

Biostratigraphy of some Callovian and Oxfordian cores off Vega, Helgeland, Norway

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Four shallow cores drilled on an E–W trending seismic line on the Trøndelag Platform 35–40 km to the west of Vega, Helgeland, Norway are described and their dinoflagellate cysts, ammonites and bivalves studied. Two new dinoflagellate cyst species, *Crussolia perireticulata* and *Glomodinium cerebraloides*, are formally described, and one new combination, *Glomodinium granulatum* (Pocock) n. comb., is proposed. Ammonites and bivalves of the genera *Pseudocadoceras*, *Longaeviceras*, *Amoeboceras*, *Praebuchia* and *Buchia* are systematically described and figured. The recorded fossils are used for a biostratigraphical interpretation. The cores represent parts of the Callovian and a nearly complete Oxfordian section. Lowermost Kimmeridgian strata are also represented.

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During the summer of 1982 the drilling ship 'Pholas' drilled 14 shallow coreholes between 65° and 66°N on offshore Norway. Most of the stations are located along two E–W running seismic lines (the strata dipping gently to the west) and the cores examined here are all from the northern of these lines 35–40 kilometres to the west of the island of Vega (Fig. 1). The cores are treated here in order of decreasing age (Fig. 2). Between the top of core 4B and the base of core 3 there is an undrilled interval of about 38 m, between 3 and 3B an interval of 32 m and between 3B and 5 the interval is 48 m (Tom Bugge, pers. comm. 1987).

Bugge, Knarud & Mørk (1984) published general geological information from IKU's mapping programme in the area and Århus, Verdenius & Birkelund (1986) gave details from a Lower Cretaceous core from the southern seismic line.

Lithology, visual kerogen and organic geochemical data

Core 4B

This core consists of 5 up to 25 cm long hammer samples from the interval 2.0–5.91 m below the sea floor. The samples from the bottom of the hole to the boundary with the Quaternary overburden at 3.8 m consist of bioturbated very

micaceous grey siltstone. Calcite cement occurs in variable amounts. XRD analyses do not reveal any dolomite or siderite. The main clay minerals are kaolinite, chlorite and mica/illite, but some mixed layer minerals also occur.

The visually examined samples have a total organic carbon content slightly above 1%, with woody material as the most important constituent. Cuticles, pollen and spores constitute 30–40% of the organic residue with *Cerebropollenites macroverrucosus*, *Callialasporites* spp. and *Cyathidites minor* as the most common taxa. Rock–Eval data show that immature type IV kerogen (T_{\max} 425–427) is dominant and the rock has only a poor potential for gas.

Core 3

The core recovery from this hole is close to 100% although there is some uncertainty with respect to the exact depth at the bottom of the hole. The penetrated strata consist mainly of micaceous non-calcareous grey siltstones similar to core 4B, but with fine sand particularly in the lower part. Heavy bioturbation by *Macaronichnus* occurs throughout and some terrestrial plant material is observed. The total organic carbon content varies between 0.6 and 0.9%.

Technical problems caused termination of the piggyback drilling operation in an at least 1.3 m

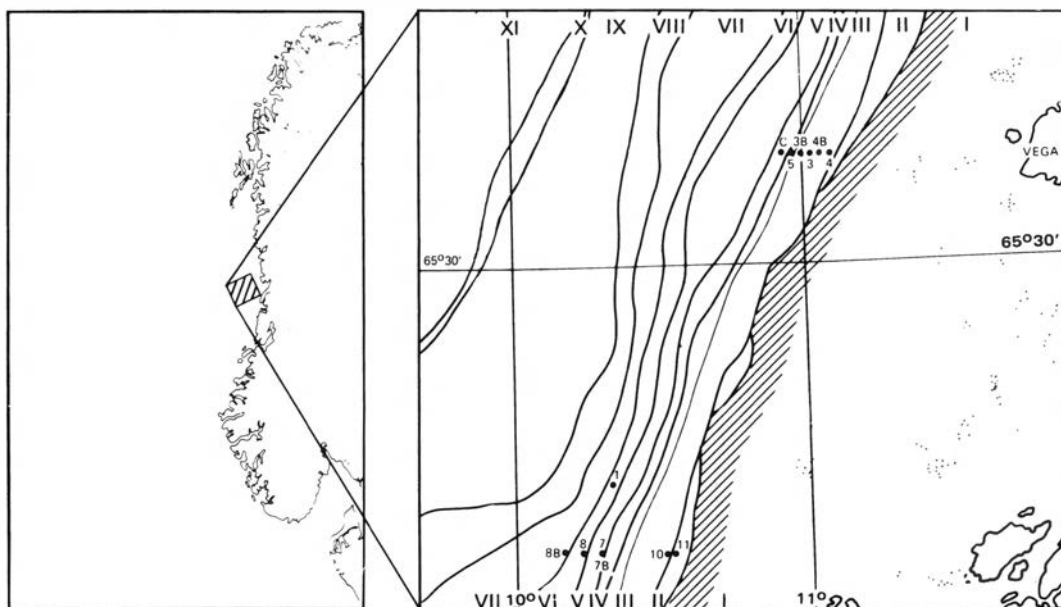


Fig. 1. Sketch map showing location of boreholes in IKU shallow drilling programme 1982. Cores 4B, 3, 3B and 5 are studied here. Roman numerals indicate seismic units.

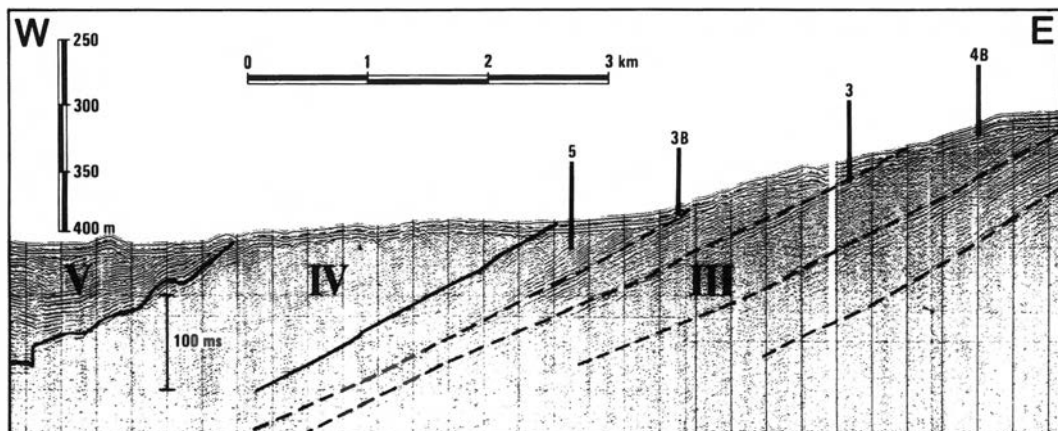


Fig. 2. Shallow seismic line B78-109 with location of studied coreholes. Seismic interpretation by Tom Bugge.

thick brown calcite and siderite cemented bed with some dolomite cement in the upper part. Two other brown carbonate cemented beds also occur in this approximately 18 m long core, one about 0.3 m thick siderite and calcite cemented and the other of at least 0.7 m thick calcite cemented at the top of the core. The carbonate is micritic with microsparitic and even some sparitic patches. All three carbonate cemented beds are very similar to the intervening siltstones in all aspects other than diagenesis.

The nine organic geochemically analysed samples from this core have a total organic carbon content of between 0.60 and 0.93%, with woody material dominant. However, the amount of cuticles, pollen (mainly bisaccates), to a lesser extent spores and in some samples in the middle and upper part of the core also dinoflagellate cysts, is large enough to influence the Rock-Eval data and give a mixed type III/IV kerogen. *Cerebropollenites macroverrucosus* and partly also *Callialasporites* spp. occur in large numbers

throughout the core. One sample at 12.4 m is particularly rich in cuticles.

The reliable T_{\max} values vary between 419 and 428 and a R_o measurement of 0.34% at 8.15 m and 0.35% at 15.8 m also implies immaturity. The drilled interval would have only a poor potential as a source rock for gas.

Core 3B

Only three 5 to 15 cm long hammer samples from a drilled section of 4 m comprise this core. They consist of micaceous non-calcareous grey siltstones similar to those found in cores 4B and 3. The mineralogy is very uniform throughout with kaolinite, chlorite and mica/illite as the quantitatively most significant clay minerals.

One organic geochemically analysed sample contains 1.37% total organic carbon of mixed type III/IV kerogen composition with T_{\max} of 427. Woody material is quantitatively most significant in two of the three samples studied in transmitted light, whereas the uppermost sample contains slightly more cuticles than woody material. Bisaccates, other gymnosperm pollen and spores are abundant throughout. The samples could have a fair potential for gas.

Core 5

Coring stopped due to technical problems in a siderite bed at 28.20 m, and drilling problems caused uncertainties with respect to correct depth below 20 m. Drilling data suggest that the recorded siderite fragments from the lowermost part of the hole represent beds in an interval dominated by poorer consolidated sediments. Carbonate beds do not occur above about 24.5 m from where bioturbated non-calcareous grey clayey siltstones with wood fragments are retrieved.

Three samples between 24.5 m and 20 m contain between 1.26 and 2.74% total organic carbon with blade opaque woody particles as the dominant constituent. Dinoflagellate cysts also contribute significantly to the organic residues. Rock-Eval pyrolysis hydrogen and oxygen indices suggest that the kerogen is type IV, except for the lowermost analysed sample at 24.44 m which is very rich in cysts and contains a mixed type II/III kerogen. The long-ranging aliphatic homology (C_7 and C_{25} with a high abundance of aromatics) may be due to the lipid rich cysts. There is a high

pristane to phytane ratio in this sample. T_{\max} values, which vary from 410 to 427 together with an R_o value of 0.37% at 24.44 m, indicate immaturity. The samples have poor to fair hydrocarbon potentials based on $S_1 + S_2$.

The interval 20.1–17 m is transitional between the beds below and above with respect to silt content, colour and degree of bioturbation and consists of micaceous non-calcareous grey silty claystone.

Two samples between 20 and 18 m from the intermediate lithology have a rich abundance of organic carbon (12.59 and 6.91%). Rock-Eval pyrolysis indicates that this is type IV kerogen, but transmitted light microscopy reveals abundant bisaccate pollen and also quite rich spore floras. Although these immature samples (T_{\max} 413–415) are rich in organic material, the hydrocarbon potential would only be for gas due to the kerogen type.

Around 17 m there is a mineralogical change associated with the income of non-calcareous dark grey shales with some mica and occasional bioturbations. Such beds occur towards the top of the core at 9.5 m. The main clay minerals in the lower part of the core are kaolinite, chlorite and illite, but there are also considerable amounts of quartz and mixed layer minerals. Above about 17 m smectite is the dominant mineral, although fair amounts of kaolinite, chlorite, illite and quartz still occur.

The change in lithology is associated with a change in the composition of the organic material as observed in Rock-Eval pyrolysis data, but not so easily seen in transmitted light except for a reduction in the number of spores. This may be due to difficulty in distinguishing between algal and degraded woody material. A sample at 17.58 m contains a type III (with type II?) kerogen. Mixed type II/III occurs throughout the rest of the core with type III dominating at 17.05 m, 15.55, 14.30, 12.14 and 11.55 m and more equal amounts of type II and III at 13.82, 12.75, 10.50 and 9.55 m. The organic richness is fairly uniform in these samples with TOC values varying between 6.54 and 8.46%. T_{\max} values from 409 to 416 are evidence of immaturity. The samples at 17.05 and 9.55 m show a long-ranging aliphatic homology (C_7 to C_{25}), indicating a lipid input with a high abundance of aromatics. In the latter sample spores are again abundant, whereas the 17.05 m sample has not been examined in transmitted light.

Systematic palaeontology

Ammonites

Pseudocadoceras sp. cf. or aff. *concinnum* (Buckman, 1927)

Fig. 3a

1927 *Pseudocadoceras?* *concinnum* (Buckman, pl. 735.

Remarks: The phragmocone from 24.80–24.60 m PMO 116.443 in core 3 shows involute coiling and a ribbed surface. The ribs are regular, sharp and strongly prorsiradiate on the outer half of the flank. No bifurcation can be recognized, but this may be due to abrasion of the ribbing on the middle part of the flanks. The venter seems to be narrowly rounded with chevron-like accentuation of the ribs.

Coiling and ribbing patterns closely resemble representatives of the genus *Pseudocadoceras* Buckman, 1918, especially *P. concinnum* with its strongly prorsiradiate ribbing.

Longaeviceras sp. cf. *keyserlingi* (Sokolov 1912) Fig. 3b–c

1912 *Cadoceras* (*Quenstedtoceras*) *keyserlingi* Sokolov, p. 25, pl. 2, fig. 2.

1977 *Longaeviceras keyserlingi* (Sokolov) Meledina, p. 136, pl. 32, figs. 2–3; pl. 34, fig. 3; pl. 35, fig. 2.

Remarks: Two fragments showing parts of flank and venter have been found between 10.30 and 10.20 m in core 3 PMO 116.444 and 116.445.

The surface of both fragments is covered by sharp, strongly prorsiradiate ribs, bifurcating close to the middle of the flanks and forming chevrons across the narrowly rounded venter. The ribs are more elevated on the venter than on the flanks and show a certain variation in strength ventrally.

The fragments are close to Upper Callovian species of *Longaeviceras*, but differ significantly from a species described from Oxfordian, *Longaeviceras staffinense* Sykes, 1975, and allied

forms. They compare very well with Upper Callovian *Longaeviceras keyserlingi* (Sokolov, 1912) in ribbing pattern, but the fragments are too poor for an exact determination.

Amoeboceras sp. cf. or aff. *rosenkrantzi* Spath 1935

Fig. 3d–g

1935 *Amoeboceras* (*Prionodoceras*) *rosenkrantzi* Spath, p. 25, pl. 12, fig. 4; pl. 13, fig. 5(M).

1961 *Amoeboceras* sp. indet. Frebold, p. 22, pl. 18, fig. 3 (m).

1979 *Amoeboceras rosenkrantzi* Spath: Sykes & Callomon, p. 888, pl. 119, fig. 10 (m); pl. 120, figs. 1–6 (m and M).

Remarks: Four fragments of *Amoeboceras* from 17.65–17.50 m in core 5 may be related to *A. rosenkrantzi* Spath. The best preserved specimen (Fig. 3d) is a fairly evolute nucleus showing coarse rectiradiate ribs turning forward close to the venter. The ribs are slightly pointed at the umbilical margin, bifurcate on the middle of the flanks, and tubercles are developed close to the venter. Two fragments (Fig. 3e–f) show the ribbing of the inner whorls. The specimen in Fig. 3e is considerably more coarsely ribbed than the specimen in Fig. 3f. Fig. 3g shows a fragment of the outer part of the shell. It is nearly smooth, only the outer prorsiradiate part of the ribs with tubercles is developed. A well-preserved rim and serrated keel are also seen.

Amoeboceras rosenkrantzi is a highly variable species, according to Sykes & Callomon (1979). The best preserved specimen (Fig. 3d) seems to be close to specimens from the Isle of Skye (Sykes & Callomon, pl. 120, fig. 1) and from the Canadian Arctic (Frebold, 1961, pl. 18, fig. 3).

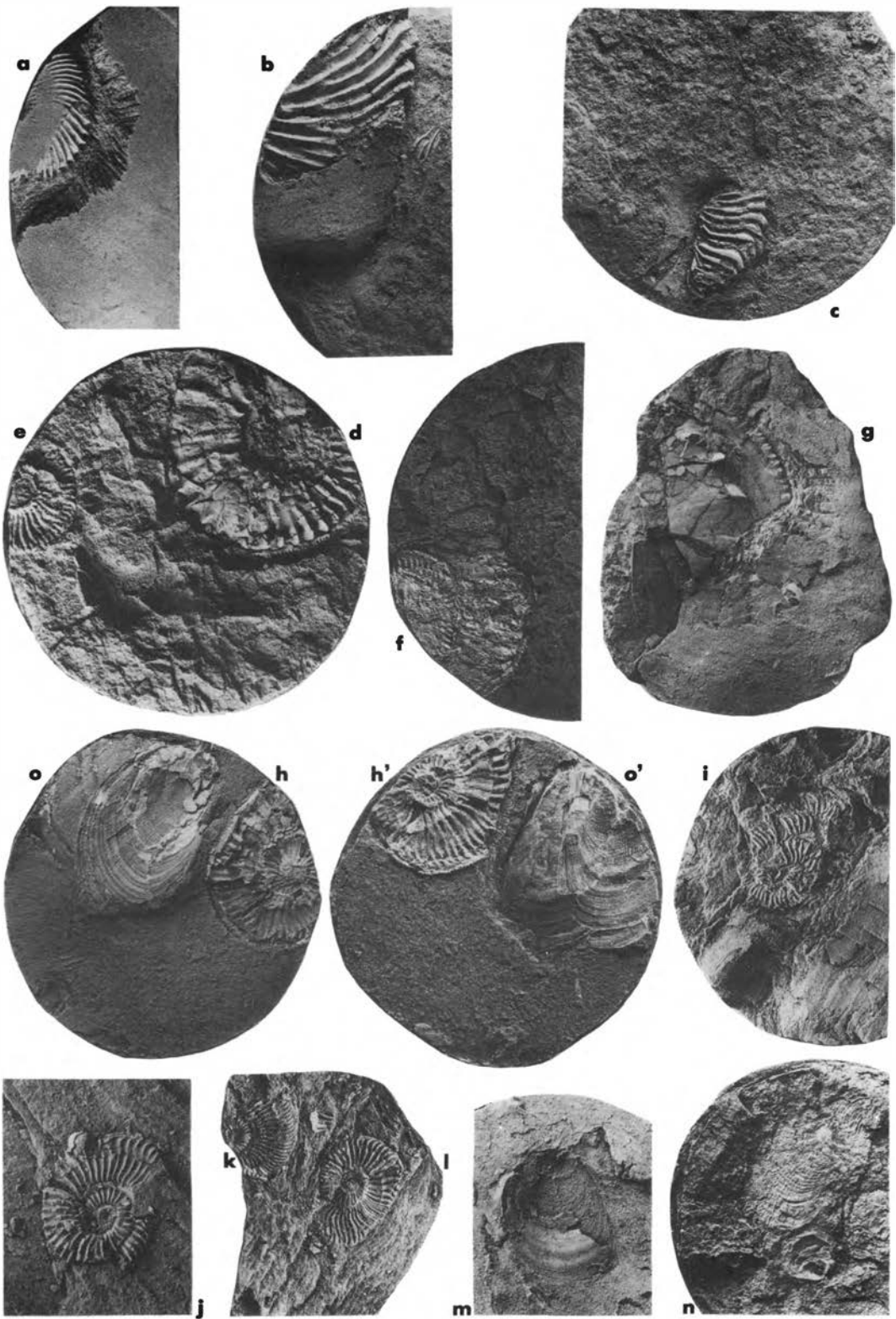
Amoeboceras sp. cf. or aff. *bauhini* (Oppel)

Fig. 3h–l

1979 *Amoeboceras* cf. *bauhini* (Oppel) (m), Sykes & Callomon, p. 889, pl. 121, fig. 6.

Remarks: Two rather poorly preserved micro-

Fig. 3. Ammonites and bivalves from cores 3 and 5 (all specimens in natural size). □a. *Pseudocadoceras* sp. cf. or aff. *concinnum* (Buckman). Core 3, 24.80–24.60 m. PMO 116.443. Callovian. □b–c. *Longaeviceras* sp. cf. *keyserlingi* (Sokolov). Core 3, 10.30–10.20 m. PMO 116.444 and 116.445. Late Callovian. □d–g. *Amoeboceras* sp. cf. or aff. *rosenkrantzi* (Spath). Core 5. d–f: 17.50 m. PMO 116.446 (d–e), PMO 116.447 (f). g: 17.65 m. PMO 116.448. All specimens from Late Oxfordian. □h–l. *Amoeboceras* sp. cf. or aff. *bauhini* (Oppel). h: Core 5, 13.94 m. PMO 116.449. i: Core 5, 14.25 m. PMO 116.450. j–l: Lower part of bed 37, Staffin, Isle of Skye. All specimens from earliest Kimmeridgian. □m. *Praebuchia* sp. cf. *lata* (Trautschold). Core 5, 17.50 m. PMO 116.451. Late Oxfordian. □n–o. *Buchia concentrica* (Sowerby). Core 5. n: 13.80 m. PMO 116.452. o: 13.94 m. PMO 116.449. Both specimens from Early Kimmeridgian.



conchs from 13.94 (PMO 116.449) and 14.25 m (PMO 116.450) bear some resemblance to *Amoeboceras* microconchs from the Isle of Skye occurring at the very base of the Kimmeridgian.

One of these specimens from the Isle of Skye was figured by Sykes & Callomon, 1979, pl. 121, fig. 6, and three other specimens are figured here for comparison (Fig. 3j–l). The specimens are characterized by rectiradiate ribs becoming prorsiradiate close to the venter, where they tend to become slightly stronger without developing real tubercles. Some of the ribs bifurcate at the middle of the whorl side. The specimens may represent forms of *Amoeboceras bauhini* not yet showing the marked spiral smooth band of that species.

Bivalves

Praebuchia sp. cf. *lata* (Trautschold 1860)

Fig. 3m

1860 *Aucella lata* Trautschold, p. 344, pl. 7, figs. 8–10.

1902 *Aucella kirghisensis* Sokolov, p. 374, pl. 14, figs. 1–5.

1981 *Praebuchia* cf. *kirghisensis* (D. Sokolov): Zakharov, p. 60, pl. 1, figs. 5–7; pl. 2, figs. 8–9; table 8a'–b' (including extensive list of synonyms).

1982 *Praebuchia kirghisensis* (Sokolov): Surlyk & Zakharov, p. 731, pl. 72, figs. 1–3.

1986 *Praebuchia lata* (Trautschold); Sey p. 130, pl. 17, figs. 4–13.

Remarks: One flattened specimen (PMO 116.451) from 17.50 m may be referred to *P. lata* on the basis of shape and the almost smooth surface. According to S. R. A. Kely (pers. comm. 1985), *P. kirghisensis* (Sokolov), used by Zakharov (1981), is a junior synonym of *P. lata* (Trautschold).

Buchia concentrica (Sowerby 1829)

Fig. 3n–o

List of synonyms up to 1981: See Zakharov (1981)

1829 *Plagiostoma concentrica* Sowerby, p. 113, pl. 559, fig. 1.

1981 *Buchia concentrica* (Sowerby, 1829): Zakharov, p. 64, pl. 3, figs. 1–12; pl. 4, figs. 1–12; table 8a", 8b", text-fig. 24r.

1982 *Buchia concentrica* (Sowerby, 1829): Surlyk & Zakharov, p. 734, pl. 72, fig. 5.

Remarks: A number of specimens of *Buchia* from the interval 13.94–13.80 m can be referred to *B. concentrica* on the basis of the shape, best seen in PMO 116.449 fig. 3. o–o', and the fine concentric and radiate ribbing forming a reticulate ornamentation.

Dinoflagellate cysts

Genus *Glomodinium* Dodekova 1975

Type species: *Glomodinium reticulopilosum* Dodekova 1975. Late Bathonian, Tchernookovo, Bulgaria.

1972 *Evansia* Pocock 1972 emend. Jansonius 1986.

Remarks: Pocock (1972) described and figured *Tenua evittii* and the type species of *Evansia*, *E. granulata*. From Pocock's figures and according to Dodekova (1975) and Jansonius (1986) it is evident that Pocock misinterpreted the 3I archeopyle of his *T. evittii* as apical. Jansonius (1986) presumed the holotype to be lost, chose a lectotype and described it as *Evansia evittii*. Jansonius (1986) also emended the diagnosis of *E. granulata* and interpreted some faint delineations as the anterior margins of 1a and 3a. Only 2a is clearly delineated as a hexagonal paraplate, which led Pocock (1972) to interpret the archeopyle as simple intercalary (I).

Dodekova (1975) erected the genus *Glomodinium* for two-layered pareodiniceans with a 3I archeopyle and described the species *Glomodinium reticulopilosum*. She also mentioned the possibility that *Tenua evittii* Pocock 1972 and *Pareodinia tripartitus* Johnson & Hills 1973 should be transferred to *Glomodinium*. Dodekova's diagnosis of *Glomodinium* is fully appropriate and is very similar to Jansonius's emended diagnosis for *Evansia*. Dörhöfer & Davies (1980) distinguished between *Pareodinia* and *Glomodinium* on the basis of archeopyle type in the same way as Dodekova (1975). Their view conflicts with the opinions of Johnson & Hills (1973) and Wiggins (1975).

Because of the inadequate original descriptions and interpretations of *E. granulata* and *T. evittii*, the faint intercalary delineations in *E. granulata*

and the existence of the genus *Glomodinium*, we think it is better to retain *Glomodinium* than to emend the diagnosis of *Evansia*, in contrast to the opinion of Jansonius (1986). The lost holotype of *T. evittii*, which is the one of the two holotypes of Pocock with the clearest 3I archeopyle and preferably should have been chosen as the type species of *Evansia*, is also an argument for rejection of this genus.

Glomodinium granulatum (Pocock) n. comb.
Fig. 4e–f

1972 *Tenua evittii* Pocock, p. 94, pl. 24, figs. 6, 8.
1972 *Evansia granulata* Pocock, p. 95, pl. 24, fig. 7, text-fig. 12, Jansonius 1986, pl. 5, figs. 1–3, text-fig. 10.

1973 *Pareodinia* sp. 1 Johnson & Hills, p. 209, pl. 3, figs. 3–4.

1975 *Pareodinia evittii* (Pocock); Wiggins, p. 105.

1975 *Pareodinia* sp. B. Wiggins, p. 108, pl. 2, fig. 11.

1975 *Pareodinia* sp. E. Wiggins, p. 109, pl. 3, figs. 6–7.

1977 *Pareodinia evittii* Bjærke, pl. 6, figs. 4–6.

1979 *Pareodinia brachytelis* Fensome, pp. 29–31, pl. 4, figs. 3, 5–7, text-fig. 11.

1980 *Glomodinium* sp. Dörhöfer & Davies, fig. 29A.

1983 *Glomodinium zabrum* Davies, p. 18, pl. 3, figs. 2–12, text-fig. 11.

1986 *Evansia evittii* (Pocock); Jansonius, pp. 208, 210, pl. 6, figs. 8–9, text-fig. 9.

1986 *Evansia zabra* (Davies); Jansonius, p. 208.

Remarks: Pocock (1972) stated that his holotype of *Evansia granulata* has an intercalary archeopyle with simple free operculum. Jansonius (1986) re-examined this holotype, differentiated the angled anterior margins of 1a and 3a and concluded that three intercalary hexagonal paraplates are lost individually from the archeopyle.

The present authors have observed the same intraspecific variation as Wiggins (1975), Fensome (1979) and Davies (1983) with respect to overall form, size, apicular structure and ornament in a material of more than one hundred well-preserved specimens from the Callovian cores offshore Helgeland, Norway and in Callovian outcrop samples from Kong Karls Land and Franz Josef Land and East Greenland. Coarsely sculptured forms with the shape of Jansonius's lec-

totype of *E. evittii* are fairly common particularly in Kong Karls Land.

The ornament is sometimes reduced in the cingular and sulcal regions and extensively developed in the antapical area. The overall sizes of 10 specimens from a sample at 14.0 m in core 3 are as follows (measurements in μm): 92×56 , 91×59 , 90×56 , 89×57 , 89×54 , 86×48 , 84×60 , 83×51 , 78×61 , 68×47 , respectively.

Jansonius (1986), on the basis of a small material, maintained Pocock's two pareodiniacean species as *Evansia granulata* and *E. evittii* on the grounds of a different overall habitus and a finer and more uniform ornament in *E. granulata*. The variation in shape and sculpture, that according to Jansonius is interspecific variation falls within the continuous variability in our material. We therefore regard *E. (G.) evittii* as synonymous with *G. granulatum*.

Glomodinium cerebraloides n. sp.
Fig. 4a–d

Holotype: Core 3, 17.00 m, slide 1, England Finder reference B27/3, fig. 4a; Callovian.

Paratypes: Nine specimens from core 3 offshore Helgeland, Norway. Callovian.

Occurrence: One to three specimens per slide are found at 23.55, 21.32, 17.00, 15.50, 12.40, and 8.16 m in core 3 (late Middle–early Late Callovian) to the west of Vega, Helgeland, Norway ($65^{\circ}38.4'N, 10^{\circ}59.2'E$).

Description: Proximate cysts with ovoidal main body and stout tapering blunt horns $5\text{--}12\ \mu\text{m}$ long. Overall dimensions $56\text{--}65 \times 33\text{--}43\ \mu\text{m}$. Wall $1\text{--}2\ \mu\text{m}$ thick, inner layer dense, outer layer thicker than inner, very characteristically rugate, slightly thickened around tip of apical horn; archeopyle intercalary, type 3I. Some or all of the three hexagonal opercular pieces often occur in place. If lost, this weakens the cysts so much that they may break off at the ventral side and apparently have apical archeopyles. No paraplate pattern determined except in the intercalary series.

Remarks: This species is easily recognized on the basis of its characteristic rugate wall ornament. Measured overall dimensions in μm : 65×43 , 65×41 , 62×33 , 60×37 , 59×40 , 56×41 , 56×33 .

Glomodinium reticulopilosum has a complicated ornament of septa and hair-like processes on the periphragm.

Genus *Crussolia* Wolfard & van Erve 1981, emend. Smelror & Århus in press. Type species: *Crussolia deflandrei* Wolfard & van Erve 1981. *Crussolia perireticulata* n. sp.

Fig. 5a-i

Holotype: Core 4B, 3.88 m slide 2, England Finder reference X16/4, fig. 5a; Callovian.

Paratypes: Approximately 50 specimens from cores 4B, 3 and 3B offshore Helgeland, Norway and 10 specimens from Kong Karls Land, Svalbard.

Occurrence: This species occurs commonly in the oldest of the three Callovian cores described here (core 4B). Scattered specimens are also found in the younger Callovian cores (3 and 3B).

The species has been recorded from the Late Bathonian to Early Oxfordian succession at Hår-fagrehaugen on Kongsøya, Kong Karls Land (Smelror, pers. observation 1987).

Description: Proximate cyst, ambitus ovoidal tapering to an apical horn, antapex rounded. Overall dimensions (70–96 × 41–63 µm (Helgeland) and 96–107 × 57–68 µm (Kong Karls Land)). Cyst wall two-layered, holocavate. Pericoel best developed apically and antapically; the distance between the walls antapically may be around 6 µm when the pericoel is well preserved. Apically the endophragm forms a short blunt horn which protrudes into the longer horn of the periphragm. The length of the horn (the distance between the walls apically) varies from 4 to 11 µm and the blunt horn often ends in a thickened apical structure.

Finely reticulate ridges connect thick endophragm and thin periphragm. These ridges are also connected on the periphragm and form an irregular meshwork of wall thickenings which apparently do not reflect the paratabulation. This

reticulum is variably developed and may be non-continuous. In a few well-preserved specimens the paracingulum and/or parasulcus may be seen as non-reticulate areas. A well-developed sulcus has only been observed on a single specimen and appears as a structure which continues far down on the hypocyst.

Archeopyle intercalary, 3I, opercular pieces often occur in place, but may be lost individually. The archeopyle formation weakens the cysts so much that they may break along the apical margin of the precingular paraplates on the ventral side.

Remarks: All the recorded cavate specimens with 3I archeopyles from Helgeland belong in this genus. In the material from Kong Karls Land there also occur a few specimens of the non-reticulate and tabulated *C. dalei* described by Smelror & Århus (in press).

Wolfard & van Erve (1981) erected the genus *Crussolia* for circumcavate Pareodiniaceae with 3I or 5I archeopyles. All the specimens in our material in which archeopyle interpretation has been possible revealed 3I archeopyles. One specimen, which Wolfard & van Erve (1981) figured and use as their main evidence for a 5I interpretation, has only three paraplates inside the cyst. During examination of additional material of *C. deflandrei* from the type section of Mt. Crussol, we observed only specimens with 3I archeopyles.

Genus *Wanaea* Cookson & Eisenack 1958, emend. Fensome 1981

Type species: *Wanaea spectabilis* (Deflandre & Cookson) Cookson & Eisenack 1958

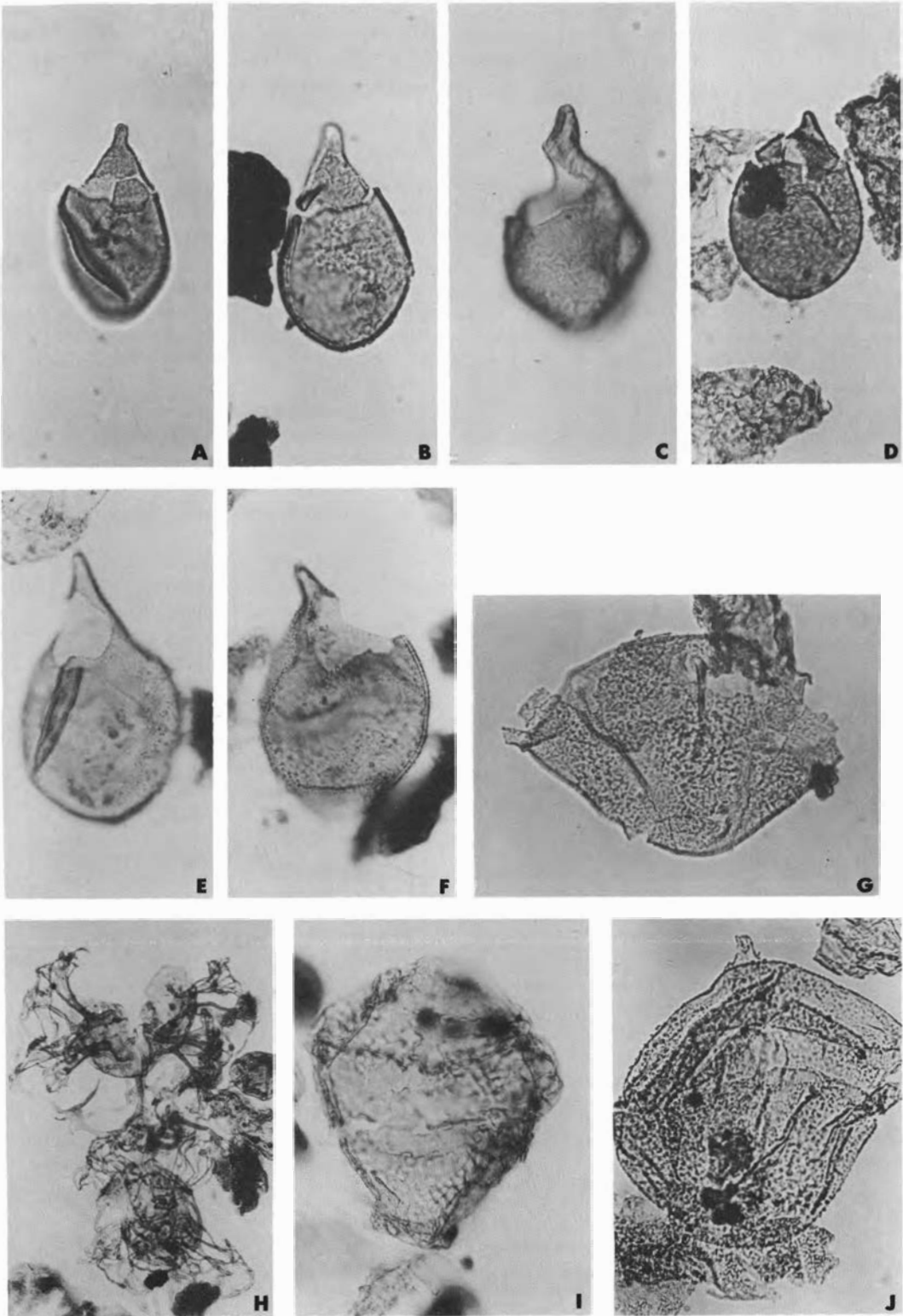
Wanaea cf. *thysanota* Woollam 1982

1972 Dinoflagellate sp. B. Pocock p. 102, pl. 23, fig. 11, text-fig. 18.

1986 *Wanaea clathrata* sensu Jansonius 1986, p. 220, pl. 3, fig. 18, text-fig. 17.

Remarks: The single recorded specimen from 5.02 m in core 3B (Late Callovian) is very similar to the specimen figured by Pocock (1972) and Jansonius (1986). Most of the radially arranged

Fig. 4. All specimens are from the Callovian except h (magnification 500× unless otherwise stated). □a. *Glomodinium cerebraloides* n. sp. Core 3 17.0 m B27/3. PMO 116.458 Holotype. □b. *Glomodinium cerebraloides* n. sp. Core 3 21.32 m/1 F27/1. PMO 116.459. □c. *Glomodinium cerebraloides* n. sp. Core 3 12.4m/1 S34/2. PMO 116.454. □d. *Glomodinium cerebraloides* n. sp. Core 3 15.5m/2 H30. PMO 116.457. □e. *Glomodinium granulatatum* (Pocock) n. comb. Core 3 14.0m/2 V33/1. PMO 116.455. □f. *Glomodinium granulatatum* (Pocock) n. comb. Core 3 14.0m/2 T29/1. PMO 116.455. □g. *Ctenododinium norrisii* (Pocock); Stover & Evitt Core 3 15.5m/2 G25/1. PMO 116.457. □h. *Rigaudella aemula* (upper) and *R. caulleryi* (lower) Core 5 23.51m/1 H12. PMO 116.460 250× Early Oxfordian. □i. *Scrinioacasus reticulata* (Pocock); Jansonius Core 3 11.45m/2 E30/4. PMO 116.453. □j. *Ctenododinium norrisii* (Pocock); Stover & Evitt Core 3 15.5m/1 J11. PMO 116.456.



flukes on the cingular flange are distally connected in contrast to what Woollam (1982) stated for *Wanaea thysanota*. *W. clathrata* has a much broader fimbriate cingular flange and the form in this case is more like *Wanaea digitata*.

Genus *Ctenidodinium* Deflandre 1938

Type species: *Ctenidodinium ornatum* (Eisenack) Deflandre 1938

Ctenidodinium norrisii (Pocock) Stover & Evitt 1978, p. 204

Fig. 4 g,j

1972 *Leptodinium norrisii* Pocock pp. 92–93, pl. 24, figs. 9–12, text-fig. 9

1975 *Dichadogonyaulax norrisii* (Pocock) Sarjeant p. 55 emend. Jansonius 1986, pp. 205–206, pl. 2, figs. 6–11, text-figs. 5–6.

1980 *Ctenidodinium* sp. Piasecki p. 50, pl. 1, figs. 1–3.

1983 *Korystocysta norrisii* (Pocock) Woollam p. 194.

Remarks: The paraplate boundaries are poorly developed in the recorded representatives of this species, which is common at 15.5 m in core 3 (*P. athleta* Zone). A distinct horn is always observed when orientation is convenient. The ornament is variably developed, but is usually similar to that seen in Fig. 6g, j. Occasionally the sculptural elements may partly coalesce or be developed as bacula.

Biostratigraphy

Core 4B

Because of low diversity assemblages of dinoflagellate cysts and unknown stratigraphic ranges of some of the species a precise age assignment for core 4B cannot be given at this stage. *Crussolia perireticulata* n. sp. is the most commonly recorded species. The absence of Bathonian index species and the dating of core 3 favours an Early to Middle Callovian age, but according to the literature none of the recorded taxa is restricted to this time interval.

Woollam & Riding (1983) reported only rare

or uncertain representatives of the *Ctenidodinium sellwoodii* group above Early Callovian, whereas Riley & Fenton (1982) claimed that it ranges up into the Upper Callovian *P. athleta* Zone.

Core 3

A specimen of *Pseudocadoceras* sp. cf. or aff. *concinnum* (Buckman 1927) was found in the carbonate cemented bed at the base of core 3. *Pseudocadoceras* is a cardioceratid microconch genus of the Boreal Callovian. Bathonian microconchs, e.g. from Svalbard and Siberia, are also often referred to this genus, but are better kept separate (see Callomon 1985, and discussion in Rawson 1982).

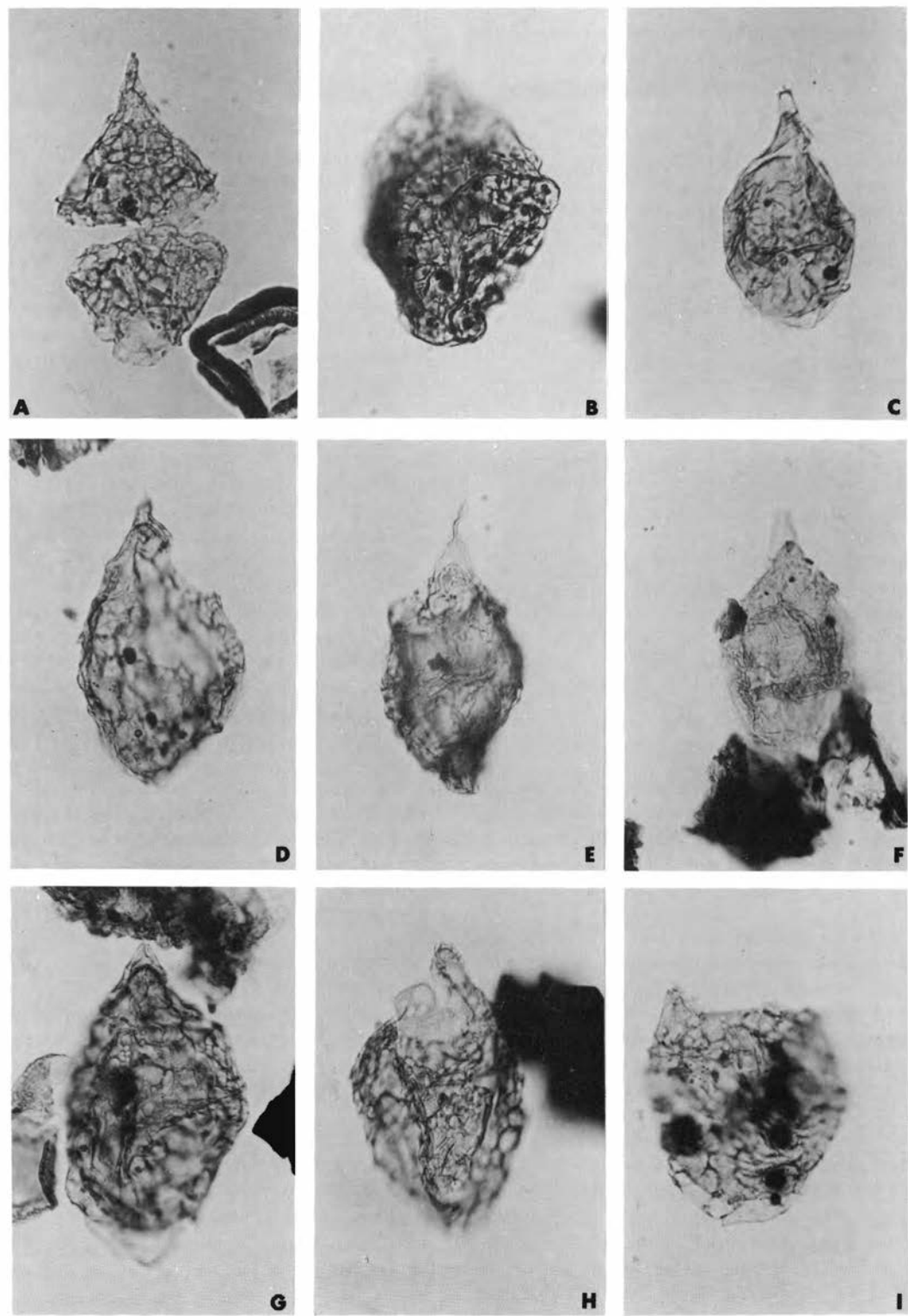
In England the type species *Pseudocadoceras boreale* Buckman 1919 (pl. 121B) occurs in the *P. koenigi* Subzone of the *S. calloviense* Zone (Callomon 1985), and other species, e.g. the closely related *P. concinnum*, occur throughout the Middle Callovian.

In North America species of *Pseudocadoceras* have been described from Alaska (Imlay 1953, 1975) and British Columbia (Frebold & Tipper 1967), and have been recorded as far south as California and Oregon (Imlay 1961). American *Pseudocadoceras* belong in at least two different faunas, that of *Cadoceras stenoloboide* and that of *Longaeviceras pomerovense*, of Middle? and Late Callovian ages respectively (Callomon 1985). The genus has also been recorded from the Callovian of northern Siberia (Meledina 1977).

It is not possible to give a very exact age to the fragment described here, but a level around the Middle/Late Callovian boundary seems probable.

The dinoflagellate cyst assemblages generally show an upward increase in diversity, especially above 17 m. Representatives of Pareodiniaceae (*Glomadinium granulatum* and *G. cerebraloides* n. sp.) occur most consistently, but the assemblages in many samples may be dominated by other species. *Nannoceratopsis pellucida* is recorded relatively commonly in carbonate cemented beds from the bottom and the top of the core. This may be due to environmental conditions, which also resulted in early diagenesis

Fig. 5. All figured specimens are Callovian representatives of *Crussolia perireticulata* n. sp. (magnification 500×). □a. Core 4B 3.88m/2 X16/4 PMO 116.463 Holotype. □b. Core 4B 5.02m/3 U23/2 PMO 116.466. □c. Core 4B 3.88m/1 K21/4 PMO 116.462. □d. Core 4B 5.02m/2 V36/3 PMO 116.465. □e. Core 3 24.8m/2 D18 PMO 116.461. □f. Core 4B 5.02m/1 Y15/2 PMO 116.464. □g. Core 4B 5.9m/1 D34/1 PMO 116.467. □h. Core 4B 5.9m/3 B18/4 PMO 116.468. □i. Core 4B 3.88m/2 E36 PMO 116.463.



KIMMERIDG.	L	P. baylei
OXFORDIAN	U	A. rosenkrantzi
		A. regulare
		A. serratum
		A. glosense
	M	C. tenuiserratum
		C. densiplicatum
	L	C. cordatum
		Q. mariae
CALLOVIAN	U	Q. lamberti
		P. athleta
	M	E. coronatum
		K. jason
		S. calloviense
	L	C. nordenskjöldi
		C. apertum

Fig. 6. East Greenland ammonite zonation (Surlyk 1977; Sykes & Callomon 1979; Callomon & Birkelund 1980).

in these beds. Riley & Fenton (1982) reported assemblages with numerous *N. pellucida* from late Early Callovian–Middle Callovian (*S. calloviense*–*E. coronatum* Zones). Here it may also be common in the *P. athleta* Zone because the presence of *Acanthaulax scarburghensis* and *Scriniodinium crystallinum* at 18.61 m, in addition to the ammonite evidence, point to a Late Callovian age. Riley & Fenton (1982) did not record *A. scarburghensis* (as *A. senta*) below the latest Callovian *Q. Lamberti* Zone in contrast to Poulsen (1985) and Piasecki (1980) who found it down in the *P. athleta* Zone. According to Poulsen (1985) *S. crystallinum* is also restricted to Late Callovian and younger beds in Jameson Land, East Greenland, in good agreement with Raynaud (1978), Riding (1982) and Woollam & Riding (1983). The first occurrences of *Gonyaulacysta jurassica*, *Palaeostomocystis tornatilis*, *Sirmiodinium grossii* and *Valensiella ovula* are found at 17.0 m and are recorded fairly consistently above this level (except *G. jurassica*). Most authors report these

species also from pre-Late Callovian strata although Riding (1982) did not find *P. tornatilis* below Late Callovian in the English Warboys borehole, Cambridgeshire.

Ctenidodinium norrisii is the most common species at 15.5 m. This record conflicts with the ranges given by Raynaud (1978) and Riley & Fenton (1982), who found *C. norrisii* in the Early and Middle Callovian (*M. macrocephalus* to *E. coronatum* Zone); Riley & Fenton reported it from the older beds, also. Pocock (1972) mentioned a dinoflagellate cyst zone towards the top of the Callovian Lower Member of the Vanguard Formation in southern Saskatchewan dominated by *Leptodinium* (now *Ctenidodinium*) *norrisii*. This zone forms a good marker horizon across southern Manitoba, Saskatchewan and Alberta and also contains *Scrinioicassis reticulata* (common at 11.45 m in our core) and some of the pareodiniacean species recorded here.

The most common representative of the Pareodiniaceae, *Glomodinium granulatum*, occurs in variable numbers in most of the examined samples. Johnson & Hills (1973) reported this species (as *Pareodinia* sp. 1) in large numbers from the Late Bathonian lower half of the interval between the *Arctocephalites* Bed and the Lower *Cadoceras* bed. This was in agreement with Fensome (1979), who found dominant *G. granulatum* (as *Pareodinia brachytelis*) together with Bathonian ammonites in his sample 144125 from Jameson Land, East Greenland.

Johnson & Hills also mentioned rare specimens from the Callovian, but interpreted these as being reworked. According to Piasecki (1980), *Glomodinium granulatum* (named *Pareodinia evittii*) ranges up into the upper part of the *P. athleta* Zone in East Greenland.

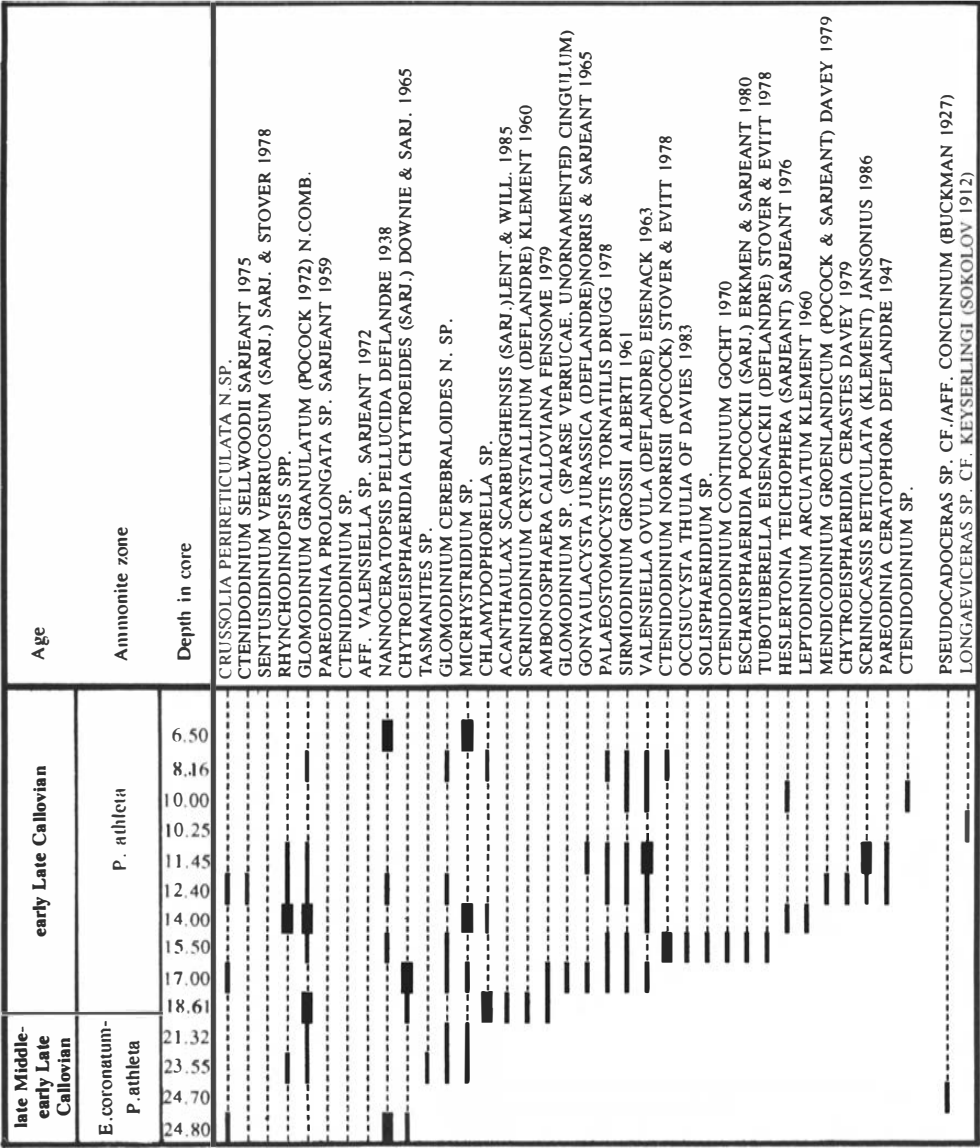
The record of two fragments of *Longaeviceras* sp. cf. *keyserlingi* (Sokolov 1912) at 10.30–10.20 m in the same core indicates a Late Callovian age at this level. *Longaeviceras* is a widely distributed, Boreal cardioceratid genus known from Siberia, northern Europe and North America.

In summary we assign the interval 24.8–21.32 to the *E. coronatum*–*P. athleta* Zones, whereas we restrict the dating to the *P. athleta* Zone for the interval 18.61–6.50 m.

Core 3B

The three samples examined from this core con-

Core 3
65° 38.4'N
10° 59.2'E



Core 4B
65° 38.4'N
11° 01.3'E

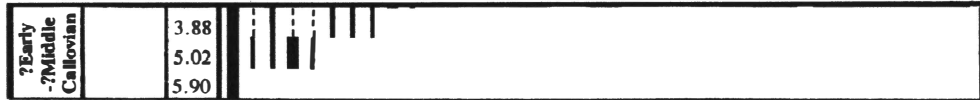


Fig. 7. Range chart showing distribution of dinoflagellate cysts and ammonites in cores 4B and 3.

tain similar dinoflagellate cyst assemblages as those in core 3. *Mendicodinium groenlandicum* is dominant in the lowermost sample. Riley & Fenton (1982) reported large numbers of this species in their Late Callovian *M. groenlandicum* Subzone, whereas Poulsen (1985) also found numerous specimens in the lowermost Oxfordian *C. scarburghense* Subzone (lower part of *Q. mariae* Zone). The presence of *G. granulatum* in the lowermost and large numbers of *C. continuum* in the uppermost sample may according to the ranges of Piasecki (1980) and Riley & Fenton (1982) favour a *P. athleta* Zone age, but an assignment to the *Q. lamberti* Zone is also possible.

Core 5

The number of dinoflagellate cysts in the lower part of this core is much greater compared with the number in core 3B below. *Ctenidodinium continuum* in the lowermost sample together with *Wanaea fimbriata* and abundant *Acanthaulax scarburghensis*, *Rigaudella aemula* and *Scriniodinium crystallinum* point to the Early Oxfordian *Q. mariae* Zone, although Berger (1986) extended the range of *W. fimbriata* down to the uppermost Callovian *Q. lamberti* Zone. All authors seem to agree that *C. continuum* does not range above the *Q. mariae* Zone, but Piasecki (1980) did not record *R. aemula* (also numerous in his assemblages) below the *C. cordatum* Zone. Because of these inconsistencies, the subdivision of the Early Oxfordian part of the section is somewhat problematic.

W. fimbriata is present in all examined samples up to 21.9 m and, according to the literature, indicates an age no younger than the Early Oxfordian *C. cordatum* Zone in agreement with the presence of *Atopodinium prostaticum*. Riley & Fenton (1982) indicated only uncertain records of this species in the *C. cordatum* Zone. Some Pareodiniaceae are transitional between *Glomodinium granulatum* and *Pareodinia ceratophora* regarding form and ornamentation, but clear 3I archeopyles have not been observed.

The recorded assemblage at 20.06 m (above the transition to darker, less silty and less bioturbated beds than below) is generally similar to those below, but no representatives of *Wanaea* have been found. *Acanthaulax scarburghensis* is dominant and most of the specimens of *Rigaudella* may be assigned to *R. caulleryi* in contrast to *R. aemula* lower in the section. The recovery points to an

Early Oxfordian age, probably the *C. cordatum* Zone.

A drastic reduction in diversity and abundance of dinoflagellate cysts takes place between 20.06 and 19.9 m. According to Piasecki (1980) the presence of *Gonyaulacysta jurassica* var. *longicornis* points to a Middle Oxfordian *C. tenuiserratum* Zone or older age.

Amoeboceras rosenkrantzi, recorded at 17.65–17.50 m, has been described from East Greenland, Scotland and the Canadian Arctic. It is the zonal index for the *A. rosenkrantzi* Zone of the top of the Oxfordian (Sykes & Callomon 1979). This zone was divided by Sykes & Callomon (1979) into two Subzones, the *A. marstonense* Subzone below and the *A. bauhini* Subzone above. New investigations have shown, however, that *A. bauhini* first appears in the *Pictonia baylei* Zone of the Lower Kimmeridgian, as do the strata in which the *A. bauhini* Subzone was first defined in Skye.

A specimen of *Praebuchia* sp. cf. *lata* is also found at 17.5 m. According to Zakharov (1981, text-fig. 30), *Praebuchia lata* is only known from the USSR, Pomerania and East Greenland, but is also recorded from the Isle of Skye and Yorkshire (S. R. A. Kelly, pers. comm. 1985). In the USSR it occurs throughout the Oxfordian, but is most common in the Late Oxfordian *Amoeboceras alternans* Zone. East Greenland occurrences can be referred to the *A. glosense*, *A. serratum* and *A. regulare* Zones of the Upper Oxfordian respectively (Surlyk & Zakharov 1982). In core 5 the species occurs together with *A. rosenkrantzi*, indicating the *A. rosenkrantzi* Zone of the latest Oxfordian.

Piasecki (1980) recorded *Paragonyaulacysta borealis* from the *A. rosenkrantzi* Zone and younger beds in East Greenland. This fits well with its presence at 16.77 m and above.

For comparison we have also examined three samples from around the Oxfordian/Kimmeridgian boundary at location 5, Staffin Bay, Isle of Skye, Scotland. These are all significantly richer and more diverse in dinoflagellate cysts than samples from approximately the same stratigraphic level in core 5. A sample from bed 35 in the *A. rosenkrantzi* Zone (1 m below the Oxfordian/Kimmeridgian boundary) containing *Ringsteadia pseudocordata* is dominated by representatives of *Criboperidinium*, *Leptodinium* and the *Systematophora orbifera/areolata* complex. *G. jurassica* is fairly common and *Scri-*

niodinum luridum and *Dinopterygium dimorphum* are present. It may be worth noting that *R. cladophora* has not been recorded.

The ammonite species recorded at 14.25–13.94 m also appears in the lower part of bed 37 at Staffin, Isle of Skye, a bed which higher up also contains typical *Amoeboceras bauhini*, particularly abundant at the top (Sykes & Callomon 1979).

A. bauhini is one of the few species of *Amoeboceras* which link Boreal and Submediterranean provinces, being distributed in Franconia, Swabia and Switzerland, England and Scotland (Sykes & Callomon 1979). Greenland occurrences referred to *A. bauhini* by Sykes & Callomon (1979) have now been referred to a separate species, *A. bayi*, by Birkelund & Callomon (1985).

The position of *A. bauhini* has recently been clarified on the basis of new stratigraphical information both in the Isle of Skye and in eastern England (see Birkelund & Callomon 1985). The position of the Oxfordian/Kimmeridgian boundary in Skye has had to be drawn at bed 36 and not at bed 38 as previously (Sykes & Callomon 1979). The present microconch may thus indicate an earliest Kimmeridgian age.

A sample with *Amoeboceras* cf. *kitchini* from the *P. baylei* Zone, bed 37 0.5 m above the Oxfordian/Kimmeridgian boundary in Skye (sample 507), is richer in woody material than the sample from bed 35 and contains common megaspores. The number of specimens of the genera *Cribroperidinium* and *Leptodinium* is very much reduced and possibly reflects a more marginal marine facies. *Rhynchodiniopsis cladophora* subsp. *extensa* and *Systematophora orbifera* are the dominant taxa and *Scriniodinium galeritum* restricts the age to no younger than the earliest Kimmeridgian *P. baylei* Zone in agreement with the ammonite evidence. Klement (1960) described *Gonyaulax cladophora extensa* from the 'Unter Malm Gamma' (Early Kimmeridgian) of southwest Germany; it has a short but not well documented range, as most authors have not differentiated between this form and *R. cladophora*.

The third Skye sample with *Amoebites* sp. from the *P. baylei* Zone, bed 37 1 m above the Oxfordian/Kimmeridgian boundary (sample 506), contains a diverse dinocyst assemblage with *R. cladophora* subsp. *extensa*, *S. orbifera*, *S. luridum*, *G. jurassica* and *Cribroperidinium* spp. still present. Additional species such as *Scriniodinium*

anceps, *Cleistophaeridium tribuliferum*, *Tubotuberella apatela* and *Ambonosphaera utera* of Piasecki 1980 are also found.

Adnatospaeridium hartzii of Piasecki (1980) at 14.0 m, recorded by Piasecki in the *A. regulare*–*R. cymodoce* Zone in Milne Land, East Greenland is supporting evidence for an age close to the Oxfordian/Kimmeridgian boundary. It also occurs in the sample with *A. cf. kitchini* from Skye. According to Woollam & Riding (1983), the presence of *Scriniodinium crystallinum* towards the top of the core restricts the dating to no younger than the earliest Kimmeridgian *P. baylei* Zone, if the English range is applicable in our area.

Buchia concentrica, common in the interval 13.94–13.80 m, is widely distributed within the Boreal and Sub-Boreal Provinces of the Boreal Realm (see map of distribution in Zakharov (1981, text-fig. 35)). According to Zakharov (1981) and Surlyk & Zakharov (1982), it is particularly abundant in the Lower Kimmeridgian (Zones of *Pictonia baylei* and *Rasenia cymodoce*), but is also known from the late Oxfordian. In core 5 it occurs together with *Amoeboceras* sp. cf. or aff. *bauhini*, supposed here to be of very early Kimmeridgian age.

Conclusion

Four shallow cores with a total core length of approximately 34 m from a 150–160 m thick Callovian–earliest Kimmeridgian section have been studied. Although large parts of the Callovian section are unrecovered, the Callovian seems to consist of fairly uniform silty sediments deposited on a shallow marine shelf with high input of terrestrial material. Most of the preserved land-derived organic material was not greatly affected during deposition although the rocks are heavily bioturbated. An estimate of the thickness of the Callovian may be in the order of 140 m, but the oldest core is not very accurately dated. Some early diagenetic carbonate cemented beds in the *E. coronatum*–*P. athleta* Zones point to certain periods with reduced sedimentation.

The Oxfordian is transgressive in the area. In its first phase, this transgression allowed the diverse dinoflagellate cyst assemblages of the Early Oxfordian known from so many areas to flourish also in the area referred to here. The bottom conditions were oxidative and the land-derived

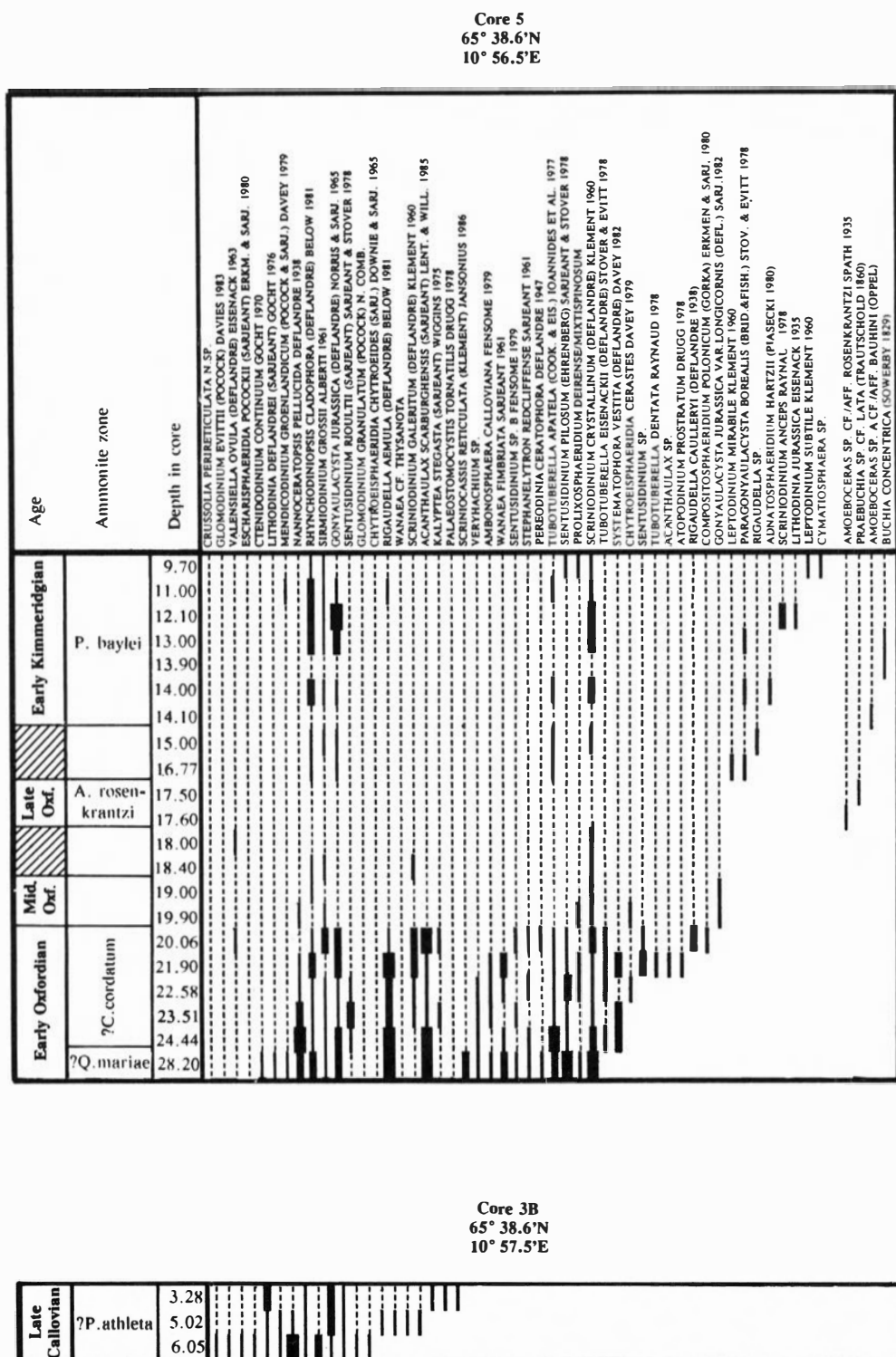


Fig. 8. Range chart showing distribution of dinoflagellate cysts, ammonites and bivalves in cores 3B and 5.

organic material, except the most resistant woody particles, gradually disappeared during repeated winnowing/reworking.

As the transgression continued in the Middle Oxfordian the sediment became darker, more fine-grained and much richer in organic material (6–13% TOC as opposed to 2%), but the bottom conditions were still oxidative in latest Oxfordian time. The rate of deposition in the Oxfordian was very low with approximate thicknesses of 8, 2 and 3 m for the Early, Middle and Late Oxfordian, respectively.

Around the Oxfordian/Kimmeridgian boundary the lithology changes to a dark grey shale, most of the bioturbation disappears, mixed type II/III kerogen types prevail and bottom conditions are no longer oxidative in the *P. baylei* Zone with 6–8% TOC.

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