1.0
	GA-41,c	1342	clayst.		1.1
	GA-40,c	1358	clayst.		0.9
	GA-38,c	1360	clayst.		0.8
F-Ib Mb.	GA-37,c	1361	clayst.	~	0.7
	GA-36,c	1373	clayst.		0.7
	GA-35,c	1373	si.cl.st.	~	0.6
	GA-33,c	1376	clayst.		1.0
	GA-31,c	1390	clayst.		1.0
	GA-29,c	1404	clayst.		0.9
	GA-26,c	1420	clayst.		1.0
	GA-24,c	1434	clayst.		0.9
	GA-22,c	1437	clayst.		1.1
	GA-20,c	1439	si.cl.st.	ψ	0.4
	GA-19,c	1450	clayst.		0.8
F-Ia Mb.	GA-18,c	1464	clayst.		0.9
	GA-16,c	1467	clayst.	~	0.7
	GA-14,c	1480	si.cl.st.	ψ	0.7
	GA-12,c	1484	clayst.		0.6
	GA-10,c	1497	clayst.		0.5
	GA- 8,c	1498	clayst.		0.7
	GA- 6,c	1511	clayst.		1.0
	GA- 4,c	1513	clayst.		1.0
	GA- 3,c	1534	clayst.		1.5
Gassum	GA- 2,c	1534	sa.cl.st.		0.9
Fm.	GA- 1,c	1536	si.cl.st.		1.4

ψ: plant remains
~: clay-ironstone
clayst.: claystone
si.cl.st.: silt-streaked claystone
sa.cl.st.: sand-streaked claystone

Kerogen categories
Relative abundances

Sample no.	Paly-nom. %	Br. wood %	Bl. wood %	Cuticle %	A.O.M. %	Total %
GA-60,c	47	27	10	0	16	100
GA-58,c	42	33	23	0	2	100
GA-57,c	20	58	20	0	3	100
GA-55,c	31	36	31	0	2	100
GA-53,c	19	59	21	0	0	100
GA-52,c	46	30	9	0	15	100
GA-51,c	70	15	7	0	9	100
GA-49,c	42	24	13	0	21	100
GA-47,c	55	20	7	0	18	100
GA-44,c	58	23	11	0	8	100
GA-42,c	33	30	36	0	2	100
GA-41,c	15	29	54	0	2	100
GA-40,c	24	34	39	0	3	100
GA-38,c	18	45	33	0	4	100
GA-37,c	27	33	38	0	1	100
GA-36,c	19	40	39	0	1	100
GA-35,c	49	33	17	0	1	100
GA-33,c	22	36	4	0	9	100
GA-31,c	25	37	33	0	4	100
GA-29,c	22	38	35	0	4	100
GA-26,c	26	34	30	0	10	100
GA-24,c	36	33	22	0	9	100
GA-22,c	24	37	29	0	10	100
GA-20,c	21	35	35	0	8	100
GA-19,c	37	43	17	0	3	100
GA-18,c	22	50	25	0	3	100
GA-16,c	28	40	27	1	4	100
GA-14,c	20	41	37	0	1	100
GA-12,c	21	42	33	0	4	100
GA-10,c	22	37	39	0	3	100
GA- 8,c	16	41	26	0	18	100
GA- 6,c	24	36	31	0	9	100
GA- 4,c	24	30	35	0	11	100
GA- 3,c	9	64	25	1	1	100
GA- 2,c	19	69	10	0	3	100
GA- 1,c	16	43	36	2	3	100

Brown wood, size groups, relative abundances
100% = total of brown wood

Sample no.	<20 microns %	20–80 microns %	>80 microns %	Total %
GA-60,c	28	66	6	100
GA-58,c	16	81	3	100
GA-57,c	36	63	1	100
GA-55,c	27	65	9	100
GA-53,c	45	51	4	100
GA-52,c	13	80	7	100
GA-51,c	14	75	11	100
GA-49,c	26	65	9	100
GA-47,c	26	66	8	100
GA-44,c	23	69	8	100
GA-42,c	6	91	3	100
GA-41,c	28	68	4	100
GA-40,c	18	81	2	100
GA-38,c	27	70	3	100
GA-37,c	16	77	7	100
GA-36,c	25	68	6	100
GA-35,c	21	74	6	100
GA-33,c	25	70	5	100
GA-31,c	27	69	4	100
GA-29,c	23	72	5	100
GA-26,c	24	69	7	100
GA-24,c	20	69	12	100
GA-22,c	32	63	5	100
GA-20,c	44	53	4	100
GA-19,c	42	56	2	100
GA-18,c	33	64	3	100
GA-16,c	24	71	6	100
GA-14,c	25	71	5	100
GA-12,c	25	71	4	100
GA-10,c	33	59	7	100
GA- 8,c	33	64	4	100
GA- 6,c	23	69	8	100
GA- 4,c	24	62	13	100
GA- 3,c	27	70	2	100
GA- 2,c	34	63	3	100
GA- 1,c	34	64	2	100

Sample no.	<20 microns %	20–80 microns %	>80 microns %	Total %
GA-60,c	58	38	4	100
GA-58,c	27	71	2	100
GA-57,c	62	35	3	100
GA-55,c	51	45	4	100
GA-53,c	56	41	3	100
GA-52,c	18	78	4	100
GA-51,c	61	39	0	100
GA-49,c	41	51	8	100
GA-47,c	32	61	7	100
GA-44,c	31	56	13	100
GA-42,c	35	63	2	100
GA-41,c	37	61	2	100
GA-40,c	31	69	0	100
GA-38,c	46	54	0	100
GA-37,c	31	67	2	100
GA-36,c	53	46	1	100
GA-35,c	31	67	2	100
GA-33,c	44	55	2	100
GA-31,c	49	50	1	100
GA-29,c	48	49	2	100
GA-26,c	57	41	2	100
GA-24,c	43	54	3	100
GA-22,c	55	44	1	100
GA-20,c	52	47	1	100
GA-19,c	55	44	1	100
GA-18,c	47	51	2	100
GA-16,c	50	50	0	100
GA-14,c	37	59	4	100
GA-12,c	32	66	2	100
GA-10,c	48	48	3	100
GA- 8,c	52	45	3	100
GA- 6,c	39	51	11	100
GA- 4,c	36	59	5	100
GA- 3,c	39	59	2	100
GA- 2,c	55	43	2	100
GA- 1,c	58	41	1	100

Kerogen categories
Absolute abundance

Sample no.	Palyno-morphs	Brown wood	<20 microns	20–80 microns	>80 microns	Black wood	<20 microns	20–80 microns	>80 microns	Cuticle	A.O.M	n
GA-60,c	248	145	41	95	9	55	32	21	2	0	83	531
GA-58,c	268	210	33	170	7	148	40	105	3	2	15	643
GA-57,c	108	310	112	194	4	106	66	37	3	1	14	539
GA-55,c	166	195	52	126	17	170	87	77	6	1	11	543
GA-53,c	103	316	143	161	12	114	64	47	3	1	0	534
GA-52,c	267	172	22	138	12	50	9	39	2	0	89	578
GA-51,c	384	80	11	60	9	36	22	14	0	1	48	549
GA-49,c	243	141	37	91	13	76	31	39	6	1	120	581
GA-47,c	320	119	31	78	10	44	14	27	3	0	104	587
GA-44,c	329	133	30	92	11	61	19	34	8	1	43	567
GA-42,c	186	170	10	155	5	203	71	128	4	0	10	569
GA-41,c	84	164	46	111	7	299	112	182	5	0	11	558
GA-40,c	153	217	38	175	4	248	76	171	1	1	18	637
GA-38,c	92	237	65	166	6	171	79	92	0	0	21	521
GA-37,c	141	169	27	130	12	196	60	132	4	0	7	513
GA-36,c	105	220	56	150	14	215	115	98	2	2	7	549
GA-35,c	278	185	38	136	11	95	29	64	2	1	5	564
GA-33,c	122	200	50	140	10	190	83	104	3	0	50	562
GA-31,c	136	199	54	138	7	179	88	90	1	2	22	538
GA-29,c	125	215	50	154	11	198	96	98	4	0	25	563
GA-26,c	139	178	42	123	13	156	89	64	3	0	53	526
GA-24,c	195	179	35	123	21	119	51	64	4	1	46	540
GA-22,c	136	206	66	129	11	165	91	73	1	0	55	562
GA-20,c	116	200	87	105	8	200	104	94	2	1	48	565
GA-19,c	208	240	101	135	4	97	53	43	1	0	17	562
GA-18,c	118	273	89	175	9	133	63	68	2	1	17	542
GA-16,c	152	215	51	152	12	146	73	73	0	3	20	536
GA-14,c	107	221	55	156	10	197	72	117	8	2	8	535
GA-12,c	121	248	61	177	10	193	61	128	4	2	23	587
GA-10,c	132	222	74	132	16	233	112	113	8	0	17	604
GA- 8,c	85	215	70	137	8	136	71	61	4	0	94	530
GA- 6,c	152	232	53	160	19	198	77	100	21	1	61	644
GA- 4,c	158	194	47	121	26	226	81	134	11	1	72	651
GA- 3,c	72	486	133	341	12	194	76	115	3	4	7	763
GA- 2,c	97	361	124	226	11	51	28	22	1	0	15	524
GA- 1,c	83	228	77	146	5	193	111	80	2	9	17	530

Terrestrial palynomorphs
Relative abundances

Sample no.	PhytOC	AmexOC	Marine palynom. %	Ratio: saccate pollen/ spores	Ratio: (P + N)/ A
GA-60,c	0.46	0.19	22	0.80	0.19
GA-58,c	0.59	0.02	–	–	–
GA-57,c	1.06	0.04	11	0.59	0.37
GA-55,c	0.80	0.02	23	1.34	0.06
GA-53,c	1.37	0.00	4	0.32	0.00
GA-52,c	0.60	0.24	–	–	–
GA-51,c	0.24	0.10	34	1.59	0.05
GA-49,c	0.47	0.26	32	1.98	0.10
GA-47,c	0.32	0.21	21	1.58	0.05
GA-44,c	0.34	0.07	31	1.84	0.04
GA-42,c	0.68	0.02	–	–	–
GA-41,c	0.91	0.02	7	0.28	0.05
GA-40,c	0.68	0.03	–	–	–
GA-38,c	0.61	0.03	18	0.47	0.02
GA-37,c	0.46	0.01	–	–	–
GA-36,c	0.59	0.01	31	0.48	0.03
GA-35,c	0.31	0.01	–	–	–
GA-33,c	0.72	0.09	24	1.67	0.04
GA-31,c	0.68	0.04	34	0.79	0.17
GA-29,c	0.67	0.04	18	0.83	0.27
GA-26,c	0.63	0.10	25	1.00	0.11
GA-24,c	0.48	0.07	30	0.72	0.33
GA-22,c	0.72	0.11	27	1.04	0.05
GA-20,c	0.31	0.04	15	0.47	0.13
GA-19,c	0.50	0.03	–	–	–
GA-18,c	0.64	0.03	16	0.15	1.19
GA-16,c	0.44	0.02	11	0.26	0.26
GA-14,c	0.52	0.01	11	0.32	0.10
GA-12,c	0.45	0.02	6	0.47	0.14
GA-10,c	0.41	0.02	41	0.88	0.04
GA- 8,c	0.48	0.13	19	0.56	0.04
GA- 6,c	0.65	0.09	28	2.50	0.05
GA- 4,c	0.62	0.11	36	1.28	0.17
GA- 3,c	1.37	0.01	5	0.05	0.00
GA- 2,c	0.71	0.03	–	–	–
GA- 1,c	1.13	0.04	0	0.11	0.00

PhytOC = (% brown wood + % black wood + % cuticle) × T.O.C.
AmexOC = % Amorphous Organic
Matter (A.O.M.) × T.O.C.
% marine palynomorphs: 100% = total palynomorphs

Number of ostracods per 100 g sediment, and ostracod diversity, according to Michelsen (1975)

Depth (m b.r.t.)	Individ. Ostracod ostrac./100gsed.	Ostracod species diversity
1210	0	–
1224	33	6
1225	37	6
1226	21	4
1227	50	4
1244	97	2
1246	4	0
1248	1	–
1264	74	6
1278	38	10
1287	33	3
1290	13	3
1300	2	–
1302	4	2
1305	2	1
1307	1	–
1311	10	14
1312	31	14
1314	0	–
1326	3	0
1328	1	–
1341	1	–
1347	5	2
1357	8	3
1359	9	3
1360	2	–
1362	3	–
1372	1	–
1404	22	1
1404	9	1
1405	8	2
1405	31	1
1406	3	1
1406	4	1
1407	7	1
1407	2	1
1417	231	3
1419	337	3
1421	1	–
1423	25	2
1434	28	3
1436	64	2
1438	10	6
1439	25	0
1440	1333	2
1451	102	3
1463	11	2
1470	403	1
1479	23	2
1485	35	2
1497	19	2
1509	41	1
1512	4	3
1515	11	1

Mean values of the kerogen categories for each lithostratigraphical unit.

	Fj. F.		Ga. F.		F-Ia M.		F-Ib M.		F-II M.		F-III M.	
	mean	n	mean	n	mean	n	mean	n	mean	n	mean	n
T.O.C.	1.0	33	1.3	3	0.8	13	0.9	11	1.4	5	1.2	4
%palynomorphs	30	33	15	3	25	13	28	11	51	5	35	4
%brown wood	36	33	59	3	38	13	34	11	22	5	38	4
%black wood	27	33	24	3	30	13	33	11	11	5	21	4
%cuticle	0	33	1	3	0	13	0	11	0	5	0	4
%A.O.M.	7	33	2	3	7	13	4	11	13	5	6	4
PhytOC	0.59	33	1.07	3	0.53	13	0.60	11	0.60	5	0.55	4
AmexOC	0.07	33	0.03	3	0.06	13	0.03	11	0.16	5	0.07	4
%marine palynom.	22	26	3	2	22	12	10	7	23	40	19	3
%spores	32	26	84	2	41	12	28	7	21	4	25	3
%saccate pollen	21	26	6	2	23	12	19	7	23	4	20	3
%non-sac. pollen	47	26	9	2	37	12	53	7	57	4	56	3
sac. pollen/spores	0.93	26	0.08	2	0.80	12	0.91	7	1.37	4	0.91	3
%dinofl. cysts	7	26	4	2	5	12	10	7	6	4	8	3
%acritarchs	89	26	96	2	93	12	87	7	83	4	87	3
%Tasmanaceae	1	26	0	2	1	12	2	7	3	4	0	3
%Pterospermel.	0	26	0	2	0	12	0	7	0	4	0	3
%Cymatiosph.	0	26	0	2	0	12	0	7	0	4	0	3
%foram.testl.	0	26	0	2	0	12	0	7	0	4	0	3
%limnic algae	2	26	0	2	1	12	0	7	8	4	4	3
(P + N)/A	0.16	26	0.00	2	0.22	12	0.09	7	0.05	4	0.21	3
Ostracods: Diversity	70	1	49	59	42	18	60	28	46	5	22	7
Number/100g sed.	11	1	55	72	148	19	20	36	13	7	35	9

Appendix E

Variations of the relative abundances of kerogen categories between the lithostratigraphical units

Kerogen categories	Borehole	Lithostratigraphical units				
		GA → F-Ia	F-Ia → F-Ib	F-Ib → F-II	F-II → F-III	F-III → F-IV
%br. wood	Fj	0%	−18%			+24%
	Frh				+ 1%	+24%
	St	+ 2%			−47%	+62%
	Ga	−21%	− 4%	−12%	+ 8%	
%bl. wood	Fj	− 8%	+ 9%			+ 7%
	Frh				− 1%	
	St	− 4%			− 7%	+ 1%
	Ga	+ 6%	+ 3%	−22%	+10%	
%palyn.	Fj	+ 8%	+ 8%			−20%
	Frh				0%	
	St	+ 2%			−17%	− 6%
	Ga	+10%	+ 4%	+23%	−11%	
PhytOC	Fj	−0.14	−0.13			+0.49
	Frh	+0.05				
	St	−1.49			−0.38	+0.22
	Ga	−0.54	+0.07	0.05		
AmexOC	Fj	+0.01	−0.01			−0.16
	Frh				0.00	
	St	−0.08			+1.37	−1.35
	Ga	+0.03	−0.03	+0.13	−0.09	
%marine palynomorphs	Fj	− 6%	+16%			−13%
	Frh				+12%	
	St	−15%			−12%	− 4%
	Ga	+19%	−12%	+13%	− 4%	
saccate pollen/sporer	Fj	+0.33	+0.92			−1.38
	Frh				−0.16	
	St	+0.06			−1.15	0
	Ga	+0.72	+0.11	+0.46	−0.46	
$\frac{P + N}{A}$	Fj	−0.04	+0.10			−0.12
	Frh				−0.27	
	St	+0.26			−0.32	0
	Ga	+0.22	−0.13	−0.04	+0.16	

Appendix F
Palaeoenvironmental indication of kerogen categories

In order to interpret the results of a palynofacies study of ancient, marine deposits, it is necessary to have detailed data from recent marine sediments for comparison.

The environmental indications of the different kerogen particle categories are discussed below. Most of the literature referred to here documents the distribution of organic sedimentary particles in recent, well studied, marine environments.

I. Palynomorphs:

This category comprises two main groups, the terrestrially derived palynomorphs (the spores and pollen), and the aquatic palynomorphs.

Terrestrial palynomorphs

The spores and pollen (sporomorphs) recorded from marine sediments originate from land plants. They are transported to the marine environment either by winds or streams. The relative importance of wind- and water transport varies, depending on the source vegetation (local or upland vegetation) (Traverse & Ginsburg 1966, Chaloner 1968, Stanley 1969), and on the physical properties of the grains (size, weight and morphology) (Müller 1959, Koreneva 1964, Stanley 1965, 1969, Traverse & Ginsburg 1966, Mudie 1982). It appears, however, that fluvial transport is generally the most important for spores and pollen and for their distribution pattern in marine sediments (Müller 1959, Traverse & Ginsburg 1966, Cross, Thompson & Zaitzeff 1966, Groot 1966, Heusser 1978, 1983, 1988).

Once the sporomorphs are immersed in water, they behave like any other sedimentary particle, and are deposited according to their hydraulic properties. The size of most microspores and pollen grains is that of coarse- to medium silt but as they are hollow or only filled with protoplasm, they are hydraulically equivalent to smaller-sized mineral particles such as fine silt or clay, and are preferentially deposited with particles of this size (Müller 1959, Stanley 1965, Davey 1971, Reid 1972, Heusser 1988).

The compositions of sporomorph-assemblages in marine sediments partly reflect the nature of the parent vegetation, but as discussed above, they are strongly affected by hydrodynamic sorting processes which fractionate the original sporomorph content according to size, density and morphotype. In general, spores and pollen from the local flora are dominant in nearshore, fine grained sediments. Sporomorphs from upland regions become relatively more abundant farther offshore (Traverse & Ginsburg 1966, Chaloner 1968, Davey 1971).

With the exception of the coarse-grained clastics of the "high energy" coastal environment, in which plant microfossils are very scarce or absent (Stanley 1965, Cross et al. 1966, Heusser 1988), the total spore-pollen content (grains per g. sediment) generally decreases offshore (Müller 1959, Traverse & Ginsburg 1966, Cross et al. 1966, Stanley 1969, Davey 1971). Furthermore, the greatest diversity of plant microfossil taxa in the sediments has been reported near the coast with the variety of forms decreasing seaward (Stanley 1969).

Spores and pollen that are relatively heavy and/or lack airbladders (sacs), tend to decrease fairly rapidly in abundance offshore (Müller 1959, Mudie 1982), whereas the lighter and/or more buoyant types (e.g. bisaccate pollen) can be carried farther offshore, and thus increase in relative abundance seawards (Müller 1959, Koreneva 1964, Traverse & Ginsburg 1966, Cross et al. 1966, Mudie 1982). For example, fern spores are primarily transported fluvially to the ocean, and are typically not transported substantial distances by ocean currents (Müller 1959, Cross et al. 1966, Heusser & Balsam 1977, Mudie 1982). Bisaccate Pine pollen, on the other hand, are very buoyant, on account of their air bladders (sacs), and remain suspended for long periods (Traverse & Ginsburg 1966, Brush & Brush 1972, Heusser 1988). They are also known to be carried thousands of miles by air currents (e.g. Melia 1984). The relative percentage of Pine pollen therefore increases selectively seaward (Cross et al. 1966, Heusser & Balsam 1977, Mudie 1982).

In Mesozoic sediments, bisaccate pollen generally seem to increase in relative abundance offshore and dominate the offshore assemblages (Hughes & Moody-Stuart 1967, Habib 1979, Tyson 1984).

According to Lund & Pedersen (1985), trilete spores comprise relatively heavy, mainly water-borne palynomorphs. In their study of the Jurassic of Jameson Land, East Greenland, the frequency of trilete spores was believed to be inversely proportional to the distance from rivers and shorelines. A maximum of bisaccate pollen was interpreted as an indicator of maximum distance from land.

Dybkjær (1988) used a similar grouping of sporomorphs to indicate variations in the palaeoenvironment. Intervals with relatively high abundances of marine palynomorphs also show high abundances of bisaccate pollen, while trilete spores showed the reverse tendencies. These intervals were interpreted as phases of low freshwater influence within the depositional environment. They generally seem to correspond to "major pulses" of the Early Jurassic transgression (Hallam 1978, 1981).

Aquatic palynomorphs

The aquatic palynomorphs recorded from marine sediments consist partly of autochthonous elements (e.g. dinoflagellate cysts, acritarchs and foraminiferal test-linings) and partly of allochthonous elements, freshwater algae, transported into the marine environment by rivers and streams.

The presence of DINOFLAGELLATE CYSTS in fossil sediments is an almost certain indication of marine to brackish-marine conditions (Dale 1983). The ecological factors limiting the distribution of recent dinoflagellate cysts seem to be very complex, and are not well understood. According to Tyson (1984, 1987), dinoflagellate cysts are mainly produced in unstable, seasonally-mixed water masses, and are thus characteristically absent or rare in marine "black shales".

The sporomorph/dinoflagellate cyst ratio within sediments generally declines offshore (Stanley 1969, Davey 1971, Davey & Rogers 1975, fig. 2).

The presence of ACRITARCHS generally indicates a marine environment. They are most numerous in the shallowest water assemblages, and also occur relatively abundantly in shallow bays and lagoons (Erkmen & Sarjeant 1980). Furthermore they are sometimes introduced into freshwater environments (Hancock & Fisher 1981).

In the acritarch group, cyst morphology seems to be associated with water depth and turbulence. Small-spined acanthomorph forms are characteristic of inshore environments (Wall 1965, Davey 1970, Fisher & Hancock 1985). The longer-spined species are inferred to have been associated with less turbulent conditions, while the short-spined forms are concentrated in the high energy facies (Wall 1965). A more varied assemblage occurs in the more open marine sediments, including acanthomorph, polygonomorph (e.g. *Veryhachium*) and netromorph (e.g. *Leiofusa*) acritarchs (Wall 1965). These observations are compatible with those of Staplin (1961) in Devonian reef deposits of Alberta.

FORAMINIFERAL TEST-LININGS ("microforaminifera") are more abundant in open marine than in littoral and estuarine environments. Concentrations of foraminiferal test-linings have been recorded from areas of upwelling, and from shallow-water, saline environments (Cross et al. 1966).

THE PRASINOPHYCEAN ALGAE are pelagic organisms (Boalch & Parke 1971). In Mesozoic black shales (the Early Toarcian Posidonia shale of Germany, the Volgian Kimmeridge Clay, and equivalents) the prasinophycean phycomata (***Cymatiosphaera*, *Tasmanaceae*, *Pterospermales***, and others) constitute an increased relative fraction of the plankton although they generally remain a small percentage of the total palynomorph population (Eisenack 1958, Wall 1965, Tyson 1984, Riegel et al. 1986).

Tasmanaceae have been recorded from shallow, brackish to marine environments, and modern forms range from open marine to inter-tidal mud-flat environments (Scull, Felix, McCaleb & Shaw 1966, Fisher 1980). The ecology of modern ***Prasinophyceae*** is not known well enough to explain their apparent preference for bituminous muds since early Palaeozoic times. Perhaps this merely reflects the lack of competition from other planktonic algae more sensitive to H_2S-contaminated water (Wille 1982).

FRESHWATER ALGAL remains can be transported to and deposited in marine environments, thus providing an indication of freshwater influence (Davey 1971).

The planktonic algae *Botryococcus* is normally considered to represent a freshwater algae, but is probably tolerant of slightly brackish water (Traverse & Ginsburg 1966, Tappan 1980).

The algal genus *Schizosporis* is also indicative of freshwater influence (Balme & Segroves 1966).

II. Terrestrial plant debris (phytoclasts):

BROWN WOOD (mainly tracheids) is almost entirely waterborne into the sea. These fragments are most abundant in regions where rivers debouch into the sea (Müller 1959, Cross et al. 1966). The larger fragments of tracheids are generally deposited nearest to the source, and the abundance and size of fragments decrease offshore (Müller 1959, Cross et al. 1966, Davey 1971, Davey & Rogers 1975, fig. 2, Tyson 1989).

Woody debris is relatively resistant to physical and biological degradation and is capable of being recycled several times without significant deterioration (Fenchel & Jørgensen 1977, Fisher 1980).

Davey (1971) divided tracheids into three size-groups: 5–20 microns (small), 20–100 microns (medium), and >100 microns (coarse). He then made a visual assessment of the proportions in which these three categories occur. He defined eleven size groups based on various possible combinations of these categories (see Davey 1971, fig. 14), and presented a scheme on the basis of which it should be possible to interpret the energy of the depositional environment, and whether it is nearshore or offshore.

BLACK WOOD comprises carbonised woody material of two genetic types (Masran & Pocock 1981, Pocock 1982):

1) Pyrofusinite (charcoal) formed by the incomplete combustion of wood or peat during natural fires.
2) Degradofusinite formed by subaerial, subaqueous, or groundwater oxidation of woody materials.

Once formed, it is extremely resistant to further oxidation and decay, and as a result is frequently all that remains following severe oxidation of an organic assemblage. Thus there is always a strong possibility that black wood may have been recycled several times (Cross et al. 1966, Schopf 1975). Such material is often the only type of kerogen recorded from coarse grained sediments, probably due to its resistance and its low buoyancy (Fisher 1980, text-fig. 1).

Due to secondary formation of black wood (by oxidation) the relative proportion of black wood in the phytoclast content is higher in more basinal sediments (Summerhayes 1987, Tyson 1989).

CUTICULAR MATTER behaves in a similar fashion to pollen and spores during transport and sedimentation in water (Cross et al. 1966). It is much less resistant to physical degradation than woody debris, and is thus rarely capable of surviving prolonged high energy transportation (Fisher 1980).

In the famous investigation of the Orinoco Delta by Müller (1959), cuticle fragments were found to be concentrated near the large delta estuaries. Both the abundance and the size decreased rapidly offshore.

RESIN has been found to be relatively abundant in highly oxidized (ancient) environments (Parry et al. 1981).

FUNGAL SPORES are probably liberated mainly from back swamp soils during heavy rainfall or by erosion of river banks. They can be transported over fairly large distances because of their generally small size (10–30 microns), but because of the lack of an initial period of wind transport, they have a more restricted distribution than tree-pollen of the same size (Müller 1959). Fungal spores and hyphae are especially numerous in deltaic deposits, and in regions where rivers debouch into the sea (Müller 1959, Cross et al. 1966, Scull et al. 1966).

III. Amorphous organic matter (A.O.M.)

A.O.M. is formed as the result of biodegradation of either marine or terrestrial source materials (Pocock 1982). It can originate from plant tissue, spores, pollen, phytoplankton and other algae, and thalloid algal matter (Venkatachala 1981b, Pocock 1982).

A.O.M. will form in any environment which is sufficiently moist and contains sufficient oxygen, or oxygen-containing compounds such as sulphates, to permit bacterial activity, but insufficient free oxygen to permit oxidation to proceed to completion (Pocock 1982).

The most important organisms responsible for the degradation process are bacteria (oxic and/or anoxic), fungi and aquatic invertebrates. Aquatic invertebrates play a major role in the degradation of organic material by reason of their burrowing activities. Bioturbation prolongs the residence time of organic matter at the sediment-water interface, the main site of degradation, and stimulates bacterial metabolism by maintaining a constant supply of organic substrates and oxidants (Yingst & Rhoads 1980, Tyson 1987).

The occurrence of A.O.M. in quantity is indicative of preservation in oxygen-deficient conditions (Fisher 1980, Summerhayes 1981, Batten 1981, 1983), due to the limited duration of degradation by aerobic bacteria and the absence of a bottom fauna to bioturbate the sediment (Tyson 1987).

A.O.M. is normally scarce or absent in coast-near deposits, due to the effect of turbulence. Accumulation of A.O.M. need not, however, necessarily indicate deposition in relatively deep water; it is only necessary to be deep enough to form a stratified water column (Tyson 1987). It is frequently the dominant type of kerogen observed in organic-rich marine sediments, and tends to correlate with the T.O.C.-values (Fisher 1980, Summerhayes 1981, 1987, Summerhayes & Masran 1983, Batten 1983, Tyson 1984, 1987, 1989). It has been suggested that rising sea-level can result in reducing bottom-conditions, thus increasing the likelyhood of preserving A.O.M. (Hallam & Bradshaw 1979, Summerhayes & Masran 1983).

TABLE 2

Range - Chart, **THE FJERRITSLEV No. 2 - Borehole** (cutting samples)

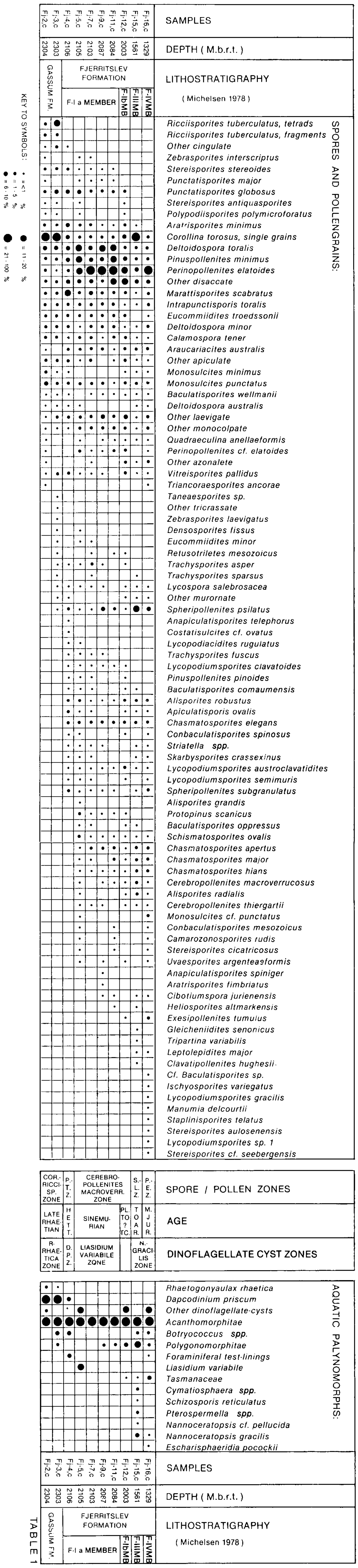

TABLE 1

Range - Chart, **THE FJERRITSLEV No. 2 - Borehole** (core samples)

Range - Chart, FREDERIKSHAVN No. 2 - Borehole (cutting samples)

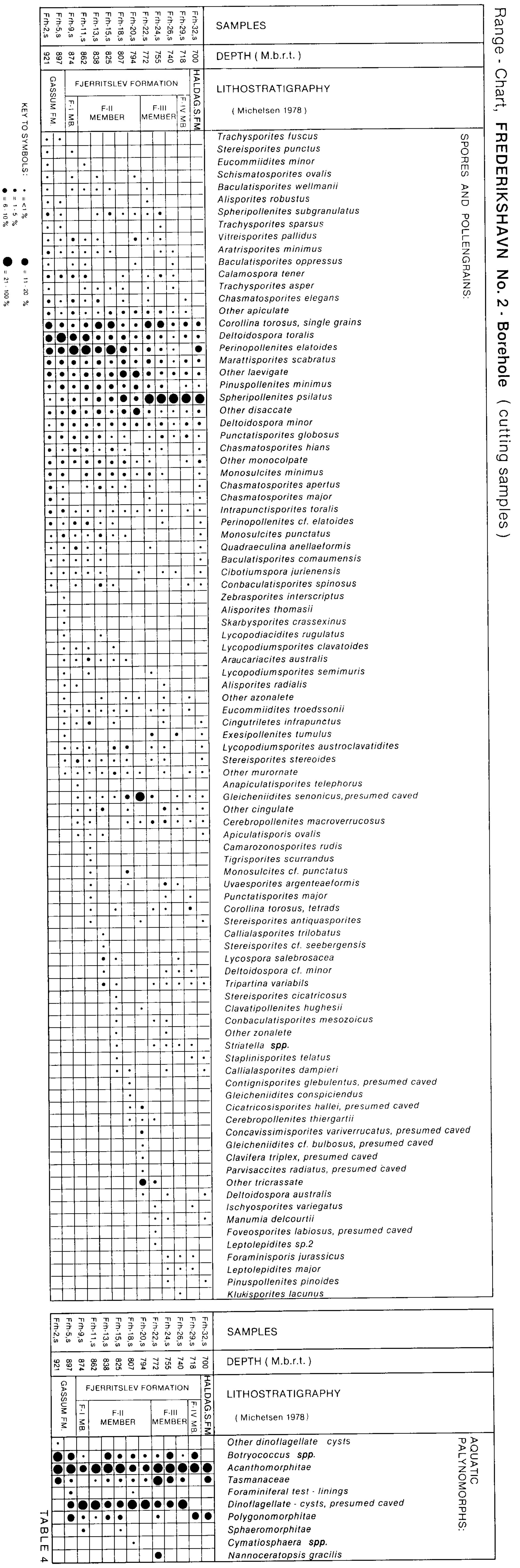

TABLE 4

Range - Chart, THE FREDERIKSHAVN No. 2 Borehole (core samples)

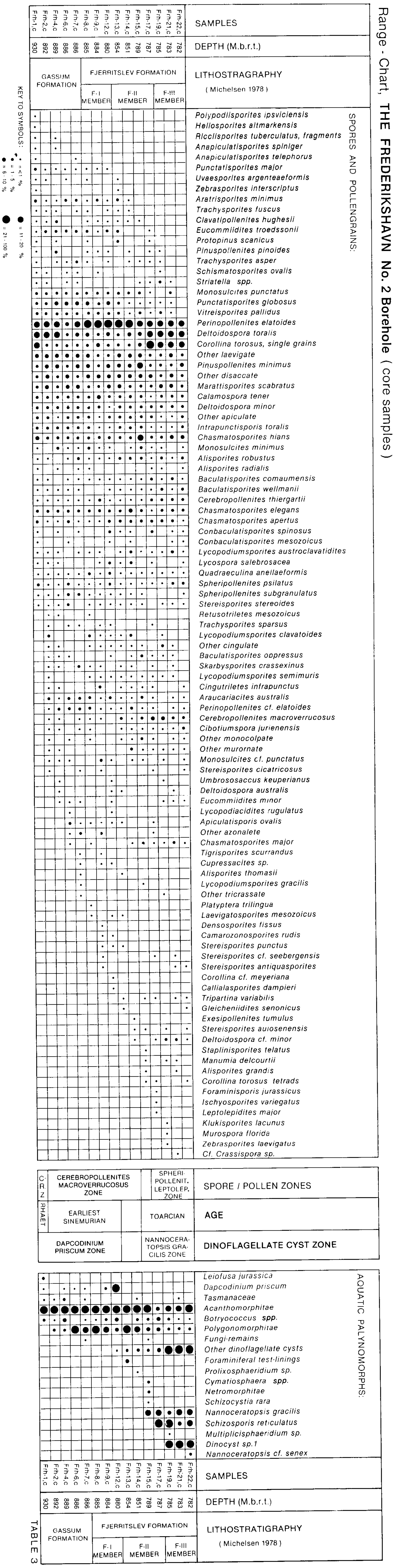

TABLE 3

Range - Chart, THE STENLILLE No. 2 - Borehole (cutting samples)

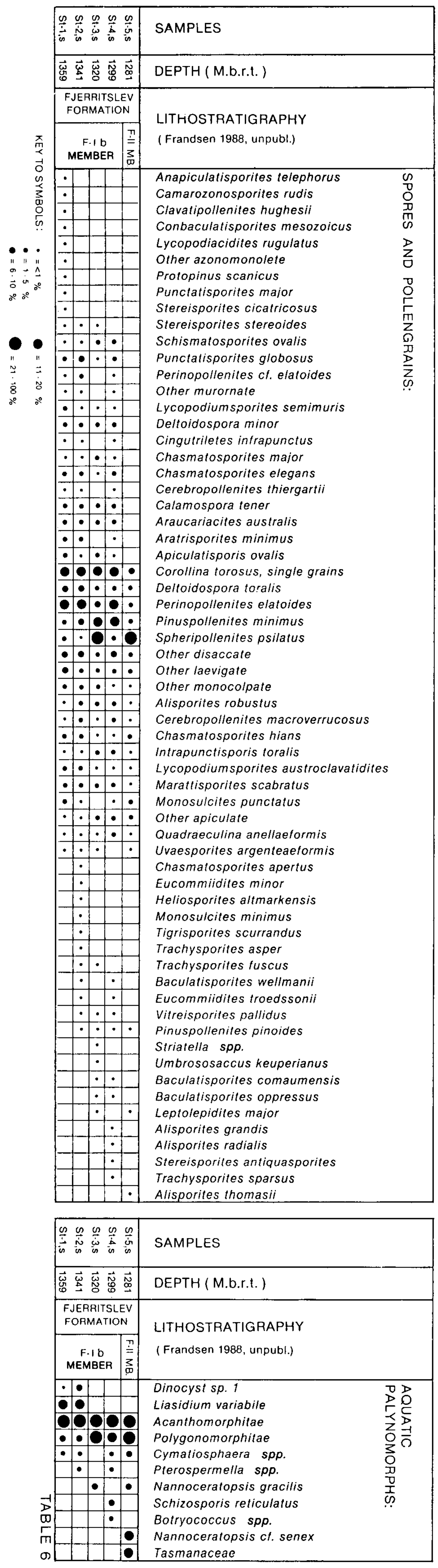

TABLE 6

Range - Chart, THE STENLILLE No. 2 - Borehole (core and sidewall core samples)

TABLE 5

This paper presents a combined spore/pollen- and dinoflagellate cyst zonation and dating of the Lower to lowermost Middle Jurassic Fjerritslev Formation in the Danish Subbasin.

The results of a detailed palynofacies-investigation generally support the previous interpretations of the depositional environment, and contribute new information. In addition, the hydrocarbon potential of the succession is assessed.

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