

Biostratigraphy and palaeoenvironmental analysis of a Lower to Middle Jurassic succession on Anholt, Denmark.

MARIT-SOLVEIG SEIDENKRANTZ

Department of Earth Sciences,
University of Aarhus,
8000 Århus C, Denmark.

EVA BUNDGAARD KOPPELHUS

Geological Survey of Denmark, Thoravej 8,
1400 Copenhagen NV, Denmark
New address: Geological Survey of
Greenland
Oster Voldegade 10
1350 Copenhagen K, Denmark

HELLE RAVN-SØRENSEN

Department of Earth Sciences,
University of Aarhus,
8000 Århus C, Denmark.

ABSTRACT

Palynomorph and foraminiferal assemblages have been studied from the Upper Pliensbachian to Bathonian of a borehole section on the island of Anholt in the Kattegat, situated near the eastern margin of the Norwegian-Danish Basin. Palynomorphs were recorded throughout the succession and have been used for both biostratigraphical and palaeoenvironmental assessments. Foraminifera were recorded from only the lower part of the succession, where they proved useful for interpreting palaeoenvironments. Four palynomorph and three foraminiferal zones have been established.

The interval encompasses a palaeoenvironmental transition from a marine, inner shelf setting to mainly terrestrial conditions. The Upper Pliensbachian-Toarcian boundary marks the beginning of a major regression, which continued through the Toarcian and Aalenian. Hence, it took place significantly earlier at Anholt than in the centre of the Norwegian-Danish Basin, where a lowering of sea level did not occur until the late Toarcian.

The Jurassic succession on Anholt spans the Fjerritslev and Haldager Sand formations; biostratigraphical data indicate that the Lower-Middle Jurassic boundary is here located within the uppermost part of the Fjerritslev Formation. The Fjerritslev and Haldager Sand formational transition was previously considered to coincide with the Lower-Middle Jurassic boundary. *J. Micropalaeontol.* **12** (2): 201-218, December 1993.

INTRODUCTION

Jurassic strata were studied from a boring on the small Danish island of Anholt in the Kattegat (Fig. 1). This site is located near the eastern margin of the Norwegian-Danish Basin, which extended across most of Denmark into the present North Sea during the Early and Mid Jurassic. This depocentre continued into the Danish-Polish Trough to the south-east, and was delimited by the Fennoscandian Shield to the north and north-east and by the Ringkøbing-Fyn High to the south (Sorgenfrei & Buch, 1964; Michelsen, 1978; Liboriussen *et al.*, 1987). Our study focuses on the biostratigraphy and palaeoecology of the uppermost Lower Jurassic to Middle Jurassic section.

Previous investigations have revealed a generally regressive phase in the uppermost Fjerritslev Formation. Deposition of open marine claystones occurred during the Pliensbachian and possibly early Toarcian, and of more restricted marine claystones during the late Toarcian (Michelsen, 1989a). Prograding delta or braided river sediments of the Haldager Sand Formation were deposited during the Mid Jurassic in the north-east of the basin (Michelsen, 1978, 1989a; Koch, 1983). The purpose of this study is to provide a biostratigraphic subdivision of the succession using microfossils, and to evaluate the palaeoenvironmental setting at the basin margin.

The succession from 196 m to 306 m depth in the Anholt core, consists of marine claystones with numerous very thin silty and sandy storm layers (a few mm or cm thick) referred to the Fjerritslev Formation, and from 104 m to 196 m depth it comprises alternating non-marine sand and silty clay layers with some thin brown coals referred to the Haldager Sand Formation (Fig. 2; Nielsen, 1992).

MATERIAL AND METHODS

The present study is based on both core material and ditch cuttings from a 306 m deep boring in the northwestern part of Anholt (Fig. 1). The boring penetrated about 104 m of Quaternary sediments before it reached deposits of Mid Jurassic age and continued into the upper part of the Lower Jurassic. The elevation of the drilling site is about 2 m above present-day sea level, and all of the depths noted are calculated below this altitude.

The material from c. 104 m to 230 m consists of both cuttings and core samples, while that from the lowest part of the boring (c. 230 m to 306 m) consists solely of core samples (Fig. 2). The lithological log (Fig. 2) was prepared by Ole Bjørnslev Nielsen (University of Aarhus). The total organic carbon content (TOC) of the sediments (Fig. 2) was analyzed at the University of Aarhus (AU), and at the Geological Survey of Denmark (DGU) O.B. Nielsen,

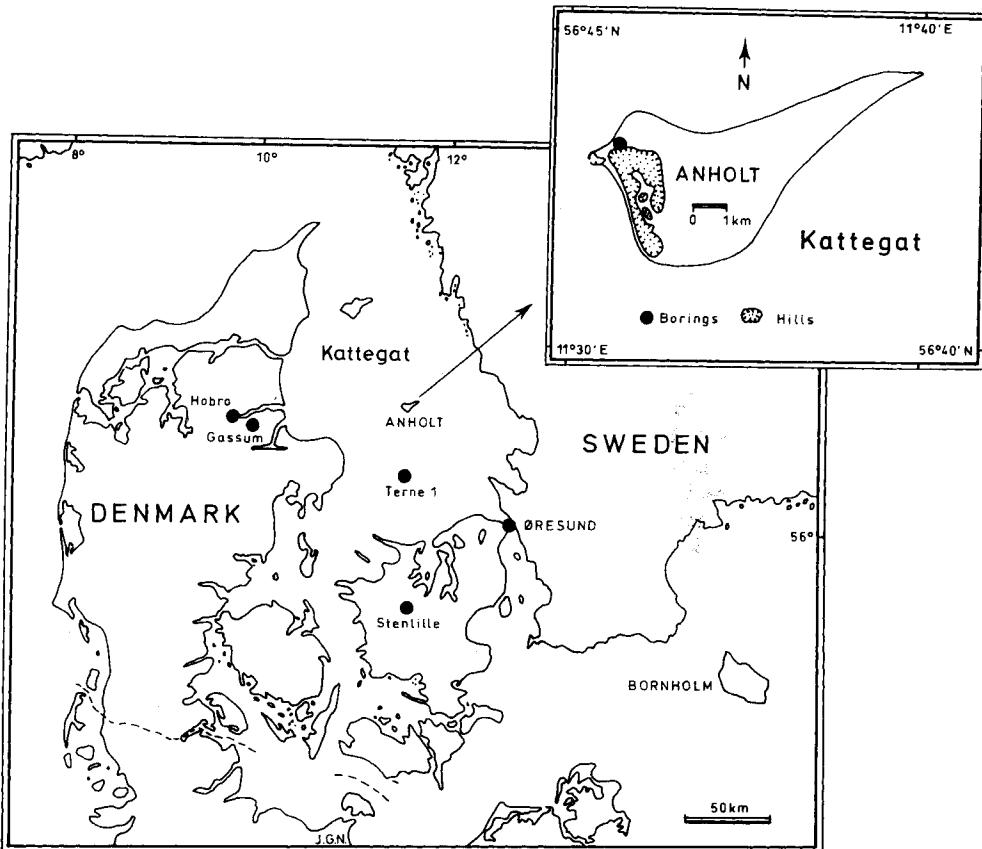


Fig. 1. Map showing the location of boreholes and outcrops mentioned in the text. The inset map of Anholt shows the location of the borehole investigated.

pers.comm 1992; B.J. Smidt, pers. comm. 1992. The spectral natural gamma ray log was measured by Korsbech & Gynther Nielsen (1990 a, b) (Fig. 2).

Eighty-three samples were analysed for their palynoflora, and 190 samples were examined for their foraminifera and megaspore content, although only 63 and 27 are illustrated on Figures 3 and 4 respectively. Representatives of other fossil groups were also encountered in the microfossil samples: juvenile bivalves and gastropods, ostracods, otoliths, scolecodonts, foraminiferal test linings, animal burrows, ammonites, and a part of a thoracic vertebra from a fish (Fig. 4). Except for megaspores, fossils were only found in 27 of these latter samples.

Palynomorphs. The samples from 306 m to 229 m depth were processed at DGU using the technique described by Poulsen *et al.* (1990). The samples from 229 m to 107 m depth were processed at the AU using the technique described by Dybkjaer (1988). Two techniques were used because the palynological analysis was divided between two separate laboratories. Where possible, 300 specimens were counted from each sample. A selection of the palynomorphs recorded is shown in Fig. 3. The palynomorph samples and slides from the lowermost interval 306 m to 229 m are stored at the DGU, whereas the samples from the upper interval 229 m to 107 m are housed

at AU.

Foraminifera and megaspores. The samples for the foraminiferal and megaspore analyses (100-500 g of sediment) were processed at AU using standard techniques for foraminifera (Meldgaard & Knudsen, 1979). All foraminifera and megaspores present in the 0.1-1.0 mm fraction were counted except for those samples which yielded more than 300 specimens. In these cases only 300 specimens were identified. Selected foraminiferal species are included in Fig. 4 as estimated numbers of specimens per 1000 g of sediment. The foraminifera are stored at AU and the megaspores at the DGU.

RESULTS

Palynological zonation

Palynomorphs were recorded from 306 m to 107 m (Fig. 3) and a total of 137 species recognised. Two assemblages and two acme zones are defined using the definitions of Hedberg (1976). The boundary

between two zones is placed in the interval between two sampling horizons (Fig. 3).

The *Nannoceratopsis senex* - *Nannoceratopsis* sp. 1 Assemblage Zone (PA), is the lowermost palynozone (Fig. 3). The assemblage is dominated by dinoflagellate cysts, especially *Nannoceratopsis senex* (Pl. 1, fig. 3) and *Nannoceratopsis* sp. 1 (Pl. 1, fig. 5). In the lowermost sample (306 m) one specimen of *Luehndea spinosa* (C. Heilmann-Clausen, pers. comm. 1991) (Pl. 1, fig. 1) and one specimen of *Mendicodinium reticulatum* (Pl. 1, fig. 2) were found. Laevigate trilete spores are common, together with abundant pollen of e.g. *Corollina torosus* (Pl. 3, fig. 2) and *Chasmatosporites hians*.

The overlying *Spheripollenites subgranulatus* Acme Zone (PB), is characterized by a diverse pollen and spore flora, a dominance of the pollen *Spheripollenites subgranulatus* (Pl. 2, fig. 10), and a high frequency of *S. psilatus* (Pl. 2, figs 12 & 13) and *Corollina torosus*. The lower boundary of this zone is defined at the increase in occurrence of *S. subgranulatus* (at 230 m). Also typical is the common occurrence of the spores *Ischyosporites variegatus* (Pl. 2, fig. 9), *Striatella jurassica*, *Taurocuporites verrucatus* (Pl. 2, fig. 2), *Foraminisporis jurasicus* (Pl. 2, fig. 4), *Polyzingulatisporites liasicus* (Pl. 2, fig. 3), and *Campenia gigas* (Pl. 3, fig. 8) and the occasional presence of the spores *Leptolepidites major* (Pl. 2, fig. 5), *L.*

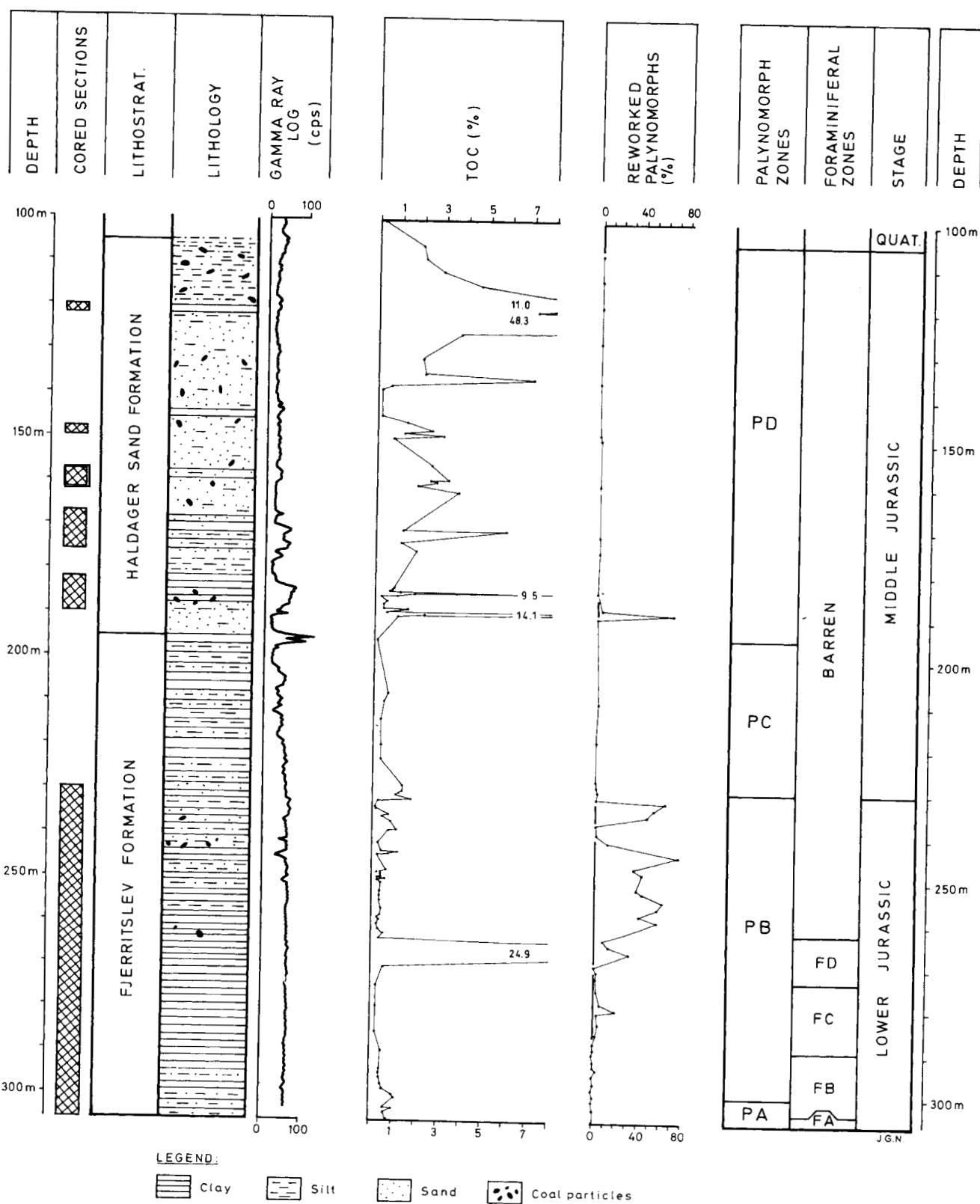


Fig. 2. Lithological log, total spectral natural gamma ray log (cps = counts per second), TOC values, and reworked palynomorphs from the lower 200 m of the Anholt boring (partly after Korsbech & Gynther Nielsen, 1990a,b; Nielsen, pers. comm. 1992; Schmidt, pers. comm. 1992).

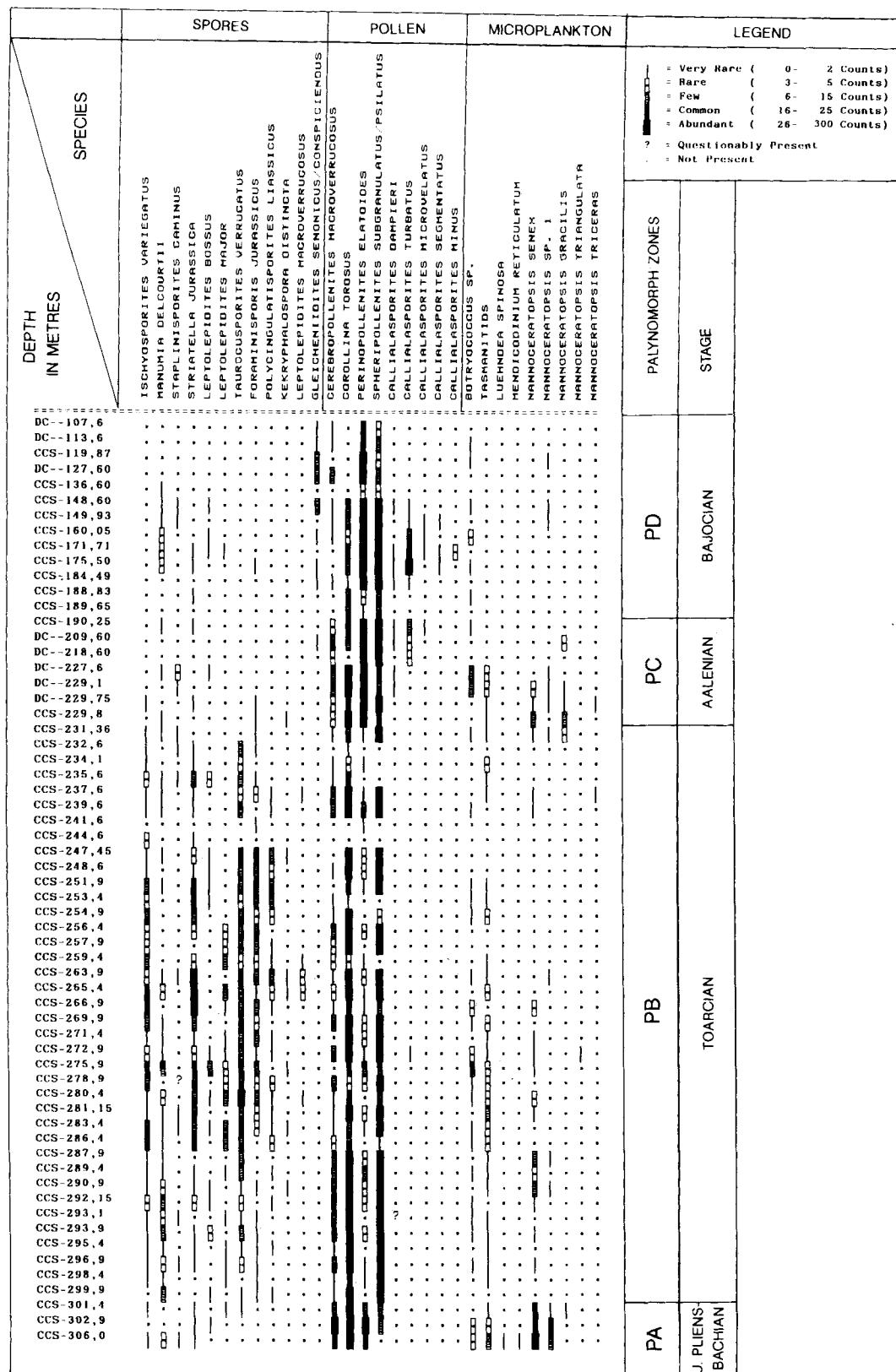


Fig. 3. The distribution of selected palynomorphs in the Jurassic part of the Anholt boring. (DC= ditch cutting sample, CCS= conventional core sample).

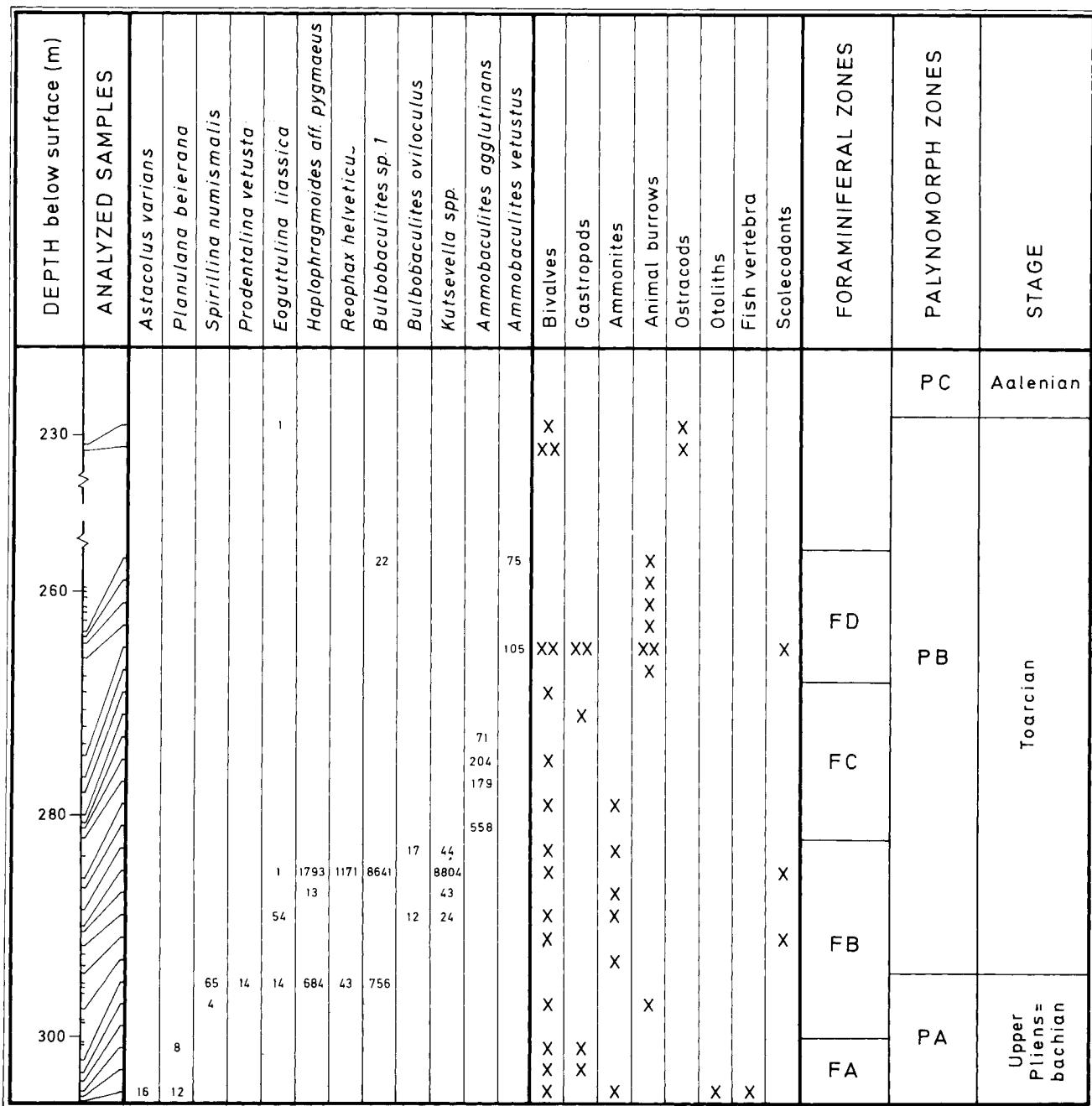


Fig. 4. The distribution of foraminifera and other fossil groups in the Jurassic interval of the Anholt boring. The selected foraminiferal species are given as an estimated number of specimens in 1000 g sediment. For other species groups: x= present, xx= frequent. All samples are from cores. Barren samples are marked with a short line in the column headed "Analysed samples".

macroverrucosus, *Manumia delcourtii* (Pl. 2, fig. 8), and *Kekryphalospora distincta* (Pl. 2, fig. 1). Unlike Zone PA, dinoflagellate cysts occur sporadically. The upper part of the zone is characterized by the presence of several megaspores, e.g. *Aneuletes patera*, *Erlansonisporites* sp., *Striatriletes excavatus*, *Hughesisporites variabilis*, *Paxillitriletes reticulatus*, and *Striatriletes sulcatus* spp. (Pl. 4, figs 1-6). The

upper part of the zone is characterized by reworked Carboniferous and Triassic spores.

The *Perinopollenites elatoides* Acme Zone (PC) comprises an assemblage of uniform composition. It is dominated by *Perinopollenites elatoides* (Pl. 3, fig. 1), "replacing" the dominance of *Spheripollenites subgranulatus* in the underlying Zone PB (Fig. 3). The lower boundary of the

CHRONO-STRATIGRAPHY (stage)		LITHO-STRATI -GRAPHY	OSTRACODS	BIOSTRATIGRAPHICAL ZONATIONS			PALYNOMORPHS	FORAMINIFERA
		Michelsen, 1975	Lund, 1977; Dybkiær, 1991	Berthelsen, 1974	Høelstad, 1985	Woolam & Riding, 1983	this study	this study
MIDDLE JURASSIC	Bathonian	Haldager			Zone III		?	
		Sand			D		PD	
	Bajocian	Formation				Superzone		Barren
	Aalenian		Poor records	Perinopollenites elatoides Zone	Zone II	Macrodinium semitubulatum Zone	PC	
LOWER JURASSIC	Toarcian	Fjerritslev	No records	Spheripollenites - Leptolepidites Zone	C ₄	Nannoceratopsis gracilis	PB	FD
		Formation						FC
	Upper Pliensbachian		O. adenticulata - N. (N.) simplex Zone	Cerebropollenites macroverucosus Zone	C ₃	Luehndea spinosa Zone	PA	FB
								FA

Fig. 5. Lower and Middle Jurassic chrono- and lithostratigraphy of the Norwegian-Danish Basin, selected palynomorph- and ostracod zonations from previous studies in the region, and the local palynomorph and foraminiferal zonation of the Anholt borehole succession.

zone is defined by the marked increase of this species (at 231.4 m). *Corollina torosus* occurs frequently, and a few specimens of *Callialasporites turbatus* (Pl. 3, fig. 7) and *Nannoceratopsis gracilis* (Pl. 1, fig. 4) are recorded together with reworked Carboniferous and Triassic palynomorphs.

The *Callialasporites turbatus* - *Callialasporites dampieri* Assemblage Zone (PD) is also dominated by *Perinopollenites elatoides*, but it is further characterized by the presence of numerous *Callialasporites turbatus* and *C. dampieri*. Other significant palynomorph species are *Callialasporites microvelatus* (Pl. 3, figs 4 & 6), *C. minus* (Pl. 3, fig. 5), *Densosporites scanicus* (Pl. 2, fig. 11), *Neoraistrickia gristhorpensis*, *Sestrosporites pseudoalveolatus*, *Gleicheniidites conspiendus*, and *G. senonicus*, and specimens of *Botryococcus* have been found sporadically throughout (Fig.

3). The assemblages from the lower half of the zone contain occasional acritarchs, which disappear in the upper part. The palynoflora of the uppermost few metres, which represents the youngest Jurassic sediments in the boring, is characterized by a low diversity and low density assemblage. Reworked Ordovician, Silurian, Devonian, and Triassic palynomorphs occur sporadically throughout.

Foraminiferal zonation

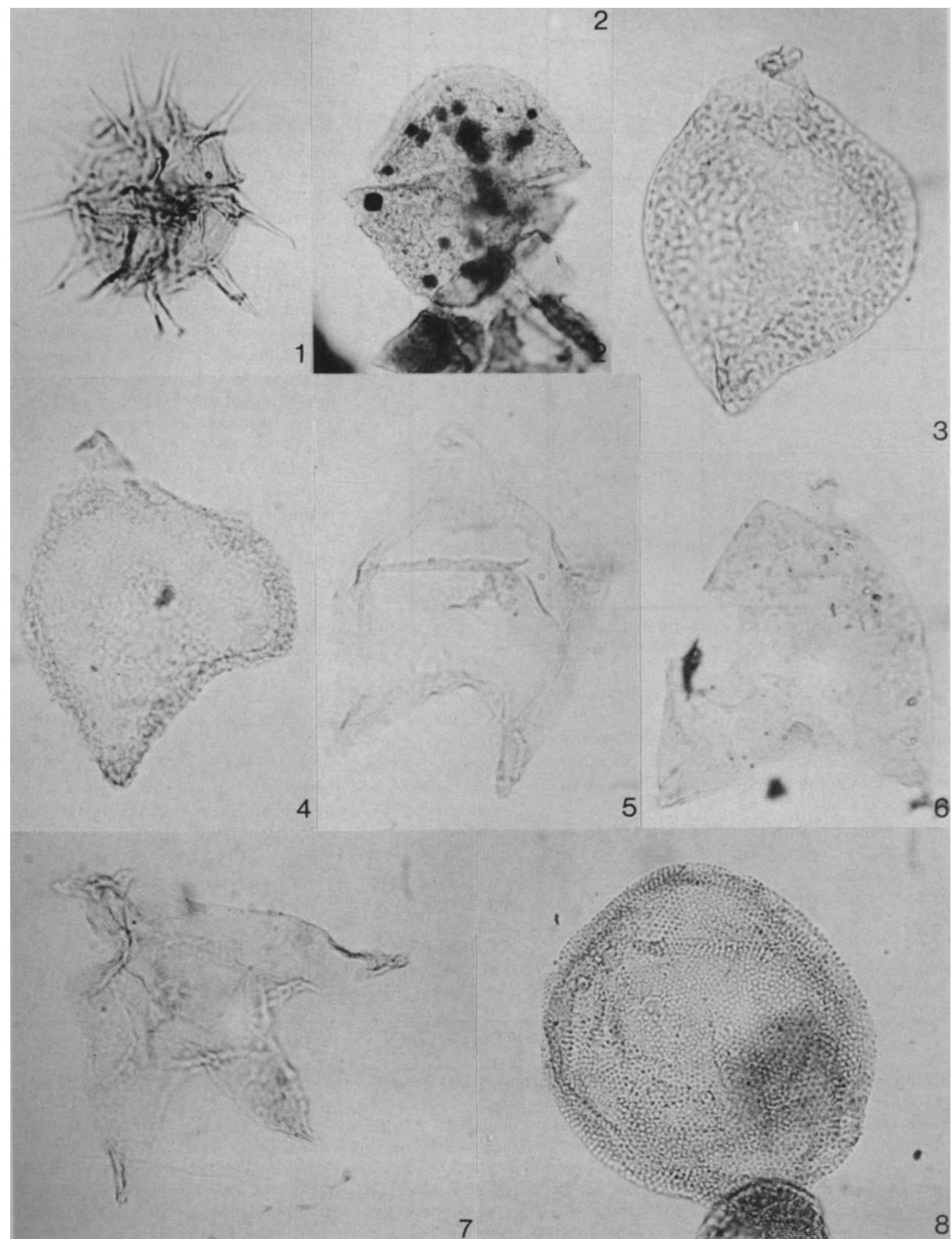
Fifteen foraminiferal species were identified in the samples examined (Fig. 4). These are concentrated in the interval 306 m to 231 m. This interval is divided into 4 foraminiferal assemblage zones (sensu Hedberg, 1976). Foraminifera were not recorded from 231-104 m. As for the palynological subdivision, zonal boundaries are placed between two

Explanation of Plate 1

Microplankton.

Light microscope photographs. Sample depth, slide number, England Finder Reference (EFR), and the Danish Geological Survey (DGU) catalogue number in brackets. Magnification x 750.

Fig. 1. *Luehndea spinosa* Morgenroth, 1970 (306 m; 1659, D4; EFR M323; DGU-1992-EBK-48). (Photograph kindly given to us by C. Heilmann-Clausen) **Fig. 2.** *Mendicodinium reticulatum* Morgenroth, 1970 (306 m; no. 6; EFR K394; DGU-1992-EBK-49) **Fig. 3.** *Nannoceratopsis senex* van Helden, 1977 (306 m; no. 6; EFR Z441; DGU-1992-EBK-50) **Fig. 4.** *Nannoceratopsis gracilis* Alberti emend. van Helden, 1977 (306 m; no. 6; EFR O244; DGU-1992-EBK-51) **Fig. 5.** *Nannoceratopsis ridingii* Poulsen, 1992 (306 m; no. 6; EFR N613; DGU-1992-EBK-52) **Fig. 6.** *Nannoceratopsis triangulata* Prauss, 1987 (296,9 m; no. 3; EFR F330; DGU-1992-EBK-53) **Fig. 7.** *Nannoceratopsis triceras* Drugg, 1978 (306 m; no. 6; EFR D583; DGU-1992-EBK-54) **Fig. 8.** *Crassosphaera* sp. (306 m; no. 6; EFR P304; DGU-1992-EBK-55)



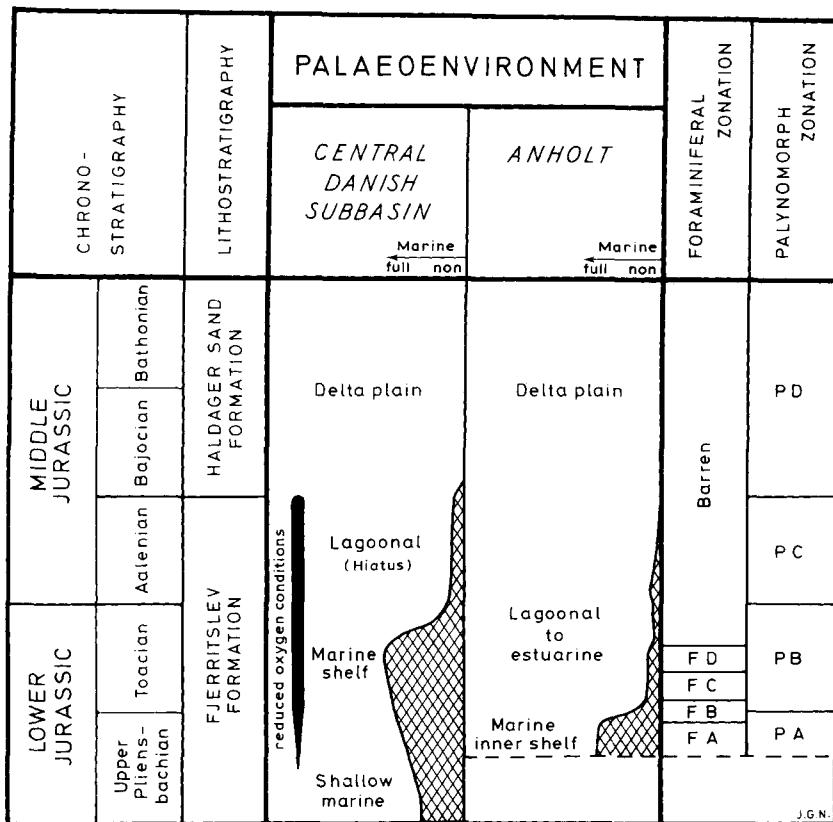


Fig. 6. Comparison of the interpreted palaeoenvironment with the palaeoenvironment of the central Danish Subbasin, as described by Michelsen (1978, 1989b).

sampling horizons (Fig. 4). The locations of the samples are shown on Fig. 4.

All foraminiferal tests are filled with pyrite and several calcareous specimens are preserved only as pyrite casts. It is possible, therefore, that some specimens may have been destroyed during diagenesis.

The lowermost *Astacolus varians* - *Planularia beierana* Assemblage Zone (FA) contains only the Nodosaridae *Astacolus varians* and *Planularia beierana* (Fig. 4). Other fossil groups recorded were gastropods, bivalves, and ammonites.

The overlying *Haplophragmoides* aff. *pygmaeus* - *Bulboculites* sp. 1 Assemblage Zone (FB) represents the most diverse Jurassic foraminiferal fauna in the boring and

includes 8 species (Fig. 4). The assemblage is characterized by the agglutinated species *Bulboculites oviculus*, *Haplophragmoides* aff. *pygmaeus*, *Reophax helveticus*, and *Kutsevella* spp. Several specimens of *Spirillina numismalis* are present in the lower part of the zone, while *Kutsevella* spp. have only been recorded in the upper part. Other fossil groups include ammonites, bivalves and scolecodonts. The lower boundary of this zone is defined by the disappearance of the Nodosaridae and the appearance of agglutinated species at about 304 m.

The *Ammobaculites agglutinans* Assemblage Zone (FC) contains almost solely the nominate arenaceous species in relatively high numbers (Fig. 4). Just a few specimens of *Ammobaculites* aff. *alaskaensis* and one specimen of a *Trochammina* were found in the uppermost two samples. The lower boundary of the zone is defined at the disappearance of the species characterizing Zone FB and the appearance of *Ammobaculites agglutinans* (at 287 m). Bivalves and gastropods are occasionally present in small numbers.

The *Ammobaculites vetustus* Assemblage Zone (FD) is characterized by the sporadic occurrence of *A. vetustus* and *Bulboculites* sp. 1. Animal burrows filled with pyrite are common. The lower boundary of this zone is defined at the disappearance of *Ammobaculites agglutinans* and the first occurrence of *A. vestustus*. The upper boundary is defined at the disappearance of foraminifera at 264 m.

The interval above Zone FD is barren of foraminifera except for a single specimen of *Eoguttulina liassica* at 231 m below core top.

CORRELATION AND STRATIGRAPHY

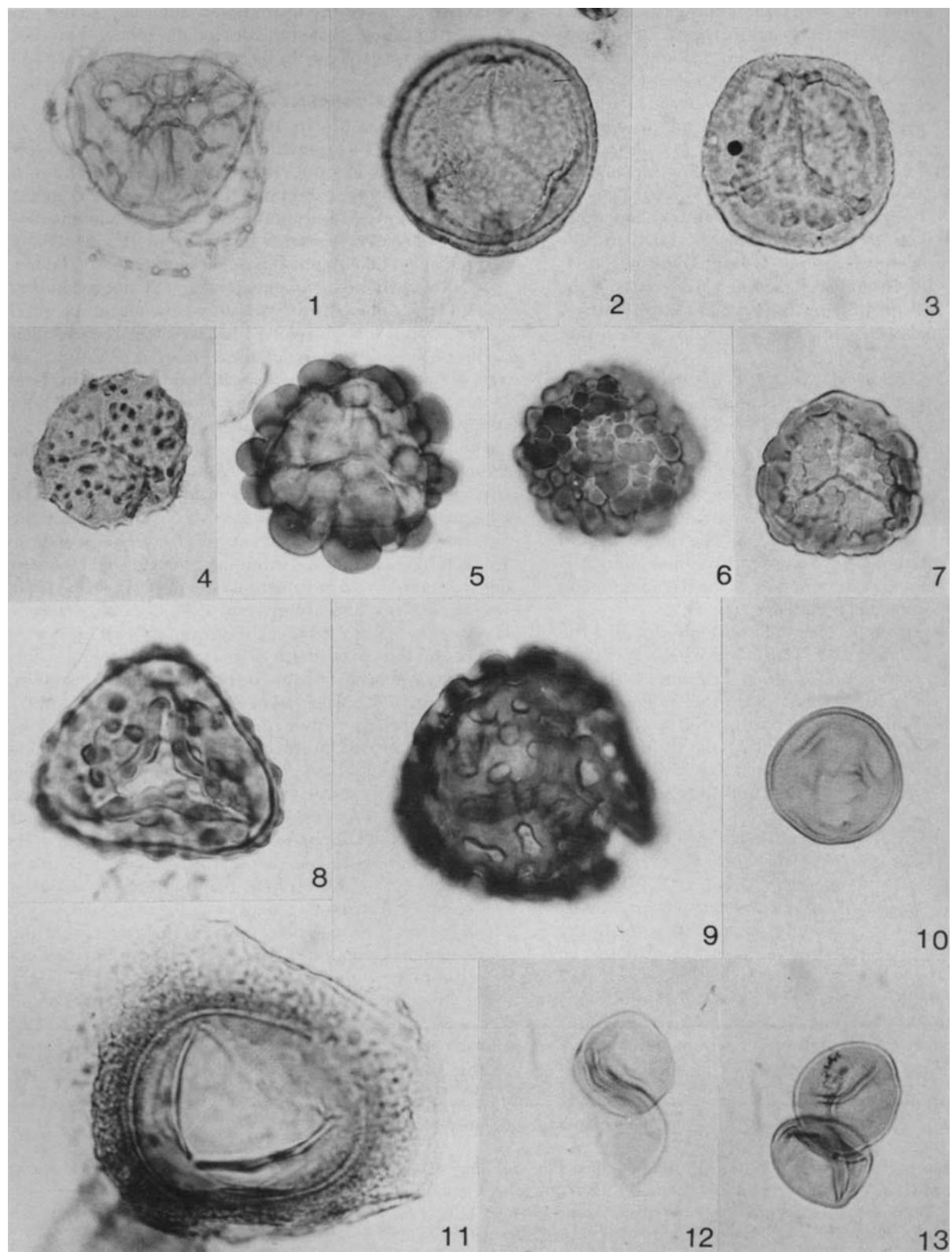
The chronostratigraphy of the Anholt section is based entirely on the palynomorphs because the foraminiferal

Explanation of Plate 2

Spores and pollen.

Light microscope photographs. Sample depth, slide number, England Finder Reference (EFR), and the DGU catalogue number in brackets. Magnification x 750.

Fig. 1. *Kekryphalospora distincta* Fenton & Riding, 1987 (283,4 m; no. 3; EFR Z284; DGU-1992-EBK-56) **Fig. 2.** *Taurocusporeites verrucatus* Schulz, 1967 (237,6 m; no. 3; EFR N514; DGU-1992-EBK-57) **Fig. 3.** *Polycingulatisporites liassicus* Schulz, 1967 (239,6 m; no. 3; EFR B360; DGU-1992-EBK-58) **Fig. 4.** *Foraminisporis jurassicus* Schulz, 1967 (237,6 m; no. 3; EFR Z513; DGU-1992-EBK-60) **Fig. 5.** *Leptolepidites major* Couper, 1958 (248,6 m; no. 2; EFR P602; DGU-1992-EBK-61) **Fig. 6.** *Leptolepidites bossus* (Couper) Schulz, 1967 (237,6 m; no. 3; EFR J361; DGU-1992-EBK-62) **Fig. 8.** *Manumia delcourtii* (Pocock) Dybkaer, 1991 (306 m; no. 6; EFR R600; DGU-1992-EBK-63) **Fig. 9.** *Ischyosporites variegatus* (Couper) Schulz, 1967 (265,4 m; no. 3; EFR D490; DGU-1992-EBK-64) **Fig. 10.** *Spheripollenites subgranulatus* Couper, 1958 (239,6 m; no. 3; EFR B360; DGU-1992-EBK-65) **Fig. 11.** *Densoisporites scanicus* Tralau, 1968 **Fig. 12, 13.** *Spheripollenites psilatus* Couper, 1958 (239,6 m; no. 3; EFR B360; DGU-1992-EBK-66)



assemblages cannot be correlated with faunas from other localities in this area. The stratigraphic correlation is based on comparisons with palynostratigraphic studies of deposits where the stratigraphical determinations are based on ammonites, ostracod, or dinoflagellate cyst assemblages.

On the basis of the abundant occurrence of the dinoflagellate genus *Nannoceratopsis* and the presence of rare specimens of *Luehndea spinosa* and *Mendicodinium reticulatum*, Zone PA is correlated with the English *Luehndea spinosa* Zone of Woollam and Riding (1983), with Zone C3 (in the Hobro-1 boring) of Bertelsen (1974), with the top of Zone C (in Gassum-1 boring) of Dybkjaer (1988) and the *Cerebropollenites macroverrucosus* Zone of Dybkjaer (1991) (Fig. 5), and with assemblages recorded from parts of the Bagå Formation on Bornholm (Fig. 1) (Koppelhus & Nielsen, in prep.). These correlations indicate a late Pliensbachian age.

The abundance of *Spheripollenites* and *Corollina*, and the presence of *Ischyosporites variegatus* and *Manumia delcourtii* indicate a Toarcian age for Zone PB. The palynomorph assemblage allows a correlation with Zone C4 (Hobro-1 boring) of Bertelsen (1974), with the *Spheripollenites-Leptolepidites* Zone in the Stenlille borings (Dybkjaer, 1991), and with Zone I in the Hasle Klinkerfabrik clay Pit, Bornholm, of Hoelstad (1985) (Figs 1, 5). The composition of the megaspore assemblages recorded from this interval is comparable to that known from part of the Bagå Formation on Bornholm (Koppelhus & Batten, 1992).

The dominance of *Perinopollenites elatoides* and the sporadic occurrence of *Callialasporites turbatus*, *Nannoceratopsis gracilis*, and *N. senex* in Zone PC (Fig. 4) suggest a correlation of that zone with the *Perinopollenites elatoides* Zone, which has been allocated a presumed Aalenian age (Dybkjaer, 1991), with Zone II of Hoelstad (1985), and with assemblages recorded in other parts of the Bagå Formation from Bornholm (Koppelhus & Nielsen, in prep.) (Figs 1, 5).

The dominance of *Perinopollenites elatoides* and the presence of *Callialasporites turbatus*, *C. dampieri*, *C. microvelatus*, *C. minus*, *Densosporites scanicus*, *Neoraistrickia gristhorpensis*, *Sestrosporites pseudoalveolatus*, *Gleicheniidites conspiciendus*, and *G. senonicus* indicate that Zone PD correlates with the Middle Jurassic Zone D in Hobro-1 of Bertelsen (1974) and with Zone III (Hasle Klinkerfabrik clay pit) of Hoelstad (1985) (Fig. 5). The lack of dinoflagellate cysts and other stratigraphically significant fossil groups hampers certain chronostratigraphical determination of this zone (and those beneath) zones. The spore/pollen

stratigraphy of the Middle Jurassic in the area is not well established. Since the examined assemblages lack any species indicating a Late Jurassic age, the zone is, however, suggested to encompass the Bajocian to Bathonian interval.

PALAEOENVIRONMENTAL CONDITIONS

The dominance of Nodosaridae (foraminifera) and dinoflagellate cysts together with a low TOC content (below 1 %) suggest a marine shelf environment with well-oxygenated bottom conditions for foraminiferal Zone FA (the lower part of palynomorph Zone PA) in the late Pliensbachian. The presence of ammonite fragments and fish remains also support this suggestion (Fig. 4). The low species diversity in the foraminiferal and dinoflagellate cyst assemblages does, however, suggest a more marginal marine aspect. It is, therefore, suggested that Zone FA was deposited under marine inner shelf conditions, an interpretation which accords with Jurassic foraminiferal facies trends documented by Gordon (1970), Nagy (1985a,b), Copestake (1989), and Nagy *et al.* (1990).

The low species diversity and the dominance of the arenaceous foraminiferal genera *Bulbobaculites*, *Haplophragmoides*, and *Kutsevella* in foraminiferal Zone FB (the upper part of palynomorph Zone PA and the lowermost part of PB), combined with the presence of 0.5 to 1 % TOC (Fig. 2), implies a well-oxygenated, shallow water environment with reduced salinities (Johnson, 1976; Løfaldli & Nagy, 1980; Nagy *et al.*, 1984; Copestake, 1989; J. Nagy, pers. comm. 1992). The foraminifera *Eoguttulina liassica* and the scolecodonts (Fig. 4) also indicate a shallow water environment, possibly of reduced salinity (Brouwer, 1969; Kozur, 1972; Copestake, 1989; Courtinat *et al.*, 1991). Furthermore, the upwards-decreasing frequency of dinoflagellate cysts and increasing amounts of spores and pollen (Fig. 3) suggest a gradual decrease in distance from the shoreline through the interval. Hence, this zone represents a regression from marine inner shelf environments of Zone FA to near lagoonal or deltaic conditions during the late Pliensbachian and early Toarcian. The presence of ammonite fragments and isolated specimens of the dinoflagellate cysts *Luehndea spinosa* and *Mendicodinium reticulatum*, indicate, however, that the marine influence on the environment of deposition had not ceased entirely.

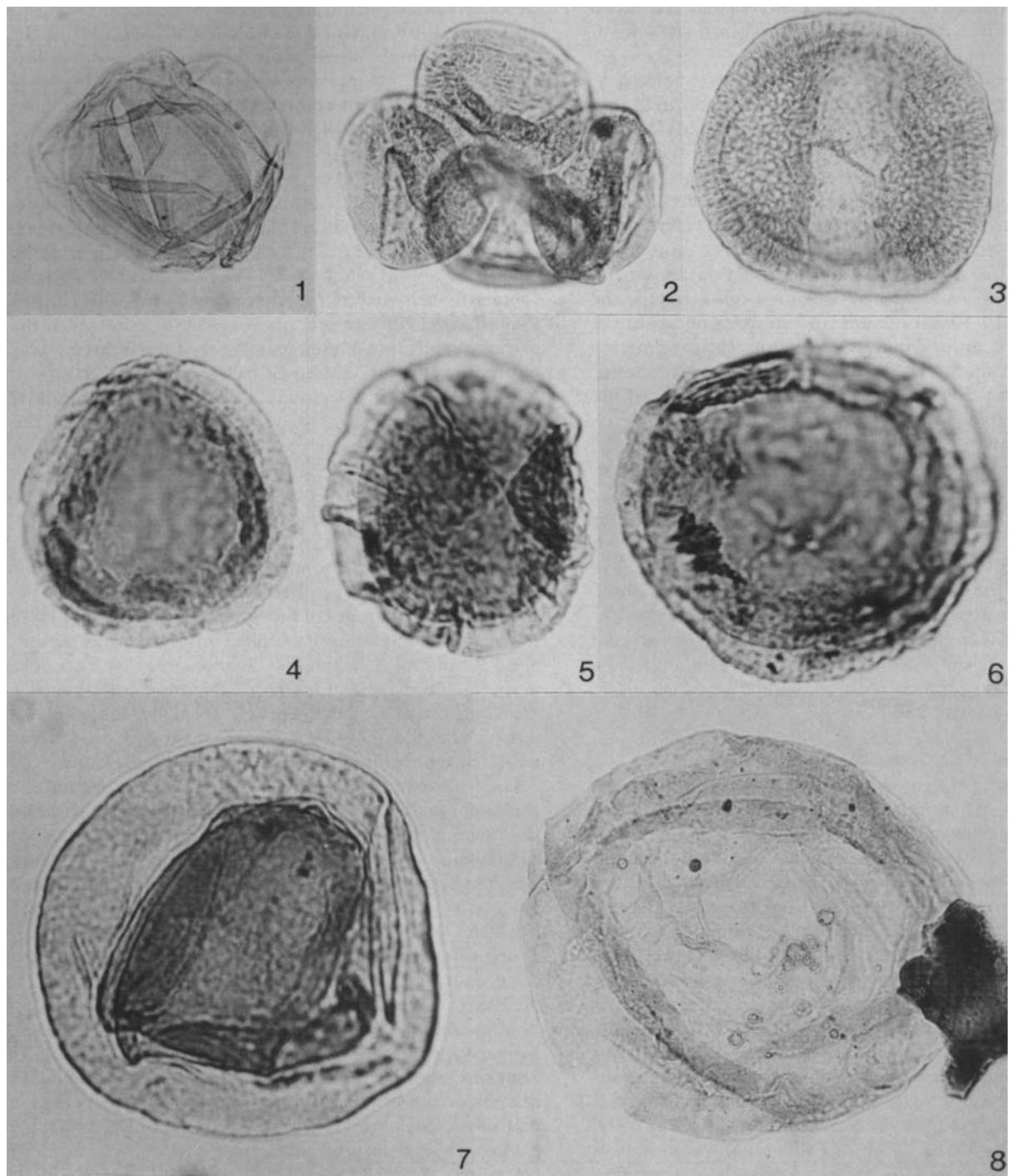
The low diversity faunas of agglutinated foraminifera in Zones FC and FD (middle part of palynomorph Zone PB), and the sparse dinoflagellate cysts, indicate a continuation of this inshore trend to a fully lagoonal to estuarine

Explanation of Plate 3

Pollen.

Light microscope photographs. Sample depth, slide number, England Finder Reference (EFR), and the DGU catalogue number in brackets. Magnification x 750, except for figs 4, 5, 6 and 7 which are x 1000, and fig. 8 which is x 560.

Fig. 1. *Perinopollenites elatoides* Couper, 1958 (229.8 m; no. 3; EFR E584; DGU-1992-EBK-67) **Fig. 2.** Tetrad of *Corollina torosus* Traverse, 1975 (306 m; no. 6; EFR W370; DGU-1992-EBK-68) **Fig. 3.** *Quadraeculina anellaformis* Malyavkina, 1949 (306 m; no. 6; EFR W370; DGU-1992-EBK-69) **Fig. 4.** *Callialasporites microvelatus* Schulz, 1966 (184 m; EFR S254) **Fig. 5.** *Callialasporites minus* (Tralau) Guy, 1971 (160 m; EFR L181) **Fig. 6.** *Callialasporites microvelatus* Schulz, 1966 (151 m; EFR H240) **Fig. 7.** *Callialasporites turbatus* (Balme) Srivastava, 1963 (175 m; EFR L184) **Fig. 8.** *Campenia gigas* Mädler, 1963 (306 m; no. 6; EFR Y420; DGU-1992-EBK-70)



environment. The general decrease in the foraminiferal and marine palynomorph content is a response to continued regression. An average of 0.5 % TOC indicates well-oxygenated conditions.

The presence of the planktonic algal genus *Botryococcus*, which is normally considered to be a freshwater indicator, but which may be tolerant of slightly brackish water (Traverse & Ginsburg, 1966; Tappan, 1980), and the lack of foraminifera (Figs 3, 4) in the upper part of the palynomorph Zone PB, indicate further regression leading to an inner deltaic or estuarine and non-marine conditions.

The presence of dinoflagellate cysts, especially *Nannoceratopsis gracilis*, and acritarchs in palynomorph Zone PC (Fig. 3) and the presence of a single foraminiferal specimen and a few specimens of ostracods and bivalves just below 230 m may indicate a brief brackish or marine influx into a mainly lagoonal or deltaic environment. *Nannoceratopsis gracilis* may have been tolerant of brackish, but not of freshwater environments (Hancock & Fisher, 1981; Riding, 1983). Although acritarchs are mainly marine they may occur relatively abundantly in shallow bays and lagoons in association with low diversity assemblages of dinoflagellate cysts, and sometimes even in freshwater environments (Erkmen & Sarjeant, 1980; Hancock & Fisher, 1981; Batten, 1982).

In the uppermost part of the Jurassic section at Anholt, Zone PD, the foraminifera and dinoflagellate cysts are lacking and acritarchs only present in the lower part and *Botryococcus* present throughout the zone. This indicate a delta plain environment with occasional brackish water influence in the lower part.

DISCUSSION AND CONCLUSIONS

The palynomorph assemblages from the Jurassic of the Anholt boring are similar to those described from other sites in the Norwegian-Danish Basin and on Bornholm (Fig. 5). This facilitates a close correlation of the Anholt section to other sections within the region. Similar assemblages have also been described, for example, from Germany (Schulz, 1967), Britain (Woollam & Riding, 1983; Riding *et al.* 1991), and East Greenland (Lund & Pedersen, 1985), suggesting a rather uniform flora over a large part of north-west Europe and Greenland during the Early - Mid Jurassic. This coincides with the relatively rather uniform climatic regime in the area during that time (Hallam, 1984).

Lower Jurassic foraminiferal faunas have been described from several localities within the Norwegian-Danish Basin and adjacent areas (Nørvang, 1957; Bang, 1968 a,b, 1971, 1973; Norling, 1970, 1972), but those from the Anholt

succession are markedly dissimilar. These previously described faunas are from older Lower Jurassic deposits and from fully marine assemblages, as opposed to the mainly marginal marine associations at Anholt. Shallow water foraminiferal faunas comparable to those encountered in the Toarcian of Anholt have, however, been encountered previously in the Lower Jurassic Wilhelmøya Formation of Spitsbergen (J. Nagy, pers. comm. 1992).

A comparison of the sedimentological and palaeontological data from the Anholt section with those from previous investigations in the region indicates a discrepancy in the timing of the onset of the regression during the latest Early Jurassic. The main phase of sea level lowering at Anholt occurred around the upper Pliensbachian/Toarcian boundary (Fig. 6), whereas in the centre of the Danish Subbasin most of the Toarcian was characterized by an increase in marine influence corresponding to the global sea level rise described by Hallam (1988). This sea level rise resulted in the establishment of stagnant bottom conditions in the centre of the basin (Michelsen, 1989b), and shallowing of the water apparently did not take place here until the late Toarcian, when a lagoonal environment was established (Michelsen, 1989a, b).

The regression at Anholt whichoccurredas early as the latest Pliensbachian, and thus slightly earlier than the shallowing in the centre of the basin, may have been caused by the prograding of the delta plain which characterized the basin during the Mid Jurassic (Michelsen, 1978). This delta progradation may have reached the more marginal Anholt area earlier than the basin centre. The Toarcian regression at Anholt may, however, also be the result of local tectonic uplift triggered within the Fennoscandian Border Zone.

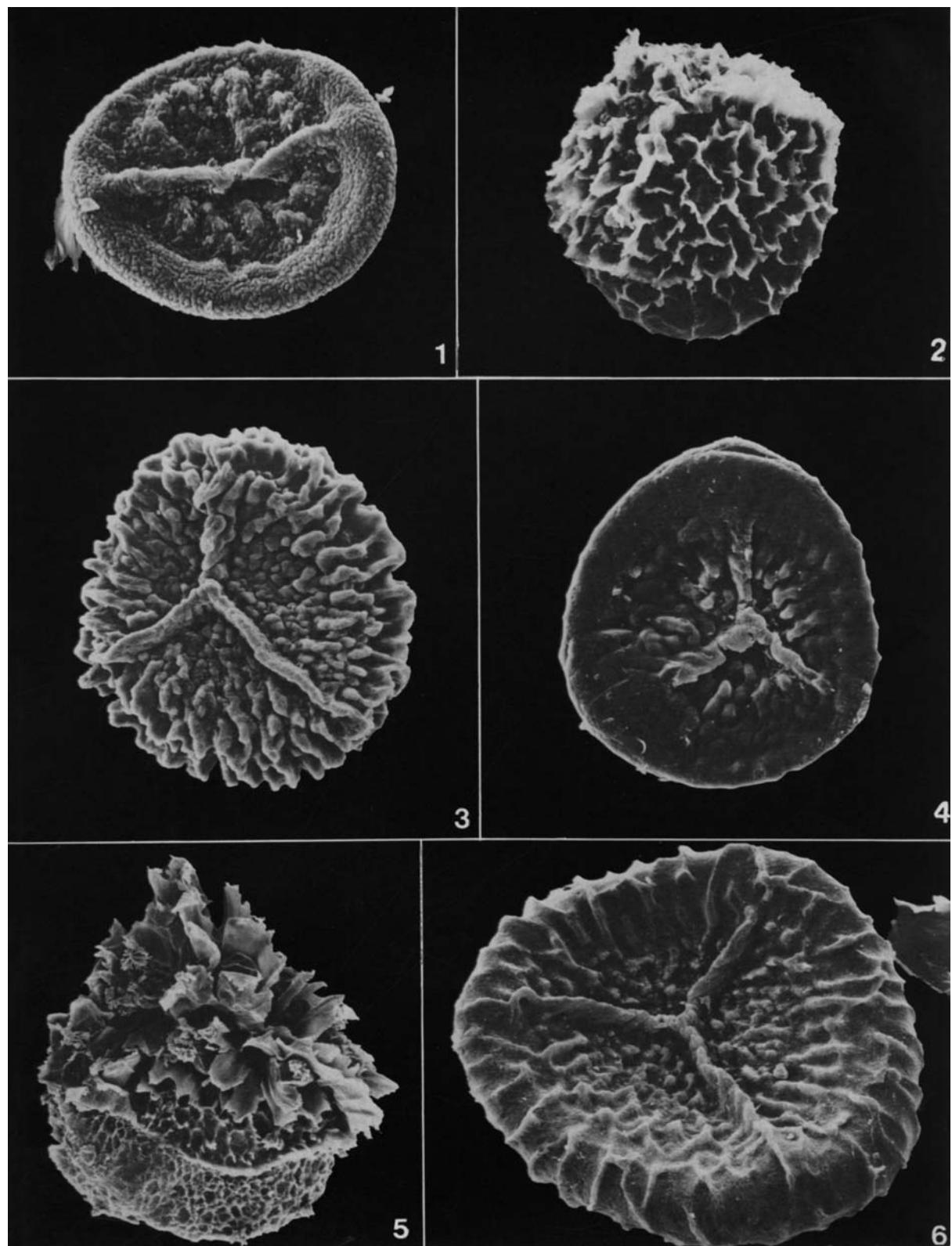
The boundary between the Fjerritslev Formation and the Haldager Sand Formation in the Norwegian-Danish Basin has previously been considered coincident with the Lower-Middle Jurassic boundary (Michelsen 1978, 1989a). More recently, though, Michelsen & Nielsen (1991) have indicated the possibility of an Aalenian age for the upper part of the Fjerritslev Formation in the Terne-1 boring (Fig.1). But they chose to place the Lower/Middle Jurassic boundary between the Fjerritslev and Haldager Sand formations on the basis of lithostratigraphy. The biostratigraphical data from the Anholt boring, however, presents new information concerning the age of this formational boundary. The boundary between the Fjerritslev and Haldager Sand formations corresponds to the boundary between palynomorph Zones PC and PD in the boring (Fig. 5) (see Nielsen, 1992). Since the palynomorph assemblage of Zone

Explanation of Plate 4

Megaspores.

Scanning electron micrographs. Sample depth, stub number, and catalogue the DGU number in brackets. Magnification x 150.

Fig. 1. *Aneuletes patera* Harris, 1961 (240.49-52 m; stub 1.1; DGU-1992-EBK-71) **Fig. 2.** *Erlansonisporites* sp. (240.49-52 m; stub 1.2; DGU-1992-EBK-72) **Fig. 3.** *Striatriletes excavatus* (Marcinkiewicz) Sweet, 1979 (240.49-52 m; stub 1.3; DGU-1992-EBK-73) **Fig. 4.** *Hughesisporites variabilis* Dettmann, 1961 (240.49-52 m; stub 1.4; DGU-1992-EBK-74) **Fig. 5.** *Paxillitriletes reticulatus* (Mädler) Hall & Nicolson, 1973 (236.69-72 m; stub 1.6; DGU-1992-EBK-75) **Fig. 6.** *Striatriletes sulcatus* (Dijkstra) Potonié, 1956 (240.12-15 m; stub 1.7; DGU-1992-EBK-76)



PC indicates an Aalenian age, the uppermost part of the Fjerritslev Formation at Anholt can be dated as Mid Jurassic.

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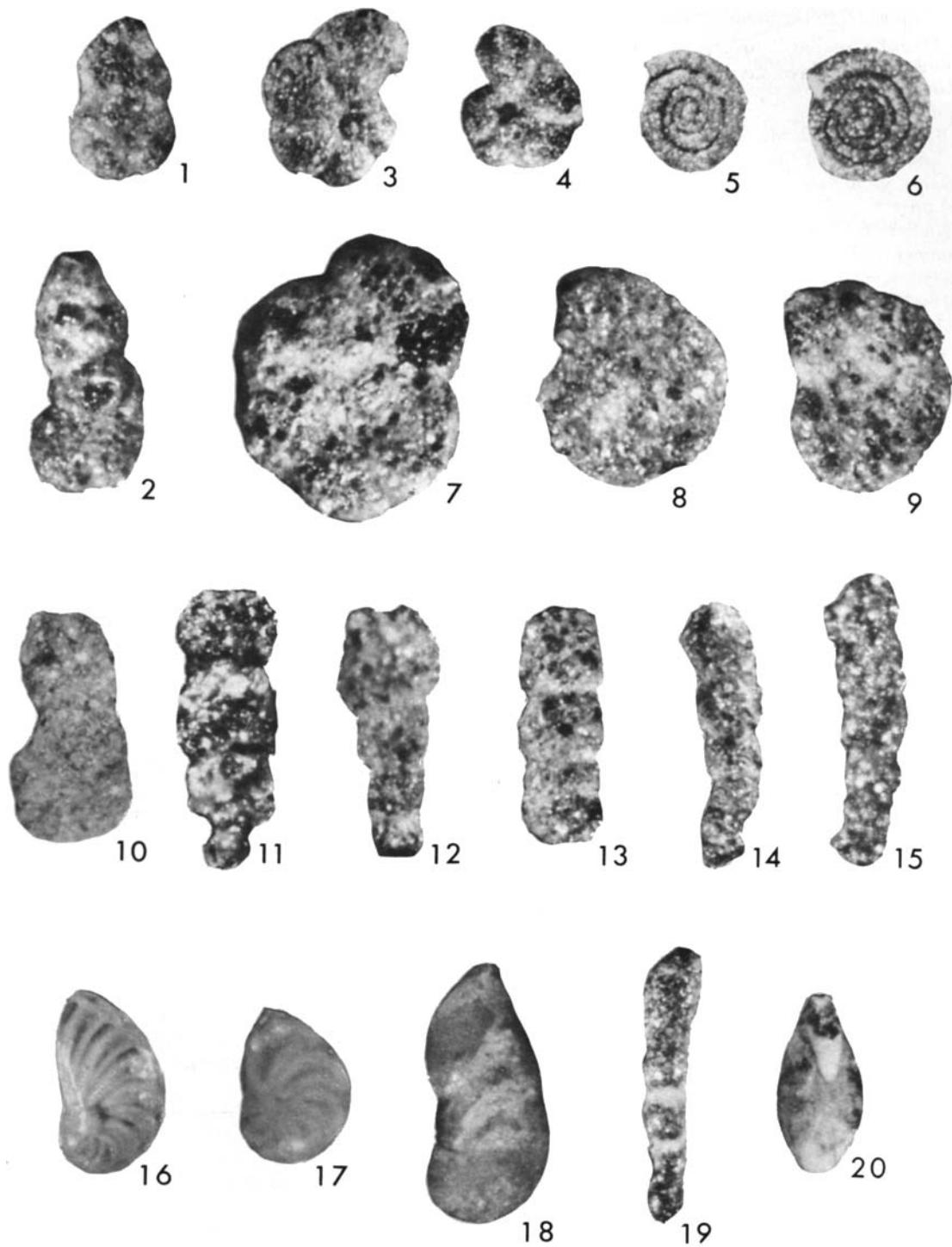
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Explanation of Plate 5

Foraminifera.

Light microscope photographs. Sample depth in brackets. Magnification x 90. **Figs 1, 2.** *Ammobaculites agglutinans* (d'Orbigny, 1846 = *Spirolina agglutinans*) (286.63-68 m). **Figs 3, 4.** *Haplophragmoides aff. pygmaeus* (Haeusler, 1881 = *Rotalia pygmaea*) (302.20-25 m). **Figs 5, 6.** *Spirillina numismalis* Terquem & Berthelin, 1875 (302.20-25 m). **Fig. 7.** *Kutsevella* sp. 1, (290.08-12 m). **Figs 8, 9.** *Kutsevella* sp. 2 (290.08-12 m). **Fig. 10.** *Ammobaculites aff. alaskensis* Tappan, 1955 (281.20-25 m). **Fig. 11.** *Ammobaculites vetustus* (Terquem & Berthelin, 1875 = *Haplophragmium vetustum*) (274.83-90 m). **Fig. 12.** *Reophax helvetica* (Haeusler, 1881 = *Dentalina helvetica*) (302.20-25 m). **Fig. 13.** *Bulbobaculites ovilculus* (Nagy, 1991 = *Bulbobaculites ovilculus*) (288.59-64 m). **Figs 14, 15.** *Bulbobaculites* sp. 1 (302.20-25 m). **Figs 16, 17.** *Planularia beierana* (Gümbel, 1862 = *Marginulina beierana*) (305.95-306.00 m). **Fig. 18.** *Astacolus varians* (Bornemann, 1854 = *Cristellaria varians*) (305.95-306.00 m). **Fig. 19.** *Prodentalina vetusta* (d'Orbigny, 1849 = *Dentalina vetusta*) (302.20-25 m). **Fig. 20.** *Eoguttulina liassica* (Strickland, 1846 = *Polymorphina liassica*) (291.80-84 m).



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- Spores and pollen
Acanthotrites varius Nilsson, 1958

Table 1.

Palynomorph and foraminiferal taxa recorded from the Jurassic section penetrated by the Anholt borehole, with author attributions and dates.

<i>Alisporites microsaccus</i> (Couper) Pocock, 1962	<i>L. major</i> Couper, 1958
<i>A. radialis</i> (Leschik) Lund 1977	<i>L. sp.</i>
<i>A. robustus</i> Nilsson, 1958	<i>Limbosporites lundbladii</i> Nilsson, 1958
<i>A. thomasii</i> (Couper) Nilsson, 1958	<i>Lycopodiacytidites rugulatus</i> (Couper) Schulz, 1967
<i>Anapiculatisporites spiniger</i> (Leschik) Schulz, 1962	<i>Lygodiosporites perverrucatus</i> Couper, 1958
<i>A. sp.</i>	<i>Manumia delcourtii</i> (Pocock), Dybkjaer, 1991
<i>Aratrisporites minimus</i> Schulz, 1967	<i>Marattisporites scabratus</i> Couper, 1958
<i>A. sp.</i>	<i>Matonisporites crassiangularis</i> (Balme) Levet-Carette, 1964
<i>Araucariacites australis</i> Cookson, 1947	"Monosaccates": <i>Paleopicea glaesaria</i> Bolkhovitina, 1956
<i>Baculatisporites comaumensis</i> (Cookson) Potonié, 1956	<i>Monosulcites minus</i> Cookson, 1947
<i>B. sp.</i>	<i>M. punctatus</i> Orlowska-Zwolinska, 1966
Bisaccates indeterminate	<i>Neoraistrickia</i> sp.
<i>Calamospora tener</i> Leschik, 1955 emend. M ädler, 1964	<i>Parvisaccites</i> sp.
<i>Callialasporites dampieri</i> (Balme) Dev, 1961	<i>Peltandripites</i> sp. cf. <i>P. tener</i> Norris, 1969
<i>C. microvelutatus</i> Schulz, 1966	<i>Perinopollenites elatooides</i> Couper, 1958
<i>C. minus</i> (Tralau) Guy, 1971	<i>P. sp.</i> cf. <i>P. elatooides</i> Couper, 1958
<i>C. segmentatus</i> (Balme) Srivastava, 1963	<i>Perotriletes</i> sp.
<i>C. turbatus</i> (Balme) Schulz, 1967	<i>Pinuspollenites minimus</i> (Couper) Kemp, 1970
<i>Campenia gigas</i> Mädler, 1963	<i>Podocarpidites</i> spp.
<i>Camarozonosporites rufus</i> (Leschik) Klaus, 1963	<i>Polycingulatisporites circulus</i> Simoncsics & Kedves, 1961
<i>Cerebropollenites macroverrucosus</i> (Thiergart) Schulz, 1967	<i>P. liassicus</i> Schulz, 1967
<i>C. thiergarti</i> Schulz, 1967	<i>Quadraeculina anelaeformis</i> Malyavkina, 1949
<i>Chasmatosporites apertus</i> Nilsson, 1958	<i>Retitriletes austroclavatidites</i> (Cookson) Potonié, 1956
<i>C. elegans</i> Nilsson, 1958	<i>R. clavatoides</i> (Couper) Döring Krutzsch, Mai & Schulz, 1963
<i>C. hians</i> Nilsson, 1958	<i>R. semimuris</i> (Danzé-Corsin et Laveine) McKellar, 1974
<i>C. major</i> Nilsson, 1958	<i>R. sp.</i>
<i>Chomotriletes minor</i> (Kedves) Pocock, 1970	<i>Retusotriletes mesozoicus</i> Klaus, 1962
<i>Cibotiumspora juriensis</i> Filatoff, 1975	<i>Rogalskaisporites cicatricosus</i> (Rogalska) Danzé-Corsin & Laveine, 1963
<i>Clavatipollenites hughesii</i> Couper, 1958 sensu Schulz, 1967	<i>Schismatosporites ovalis</i> Nilsson, 1958
<i>Conbaculatisporites mesozoicus</i> Klaus, 1960	<i>Sculptisporis aulosenensis</i> (Schulz) Koppelhus, 1991
<i>C. spinosus</i> (Mädler) Lund, 1977	<i>Semiretisporites</i> sp.
<i>Converrucosisporites</i> sp.	<i>Sestrosporites pseudoalveolatus</i> (Couper) Dettmann, 1963
<i>Corollina meyeriana</i> (Klaus) Venkatachala & Góczán, 1964	<i>Sphaeropollenites psilatus</i> Couper, 1958
<i>C. torosus</i> Traverse, 1975	<i>S. subgranulatus</i> Couper, 1958
<i>Cyathidites</i> sp.	<i>Staplinisporites caminus</i> (Balme) Pocock, 1970
<i>Cypressacites</i> sp.	<i>Stereisporites antiquasporites</i> (Wilson & Webster) Dettmann 1963
<i>Deltoidospora minor</i> (Couper) Pocock, 1970	<i>S. stereoides</i> (Potonié & Venitz) Pflug in Thomson & Pflug, 1953
<i>D. toralis</i> (Leschik) Lund, 1977	<i>Striatella jurassica</i> Mädler, 1964
<i>D. sp. cf. D. minor</i> (Couper) Pocock, 1970	<i>S. parva</i> (Li & Shang) Filatoff & Price, 1988
<i>Densoisporites scanicus</i> Tralau, 1968	<i>S. seebergensis</i> Mädler, 1964
<i>D. velatus</i> Weyland & Krieger, 1953	<i>Taurocospores verrucatus</i> Schulz, 1967
<i>Dicyclosporis radiatus</i> (Schulz) Jansonius & Hills, 1990	<i>Todisporites major</i> Couper, 1958
<i>Eucommiidites minor</i> Groot & Penny, 1960	<i>T. minor</i> Couper, 1958
<i>E. troedssonii</i> Erdtmann, 1948	<i>Trachysporites asper</i> Nilsson, 1958
<i>Exesipollenites tumulus</i> Balme, 1957	<i>T. sp.</i>
<i>Foraminisporites jurassicus</i> Schulz, 1967	<i>Tripartina variabilis</i> Malyavkina, 1949
<i>Gleicheniidites conspiendus</i> (Bolkhovitina) Krutzsch, 1959	<i>Uvaeisporites argenteaformis</i> (Bolkhovitina) Schulz, 1967
<i>G. senonicus</i> Ross, 1949	<i>U. sp. cf. U. microverrucatus</i> Schulz, 1967
<i>Iraqispora labrata</i> Singh, 1964	<i>Verrucosisporites obscurilaesuratus</i> Pocock, 1962
<i>Ischyosporites variegatus</i> (Couper) Schulz, 1967	<i>Vitreisporites pallidus</i> (Reissinger) Nilsson, 1958
<i>Kekryphalospora distincta</i> Fenton & Riding, 1987	
<i>Klukisporites lacunus</i> Filatoff, 1975	
<i>Kraeuselisporites reissingeri</i> (Harris) Morbey, 1975	
<i>Laevigatosporites dubius</i> Nilsson, 1958	
<i>L. mesozoicus</i> Schulz, 1967	
<i>Leptolepidites bossus</i> (Couper) Schulz, 1967	
<i>L. macroverrucatus</i> Schulz, 1967	
Megasporites	
<i>Aneuletes patera</i> Harris, 1961	
<i>Cabochonicus carbunculus</i> (Dijkstra) Batten & Ferguson, 1987	
<i>Echitriletes hispidus</i> Marcinkiewicz, 1960	

Erlansonisporites sp.
Horstisporites sp.
Hughesiporites variabilis Dettmann, 1961
Paxillitriletes sp.
Striatriletes excavatus (Marcinkiewicz, 1962) Sweet, 1979
S. sulcatus (Dijkstra) Potonié, 1956

Microplankton

Acanthomorphitae spp.
Botryococcus spp.
Crassosphaera hexagonalis Wall, 1965
Cymatiosphaera pachytheca Eisenack, 1957
C. spp.
Lecaniella foveata Singh, 1971
Leiosphaeridia spp. (reworked).
Luehndea spinosa Morgenroth, 1970
Mendicodinium reticulatum Morgenroth, 1970
Micrhystridium sp.
Nannoceratopsis gracilis Alberti emend. van Helden, 1977
N. senex van Helden, 1977
N. sp. 1 (N. *ridingii* Poulsen, in press)
N. triangulata Prauss, 1987
N. triceras Drugg, 1978
Ovoidites spp.
Pterospermella sp.
Tasmanites sp.

Tetraporina compressa Kondratev, 1963
Veryhachium sp.

Foraminifera

Ammobaculites agglutinans (d'Orbigny, 1846 = *Spirolina agglutinans*)
Ammobaculites aff. alaskensis Tappan, 1955
Ammobaculites vetustus (Terquem & Berthelin, 1875 = *Haplophragmium vetustum*)
Astacolus varians (Bornemann, 1854 = *Cristellaria varians*)
Bulbobaculites oviloculus (Nagy, 1991 = *Bulbobaculites oviloculus*)
Bulbobaculites sp. 1
Eoguttulina liassica (Strickland, 1846 = *Polymorphina liassica*)
Haplophragmoides aff. pygmaeus (Haeusler, 1881 = *Rotalia pygmaea*)
Kutsevella sp. 1
Kutsevella sp. 2
Planularia beierana (Gümbel, 1862 = *Marginulina beierana*)
Prudentalina vetusta (d'Orbigny, 1849 = *Dentalina vetusta*)
Reophax helvetica (Haeusler, 1881 = *Dentalina helvetica*)
Spirillina numismalis Terquem & Berthelin, 1875
Trochammina sp.