Biostratigraphy of a Lower Cretaceous section from Sklinnabanken, Norway, with some comments on the Andøya exposure

NILS AARHUS, JACOB VERDENIUS & TOVE BIRKELUND

Aarhus, N., Verdenius, J. & Birkelund, T.: Biostratigraphy of a Lower Cretaceous section from Sklinnabanken, Norway, with some comments on the Andøya exposure. *Norsk Geologisk Tidsskrift*, Vol. 66, pp. 17–43. Oslo 1986. ISSN 0029-196X.

Ryazanian black shales in a core close to the eastern margin of the Trøndelag Platform offshore Helgeland, northern Norway are overlain by a condensed latest Ryazanian-Barremian sequence of grey and red Utvik Formation equivalent marls and mudstones. Palaeontological studies show that the 'Late Cimmerian Unconformity' represents only a minor hiatus in the Upper Ryazanian. Upper Valanginian-Lower Hauterivian beds seem to be absent. The generalized model for the North Sea and adjacent areas (Rawson & Riley 1982) thus seems applicable to more northern areas, as would be expected if sedimentation was mainly controlled by eustatic sea level changes. The section is compared to the Lower Cretaceous sequence at Andøya, the stratigraphy of which is revised.

N. Aarhus & J. Verdenius, Inst. for kontinentalsokkelundersøkelser og petroleumsteknologi A/S, Postboks 1883, 7001 Trondheim, Norway.
T. Birkelund, Inst. for hist. geol. og palæont., Københavns Universitet, Øster Voldgade 10, DK-1350, København K, Denmark.

The major break interpreted from seismic profiles and lithology at the base of the Valhall Formation in the North Sea and adjacent areas also occurs on seismic profiles offshore Helgeland (Fig. 1) in equivalent stratigraphic position. This 'Late Cimmerian Unconformity' appears on Fig. 2 as an erosional surface with no angular discordance between the two units. During the summer of 1982 the beds around the boundary were cored at 65°06.0′N, 10°17.3′E by the drilling ship 'Pholas' in a shallow drilling programme along E–W seismic profiles in the area. The strata are dipping gently to the west. This drilling programme is part of a mapping programme run by IKU (Maisey & Wøien 1983, Bugge, Knarud & Mørk 1984).

Material

Two cores were recovered from the same site due to technical problems in the first hole. The technique involves sampling by mechanical hammering through the outer drill string. Wire line coring can start when reasonably well consolidated strata have been reached. Only three hammersamples are available from the 5.1 m deep corehole 7. Seven hammersamples were collected from the upper part (4.5–9.2 m) of corehole 7B. Wire line coring with 100% recovery started at 9.2 m and continued to the base at 28.55 m. The palynological slides with the figured palynomorphs are housed in the Paleontologisk Museum, Oslo (PMO).

Core description

The interval 28.55–11.00 m in core 7B (Fig. 3) consists of black homogeneous organic-rich claystones. Neither sedimentary structures nor bioturbation were observed. Some specimens of the bivalve genus *Buchia* occur. Smectite is the dominant clay mineral. The total organic carbon content varies from 4 to 11%, and the rock has a rich hydrocarbon potential. Immature unstructured organic material is dominant, but palynomorphs and woody material also occur.

At 11.00 m there is an abrupt lithological change at a planar boundary (as seen in a core 5 cm in diameter) to an approximately 20 cm thick light grey and grey intraformational conglomeratic limestone. The clasts and matrix are differentiated on their colours, but interfinger and may be difficult to distinguish.

Above there are 25 cm of calcareous mudstone below another more well cemented micritic limestone without intraclasts at 10.55 m. The calcite

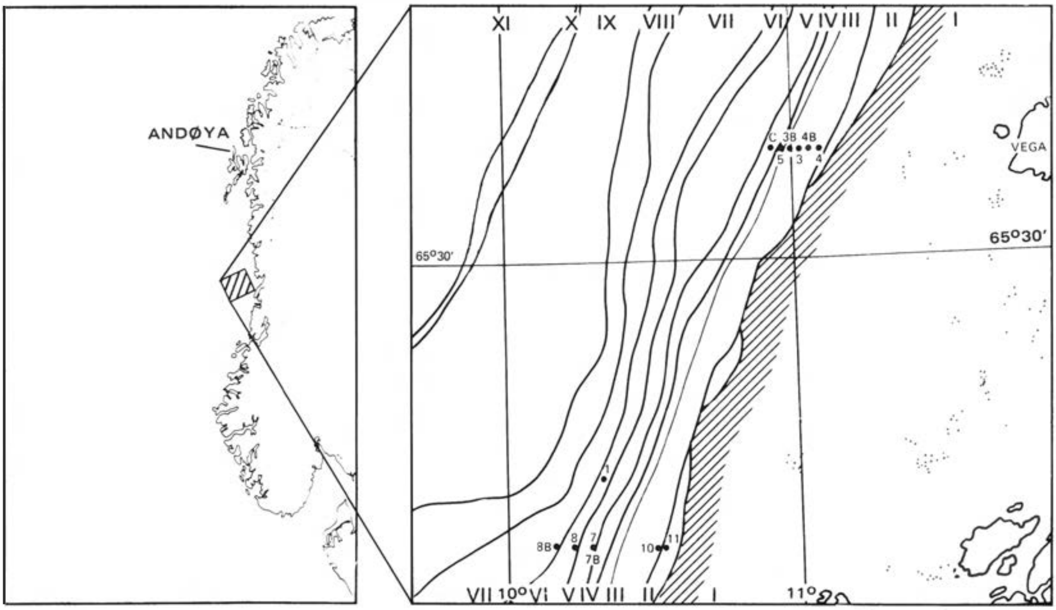


Fig. 1. Sketch map showing location of boreholes in IKU shallow drilling programme 1982. Cores 7 and 7B (same location) are here studied. Roman numerals indicate seismic units. The location of Andøya is also shown.

content is 90% at 10.45 m and decreases to 75% at 10.20 m from where it is further reduced to 15–40%. Siderite and dolomite do not occur. At 7.30 m there is a colour change of the marl from light grey to redbrown associated with the disappearance of pyrite.

Calcareous fossil fragments are few both in the limestones and marls. A few *Inoceramus* frag-

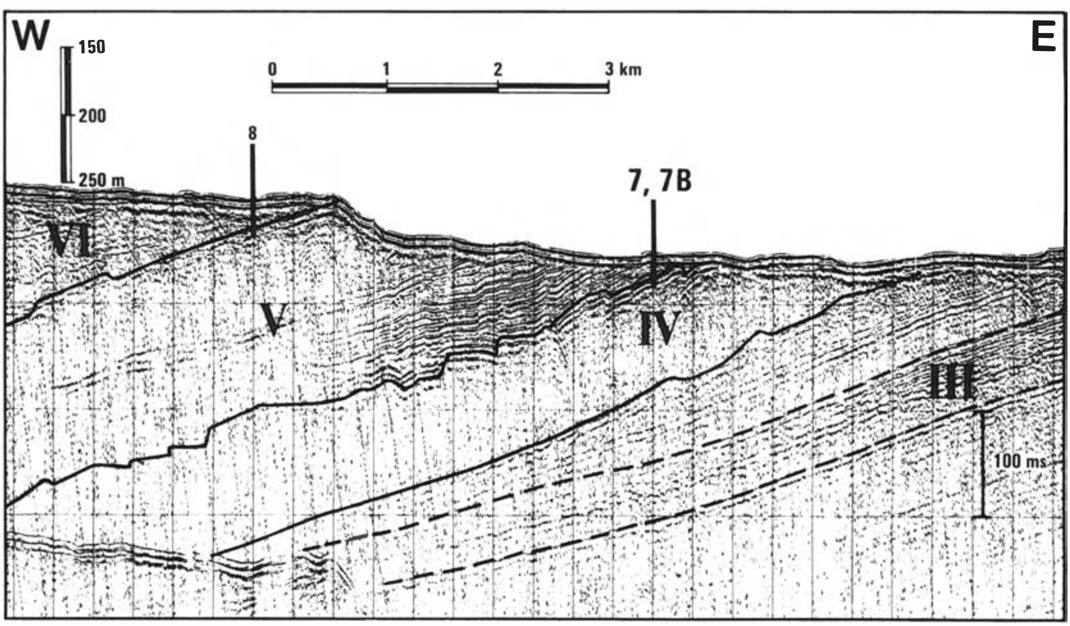


Fig. 2. Shallow seismic line B78–103 with location of studied coreholes. Seismic interpretation by Tom Bugge.

ments are found, some of them bored probably by sponges (*?Clionia*). Fungal borings are present in woody fragments from all the nine very small (except at 10.10 m) organic residues recovered from the interval 10.30–9.35 m. These woody fragments may well be reworked from the Ryazanian, whereas the rest of the reworked organic material was less resistant and has not been preserved.

The redbrown calcareous claystone in the two lower hammersamples (4.00–4.30 m and 5.00–5.10 m) from corehole 7 is similar to that above 7.30 m in corehole 7B. Reduction spots and *Inoceramus* fragments occur. There is a thin grey bed around 4.24 m. The redbrown hammersample at 2 m in hole 7 contains pebbles icedropped in calcareous clay similar to that below and represents Quaternary cover consisting mostly of in situ or nearly in situ weathering products.

28.55–10.85 m Ryazanian

Palynology

The occurrences of *Batioladinium pomum* (lamplughii zone, eastern England, but younger in the Haldager borehole no. 1) and *B. radiculatum* (*runctoni-icenii* zones, eastern England) (Davey 1982) throughout the black shale unit point to an age no older and hardly younger than Ryazanian. *Systematophora palmula, Stiphrosphaeridium arbustum* and *Kleithriasphaeridum porosispinum* from 23.32 m and upwards support a Ryazanian dating.

Egmontodinium expiratum from the base to 16.65 m, according to Davey, would restrict the age to the *runctoni* zone (earliest Ryazanian). Other species in the core which occur consistently and have extinctions similar to that of *E. expiratum* are *Stiphrosphaeridium dictyophorum* and *Dingodinium spinosum*. They are, however, not found below 25.60 m. We think they have some stratigraphic potential in the area. This is also the case for *Systematophora palmula* (present in the *albidum* Zone in the Speeton Clay according to Davey (1982)). In contrast to in England, it has a partly overlapping range with that of *E. expiratum* and occurs to the top of the black shale. The recorded species thus conflict with some of the ranges in Davey (1982). Based on macrofossil evidence, a middle Late Ryazanian *tzikwinianus* zone age seems likely at 13.20 m.

The unit is otherwise characterized by consistently occurring *Tubotuberella apatela, Chlamydophorella membranoidea, Sirmiodinium grossii, Gochteodinia villosa* and *Scriniodinium pharo* which all are in accordance with a Ryazanian dating. *S. grossii* is common to abundant in the uppermost metre of the black shale, at 11.25 m together with *Hysterichodinium voigtii*. This is probably a result of change in environment; the luxuriance of these species is associated with the incoming of a bivalve bottom fauna which possibly reflects improved circulation of water. Samples at 12.60 and 11.51 m, however, do have high proportions of phytane. Some workers take this as an indication of reducing depositional environment. The rich content of organic material (although unstructured) also suggests that reducing or oxygen-poor bottom conditions still prevailed. Possibly *Buchia* or some species of this genus could live in water with low oxygen content. But we will not completely exclude the possibility that these shells may have been dropped into the sediment.

Nannofossils

Samples in the black claystone proved to be barren. The interval 10.95–10.85 m yielded a species-poor nannofossil association dominated by *Ellipsagelosphaera* spp. Of biostratigraphic significance is the presence of *Palaeopontosphaera salebrosa, Nannoconus colomi, Nannoconus globulus* and *Nannoconus steinmanni.*

Nannoconids have not been reported before from earliest Cretaceous strata of north-western Europe. According to Deres & Achéritéguy (1980), the above-mentioned nannoconids and the absence of younger forms are characteristic for a Berriasian age. A remarkable element in both samples is *Sollasites arcuatus*. In the Speeton Clay, this species is restricted to bed D6 (Berriasian) according to Black (1971) and our own observations.

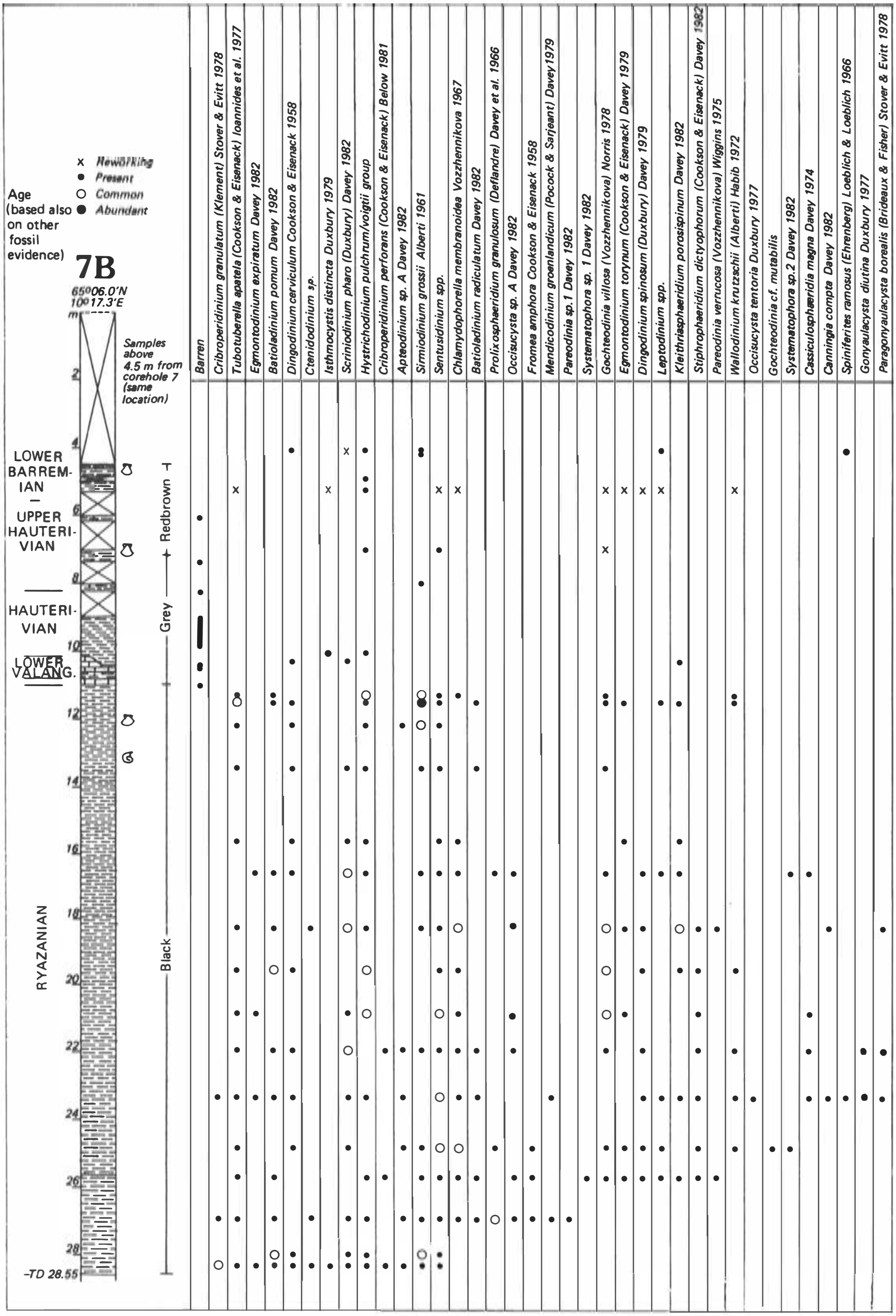
Macrofossils

A fragment of an ammonite has been found at 13.20 m and in the interval from 12.00–11.95 m a number of heavily crushed buchiid bivalves occur. In spite of the poor preservation, the material gives a clue as to the age of this part of the core.

Surites sp. cf./aff. *tzikwinianus* (Bogoslovsky, 1897)

1897 *Olcostephanus tzikwinianus* Bogoslovsky, p. 59, 141, pl. 2, figs. 6a-d.

1964 *Surites tzikwinianus* (Bogoslovsky): Donovan, p. 31, pl. 7, fig. 1.


x Reworking
• Present
○ Common
● Abundant
Age (based also on other fossil evidence)
7B
65°06.0'N
10°17.3'E
Samples above 4.5 m from corehole 7 (same location)
LOWER BARREMIAN – UPPER HAUTERIVIAN
HAUTERIVIAN
LOWER VALANG.
RYAZANIAN
Redbrown
Grey
Black
-TD 28.55
Barren
Cribroperidinium granulatum (Klement) Stover & Evitt 1978
Tubotuberella apatela (Cookson & Eisenack) Ioannides et al. 1977
Egmontodinium expiratum Davey 1982
Batioladinium pomum Davey 1982
Dingodinium cerviculum Cookson & Eisenack 1958
Ctenidodinium sp.
Isthmocystis distincta Duxbury 1979
Scriniodinium pharo (Duxbury) Davey 1982
Hystrichodinium pulchrum/voigtii group
Cribroperidinium perforans (Cookson & Eisenack) Below 1981
Apteodinium sp. A Davey 1982
Sirmiodinium grossii Alberti 1961
Sentusidinium spp.
Chlamydophorella membranoidea Vozzhennikova 1967
Batioladinium radiculatum Davey 1982
Prolixosphaeridium granulosum (Deflandre) Davey et al. 1966
Occisucysta sp. A Davey 1982
Fromea amphora Cookson & Eisenack 1958
Mendicodinium groenlandicum (Pocock & Sarjeant) Davey 1979
Pareodinia sp.1 Davey 1982
Systematophora sp. 1 Davey 1982
Gochteodinia villosa (Vozzhennikova) Norris 1978
Egmontodinium torynum (Cookson & Eisenack) Davey 1979
Dingodinium spinosum (Duxbury) Davey 1979
Leptodinium spp.
Kleithriasphaeridium porosispinum Davey 1982
Stiphrosphaeridium dictyophorum (Cookson & Eisenack) Davey 1982
Pareodinia verrucosa (Vozzhennikova) Wiggins 1975
Wallodinium krutzschii (Alberti) Habib 1972
Occisucysta tentoria Duxbury 1977
Gochteodinia cf. mutabilis
Systematophora sp.2 Davey 1982
Cassiculosphaeridia magna Davey 1974
Canningia compta Davey 1982
Spiniferites ramosus (Ehrenberg) Loeblich & Loeblich 1966
Gonyaulacysta diutina Duxbury 1977
Paragonyaulacysta borealis (Brideaux & Fisher) Stover & Evitt 1978

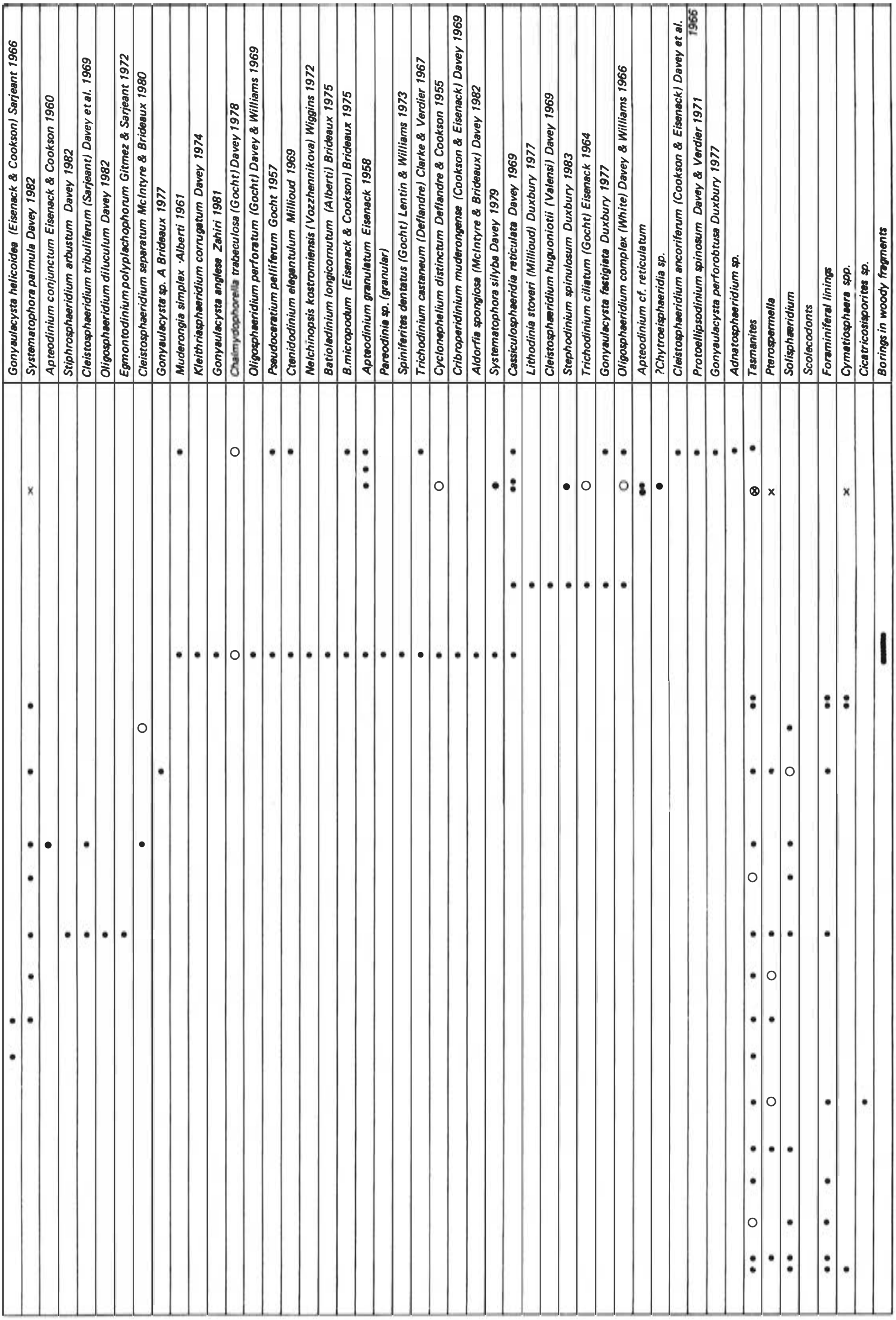


Fig. 3. Palynological range chart from cores 7 and 7B.

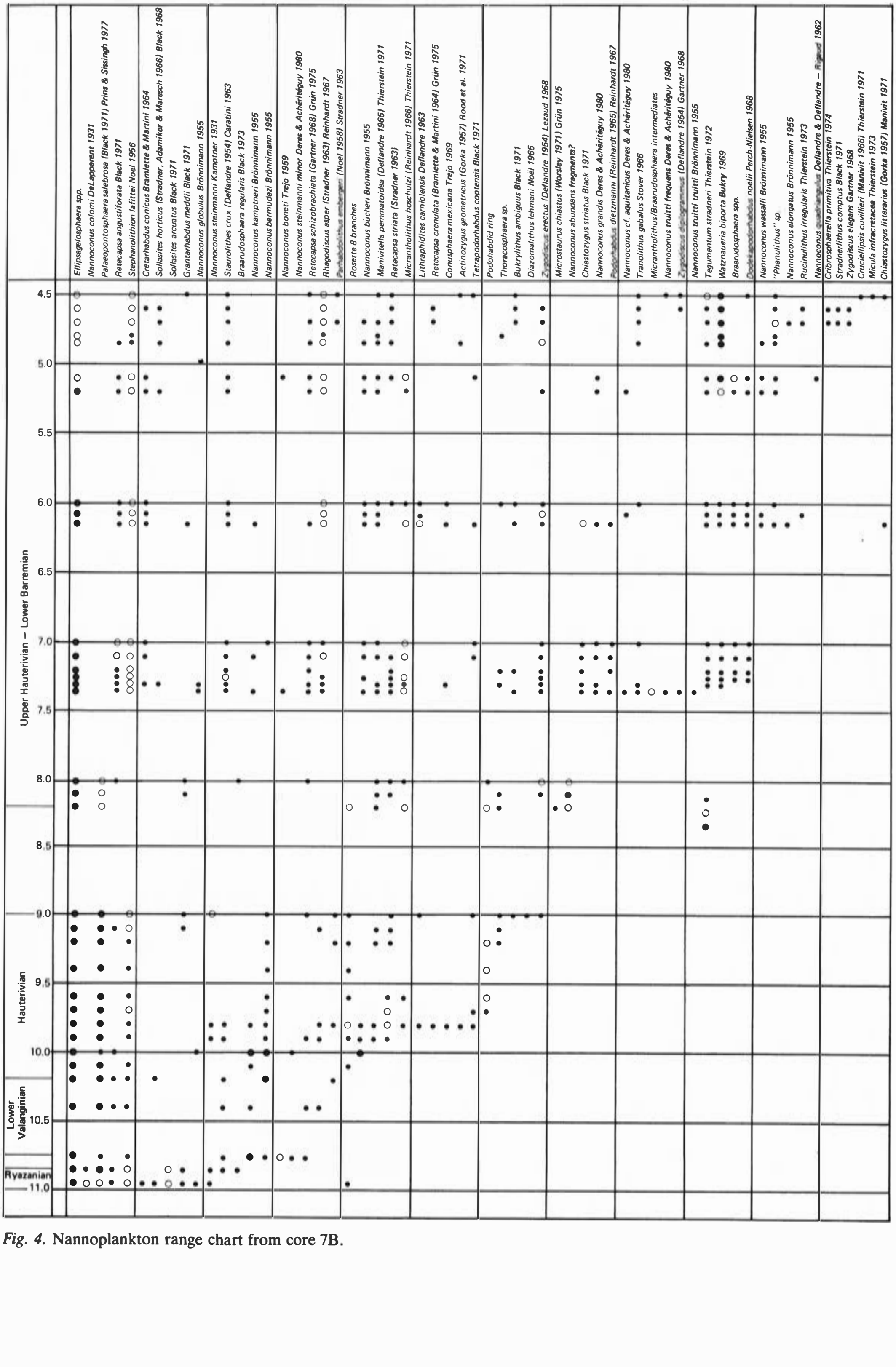


Fig. 4. Nannoplankton range chart from core 7B.

Fig. 5. Fragment of *Surites* sp. cf./aff. *tzikwinianus* (Bogoslovsky, 1897) at 13,20 m in core 7B. PMO 113.363.

?1965 *Tollia* (*Tollia*?) aff. *simplex* (Bogoslovsky): Jeletzky, p. 38, pl. 8, fig. 8.
1978 *Surites tzikwinianus* (Bogoslovsky): Surlyk, p. 32, pl. 7, fig. 1.
1979 *Surites* cf. *tzikwinianus* (Bogoslovsky): Mesezhnikov et al., p. 68, 70, pl. 1, fig. 10.

The single fragment from 13.20 m (Fig. 5) is heavily distorted. Coiling is fairly evolute. The ribbing pattern is best seen on a cast of the imprint. The ribs are sharp and bifurcate or, in a few cases, trifurcate on the middle of the flanks. They seem to show a forward bend ventrally and a single constriction is developed.

The coiling and the ribbing pattern are in good agreement with representatives of the genus *Surites* from the *S. tzikwinianus* Zone. The fragment compares well with material referred to *S. tzikwinianus* from East Greenland by Donovan (1964) and Surlyk (1978). A *Surites* sp. from the same level as *S. tzikwinianus* described from East Greenland by Donovan (1964, p. 32, pl. 7, figs. 2–5) shows occasional constrictions, as does the present species. There is also a similarity with the specimen figured by Mesezhnikov et al. (1979) from the Petshora River Basin.

Surites tzikwinianus is a Boreal species, known from East Greenland, the Russian Platform, Siberia (Taimyr, Anabar-Katanga, Petshora) and possibly also from Vancouver Island, Canada (see discussion in Saks et al. 1972, p. 114 and Jeletzky 1984, p. 217).

Surites tzikwinianus characterizes the *S. tzikwinianus* Zone of the Russian Platform and defines a level above the *Surites analogus* Zone of Siberia (see Mesezhnikov et al. 1979). In East Greenland it is confined to a level between *Surites analogus* and *Bojarkia mesezhnikovi* (Surlyk 1978).

The occurrence of this fragment seems thus to indicate the presence of Upper Ryazanian at this level.

Buchia cf. *volgensis* (Lahusen, 1888)
1888 *Aucella volgensis* Lahusen, p. 16, pl. 3, figs. 1–17.
1978 *Buchia volgensis* (Lahusen): Birkelund, Thusu & Vigran, p. 56, pl. 4, figs. 1–4; pl. 5, figs. 4–6.
1978 *Buchia volgensis* (Lahusen): Surlyk, p. 32, pl. 6, figs. 1–5.
1981 *Buchia volgensis* (Lahusen): Zakharov, p. 125, pl. 37, figs. 5–7; pl. 38, figs. 1–3; pl. 39, figs. 1–4; pl. 40, figs. 1–2; text-fig. 23.
1981 *Buchia volgensis* (Lahusen): Zakharov, Surlyk & Dalland, p. 264, pl. 1, fig. 5.
1982 *Buchia volgensis* (Lahusen): Surlyk & Zakharov, p. 740, pl. 75, fig. 2.
1984 *Buchia (Buchia) volgensis* (Lahusen): Kelly, p. 58, pl. 10, figs. 1, 3, 4, 7, 8.

The *Buchia* material consists of a few crushed specimens from the 12.00–11.95 m interval. The only fairly well preserved specimen shows a slightly crushed right valve with part of the umbo of the left valve preserved. Another heavily distorted specimen has a convex left valve and a much less convex right valve.

Buchia volgensis is widely distributed in the Boreal Realm and is known as far south as the southern Caspian Sea in Asia and as far south as California in the Pacific (see distribution map in Zakharov 1981, p. 130).

The stratigraphy of *B. volgensis* has most recently been discussed by Zakharov (1981), Zakharov et al. (1981), Surlyk & Zakharov (1982), Kelly (1984) and Jeletzky (1984).

In most parts of the Boreal Realm the species has its first occurrence in the *Hectoroceras kochi* Zone. It reaches its main abundance in the *Surites analogus* Zone and has its last appearance in the *Bojarkia mesezhnikovi* Zone.

This is in good accordance with the occurrence of *Surites* sp. cf./aff. *tzikwinianus* 1.20 m below.

10.75–10.20 m Lower Valanginian

Palynology

We have recorded no marine palynomorphs in the limestones at 11.00 and 10.40 m. However, a poor assemblage with *Scriniodinium pharo* is present at 10.36 m. According to Duxbury (1977) and Davey (1979, 1982), *S. pharo* ranges no higher than earliest Valanginian.

Nannofossils
At 10.75 m, a nannoflora of mainly nannoconids and *Ellipsagelosphaera* spp. is met. The deepest occurrence of *Nannoconus kamptneri, Nannoconus bermudezi* and *Nannoconus boneti* and the presence of *Nannoconus steinmanni minor* are evidence of a Valanginian age. In the overlying limestone unit (samples 10.40 m and 10.20 m) the nannoconids lose their predominance, but in other aspects there is no change in the nannofossil association.

10.20–9.00 m Hauterivian

Palynology
A diverse dinocyst flora with *Batioladinium longicornutum, B. micropodum, Muderongia simplex, Pseudoceratium pelliferum, Gonyaulacysta anglese, Nelchinopsis kostromiensis* and *Chlamydophorella trabeculosa* as the most age-significant species occurs at 10.10 m and indicates a *regale* Zone or younger Hauterivian age. *M. simplex* may, according to Davey (1979), restrict the age to the middle part of the Hauterivian (*regale-gottschei* Zones).

Thus a hiatus representing Late Valanginian and Early or earliest Hauterivian may be located between 10.10 and 10.36 m, probably at the lithological change at 10.20 m.

The recovery in the samples above 10.10 m is much reduced. Nine samples between 10.00 and 8.00 m are barren or nearly so with respect to palynomorphs.

Nannofossils
In grey marl that is found immediately over the previous sample at 10.20 m, *Ellipsagelosphaera* spp. and *Palaeopontosphaera salebrosa* are dominant or very numerous in all samples. *Nannoconus bücheri* at 10.00 m and *Retecapsa striata* at 9.90 m give evidence of a Hauterivian age. We prefer, however, to situate the stratigraphic boundary at the lithological break at 10.20 m, under the assumption that the absence of index forms in the deepest samples has been caused by less favourable conditions in the early stage of a new sedimentary cycle.

The range of the species logged as *Retecapsa striata* is probably a combination of the ranges of *Cretarhabdus loriei* (sensu Sissingh 1977) with *Polypodorhabdus madingleyensis* and *Cretarhabdus striatus* as mentioned by Taylor (1982). Based on the work of Sissingh and on experience from the North Sea, we assume that the lowest occurrence of this form in the Lower Cretaceous is of stratigraphic significance. Its taxonomic situation and relation to the Jurassic *Polypodorhabdus madingleyensis* have to be checked, however. Coccoliths are poorly represented in the deeper part of the interval, but *Nannoconus* spp. are very numerous. *Nannoconus bücheri* is abundant at 10.00 m. This species occurs at a few localities in the Hauterivian, but has a more extended distribution during the Barremian and Aptian (Deres & Achéritéguy 1980).

Nannoflora diversity increases markedly at 9.80 m. At this level the deepest occurrence of *Conusphaera mexicana* and *Actinozygus geometricus* is logged. In the South European province, these species occur from the earliest Cretaceous and Late Jurassic respectively, whereas in Great Britain they occur from the Early Hauterivian *noricum* Zone (Taylor 1982).

8.20–4.00 m Upper Hauterivian – Lower Barremian

Palynology
An assemblage with *Sirmidodinium grossii* occurs at 8.00 m and points to an age no younger than Barremian. *S. grossii* is also present at 4.13 and 4.00 m in core 7.

The assemblage at 8.00 m includes *Lithodinia stoveri, Gonyaulacysta anglese* and *G. fastigiata.* Duxbury (1977) found *L. stoveri* only in latest Hauterivian strata, but may occur higher (Renéville & Raynaud 1981). *G. anglese* occurs in the Hauterivian and in the earliest Barremian in the Barremian stratotype (Zahiri 1981).

The assemblages of most samples from the red-brown marls of both core 7 and 7B are characterized by *Oligosphaeridium complex* (grading into *O. asterigerum*), *Trichodinium ciliatum, T. castaneum, Cyclonephelium distinctum, Apteodinium granulatum* (occasionally tabulated), *Ellipsoidictyum imperfectum* and *Systematophora silyba.* Most of these species are not very age significant, although *T. ciliatum* according to Davey (1979) does not range above early Barremian.

The more diverse assemblage at 4.20 m in hole 7 includes several pre-Aptian elements such as

Ctenidodinium elegantulum, Occisucysta tentoria and *Gonyaulacysta fastigiata.*

The presence at 4.20 m also of *Muderongia simplex* does, according to Davey (1979, 1982), indicate an early Late Hauterivian age to the top of the core. Additional evidence suggestive of the Hauterivian is the presence of *Gonyaulacysta perforobtusa,* which Duxbury (1977) found only in the Hauterivian, and the lack of exclusively Barremian and younger species such as *Odontochitina operculata.*

The earliest Valanginian and older *Scriniodinium pharo* at 4.03 m in core 7 and *Gochteodinia villosa* (forms very similar to those recorded from the Ryazanian strata below) at 7.03 and 5.25 m in 7B suggest reworking.

Nannofossils

Three samples from the hammer-core at 8.20–8.00 m yielded numerous 5–7 sided discs of slightly irregular symmetry. These objects are strongly reminiscent of fragments of *Nannoconus abundans,* but undamaged specimens have not been found. In Great Britain, *Nannoconus abundans* is mentioned from the latest Hauterivian and Barremian (Perch-Nielsen 1979, Taylor 1982). According to Deres & Achéritéguy (1980), the full range of this species is Barremian and Aptian. The presence of *Palaeopontosphaera salebrosa* in the same samples necessitates some comment. According to Taylor (1980), the latest occurrence of this species is situated in the earliest Barremian. However, Sissingh (1977) gives a latest occurrence in the Lower Hauterivian (zone 4a). Black (1971) and Perch-Nielsen (1979) did not find this species in the Speeton Clay in strata younger than Hauterivian. In our corehole 7B, this species is common to abundant from 9 m downward, but clearly less common in the 8.20–8.00 m interval. It is possible that this species is reworked here. Similarly, reworking could have affected the range of this species elsewhere in the North European basins, where sedimentation breaks are not uncommon in the Lower Cretaceous.

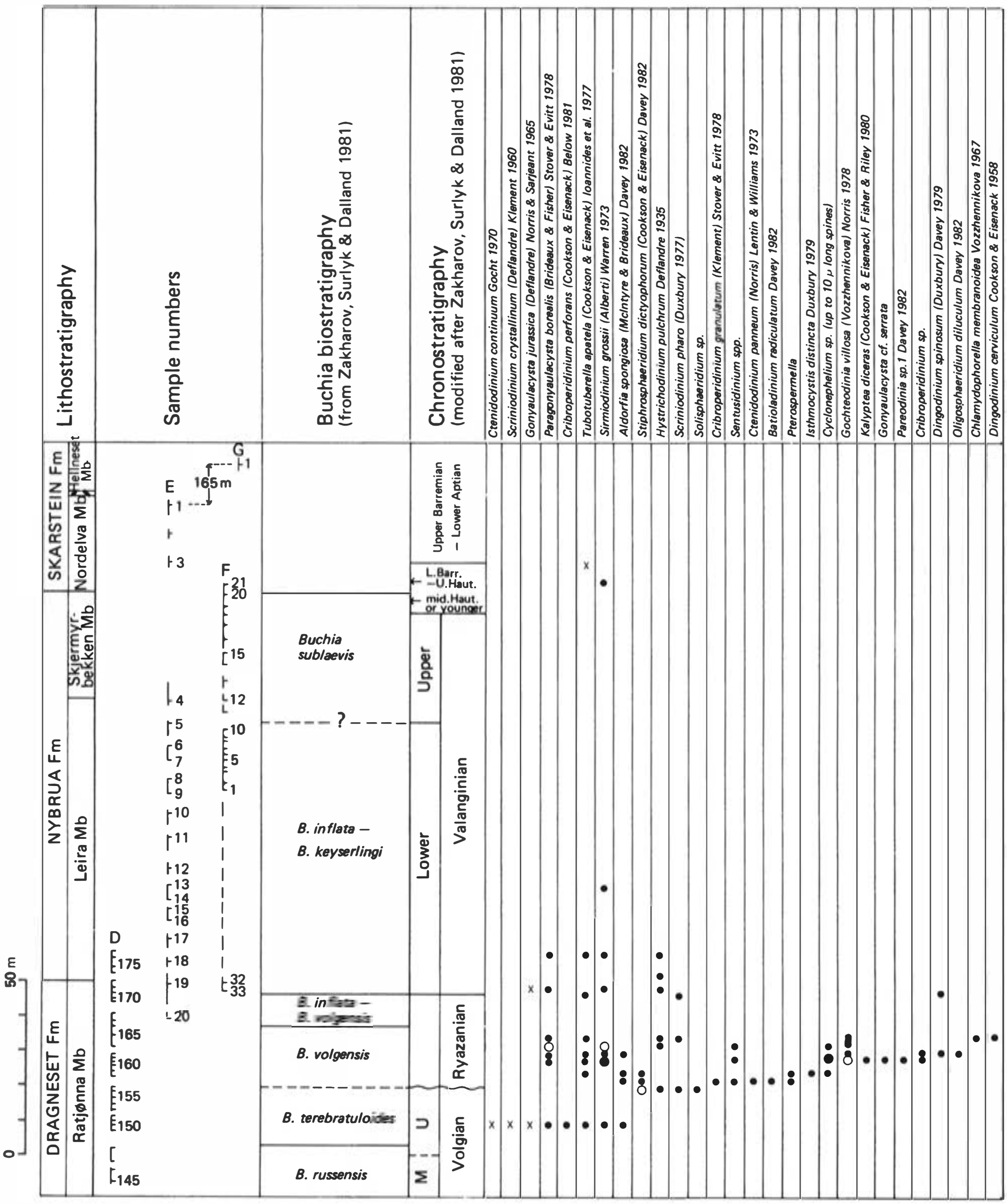
The interval from 7.36 m to 4.50 m consists of four hammer-cores separated by unsampled intervals. The nannofossil distribution chart shows a pattern of earliest occurrences that is suggestive of several minor breaks, e.g. one below 7.36 m, one between 7.36 m – 7.30 m, one below 6.17 m and one between 4.80 m – 4.70 m. In-between these breaks, the nannofossil associations of consecutive samples are quite homogeneous. For this reason we assume that the sections between the breaks each represent a sedimentary cycle. The logged earliest occurrences do not lead to a straightforward age conclusion. It is possible that the nannofossil association variations of these cycles largely testify to reworking and resedimentation. Several earliest occurrences of taxa are noted that occur in the Hauterivian according to Taylor (1982), e.g. *Chiastozygus striatus, Tegumentum stradneri* and *Tranolithus gabalus.* Part of the evidence is consistent with a Barremian or younger age, e.g. the earliest occurrence of a characteristic *Nannoconus* assemblage (Perch-Nielsen 1979, Deres & Achéritéguy 1980). On the other hand, the presence of an assemblage of *Braarudosphaera* spp. and isolated occurrences of *Rucinolithus irregularis* and *Cribrosphaerella primitiva* might imply an even younger age, e.g. Aptian.

There are several possibilities for error, because of the character of the studied section and our imperfect knowledge of Early Cretaceous nannofossils and their ranges. At present we assume that the best nannofossil evidence is in favour of a Late Hauterivian – Barremian age.

Several features deserve comment. *Braarudosphaera* spp., which is encountered from 7.25 m upward, occurs nearly exclusively in the form of segment fragments. These fragments were initially related to *Braarudosphaera hockwoldensis,* implying an Aptian age (Perch-Nielsen 1979). Because of the predominance of fragments, we suppose that the form of the pentalith segments could very well be an artifact. Common *Braarudosphaera* as observed may be related to marginal marine conditions and may have little biostratigraphic significance.

Nannoconus spp. are well preserved in the interval under discussion. *Nannoconus grandis, N. aquitanicus, N. truitti frequens* and *N. truitti truitti* occur simultaneously at 7.36 m. The correlation of this assemblage with other sections reveals some discrepancies. It is probable that a typical *Nannoconus* assemblage developed in the Early Barremian (Perch-Nielsen 1979). According to Deres & Achéritéguy (1980), the *Nannoconus truitti* group has its earliest occurrence in the Aptian. Taylor (1982) mentions no *Nannoconus* at all before the Late Hauterivian in Great Britain. In the Barremian, she logs *Nannoconus abundans* as only representative, whereas an enriched assemblage that also contains *Nannoconus truitti,* reappears in the Late Aptian.

The discrepancies that are mentioned may



partly be caused by differences in species concept and the taxonomy of *Nannoconus*. In addition, some biostratigraphic inconsistencies can have their cause in the environmental restrictions of this group. More study of *Nannoconus* will be necessary to make full use of its possibilities.

Our *Nannoconus* results fit best with the trend of those summarized by Perch-Nielsen (1979) for the Tethyan realm that are markedly different from the results obtained on the British Isles. Deres & Achéritéguy (1980) let their stratigraphic scheme be controlled by a strict subdivi-

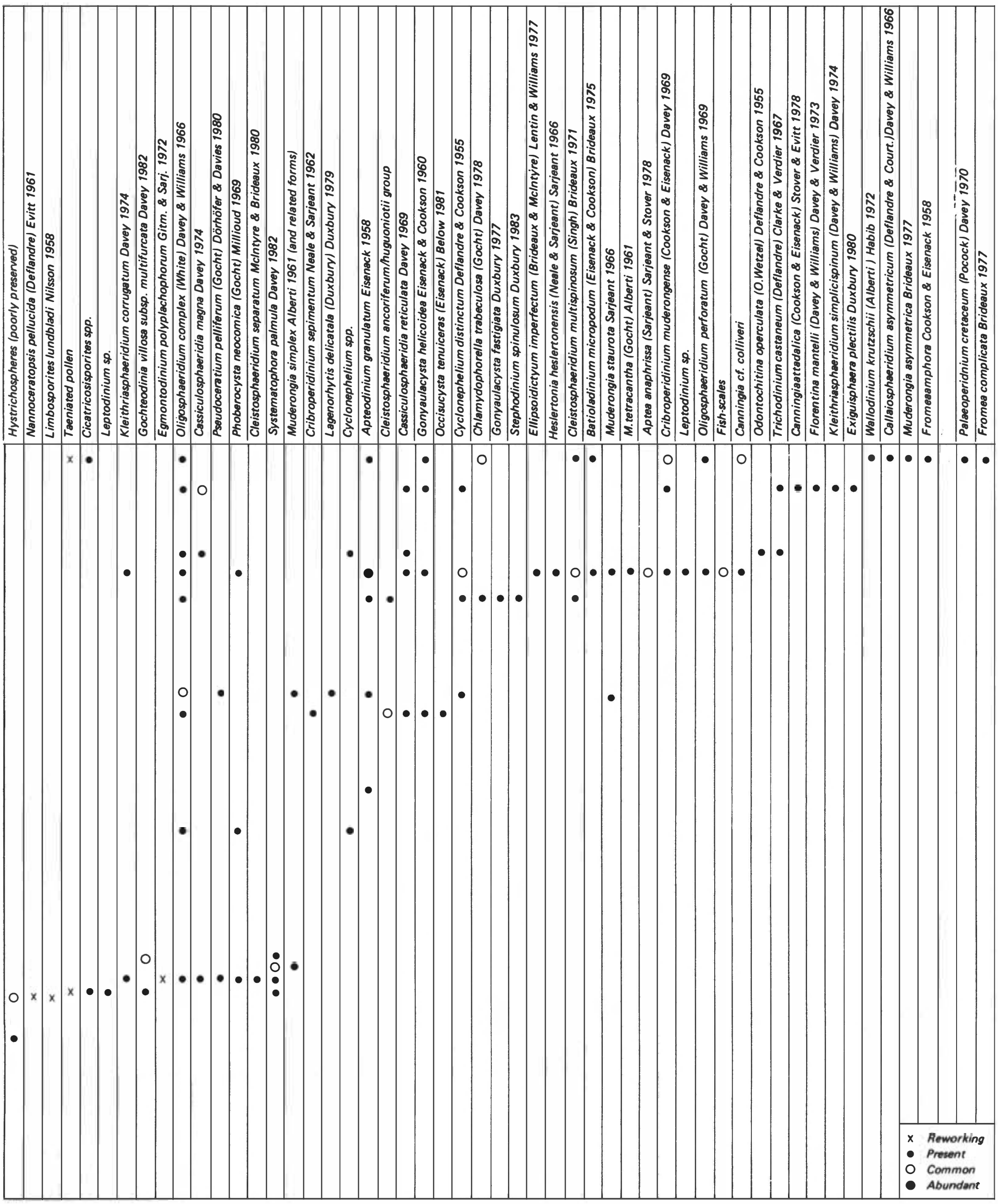


Fig. 6. Palynological range chart from the upper part of the Mesozoic sequence on Andøya.

sion in stages; this does not facilitate its correlation to other biostratigraphic results.

The presence of *Watznaueria biporta* needs some comment. Perch-Nielsen (1979) mentions an occasional occurrence of this species from the later Hauterivian, and its regular presence from the Aptian onward. Taylor (1982) mentions *Watznaueria biporta* from the latest Hauterivian and up, whereas *Watznaueria barnesae* ranges over the entire Early Cretaceous.

In nearly all samples used in this study, specimens of the *Watznaueria/Ellipsagelosphaera* plexus are very numerous. Consequently first occurrences that by their nature are rare in a sample, are easily overlooked if no exhaustive search is made. The earliest occurrence of *Watznaueria biporta* in our samples is not considered of great stratigraphic value.

Comments on the Lower Cretaceous stratigraphy of Andøya

A number of geologists have, since around 1870, contributed to the understanding of the Jurassic – Lower Cretaceous sequence of Andøya. Sokolov (1912), Ørvig (1953, 1960), Birkelund, Thusu & Vigran (1978), Løfaldli & Thusu (1979) and Zakharov, Surlyk & Dalland (1981) studied palaeontological aspects of the Lower Cretaceous strata. We have here reinvestigated some Cretaceous palynological slides as they are relevant for the Sklinnabanken core.

Dalland (1975) reviewed the stratigraphy and presented the sedimentology of Andøya. Below the Valanginian sandstones in his Leira Member he described some dark, partly laminated siltstones of the mainly Volgian Ratjønna Member with hard, light, slightly calcareous sandstone layers in the upper part. At the top the Ratjønna Member contains a few metres of sediment which Dalland (1981) distinguished as shales.

Birkelund, Thusu & Vigran (1978) assigned a Middle Volgian – Ryazanian age for the Ratjønna Member. They found Ryazanian evidence only in the uppermost part where *Surites* (*Bojarkia*) cf. *mesezhnikovi* and *Buchia volgensis* occur together, suggesting that these beds (D164) may be referred to the youngest Ryazanian ammonite zone in the Boreal Realm. According to Casey (1973) this can be correlated with the *stenomphalus* and *albidum* Zones of eastern England.

Zakharov, Surlyk & Dalland (1981) found an assemblage in D171 with *Buchia inflata* and *B.* ex gr. *volgensis* above the Late Ryazanian assemblage of Birkelund et al. (1978). Evidence from Petschora and Cheta River basins points to a latest Ryazanian age (upper part of *Bojarkia mesezhnikovi* Zone) (Zakharov 1981).

Age-significant macrofossils have so far not been found in the uppermost part of the sequence, the Skarstein Formation of Ørvig (1960). Birkelund, Thusu & Vigran (1978) assigned a Cretaceous (Aptian?) age on the basis of dinocysts in the lowermost beds of the Nordelva Member. Later Løfaldli & Thusu (1979) on micropalaeontological evidence modified the dating of the whole formation to ?Barremian – ?Aptian.

Palynology

We have here reexamined some samples collected by Dalland and examined palynologically by Thusu in Birkelund, Thusu & Vigran (1978) and Løfaldli & Thusu (1979), see Fig. 6. The Upper Volgian sample D150 with *Buchia terebratuloides* (Zakharov, Surlyk & Dalland 1981) contains *Cribroperidinium perforans, Aldorfia spongiosa* and a few other species consistent with a Late Volgian age, but alone only indicative of a Middle Volgian or younger age. Reworked specimens from Late Callovian or Oxfordian strata are present.

Scriniodinium pharo in sample D156 points to a latest Volgian to earliest Valanginian age. The co-occurrence of common *Stiphrosphaeridium dictyophorum* according to Davey (1982) favours an Early Ryazanian age, although evidence from Sklinnabanken suggests that it may range higher (5 m below *Surites* cf./aff. *tzikwinianus*). *Batioladinium radiculatum* (in D157) according to evidence from Sklinnabanken also seems to range higher than the earliest Upper Ryazanian *icenii* Zone as claimed by Davey (1982).

We have recorded only somewhat longer ranging species in D158. The abundance of *Sirmiodinium grossii* in D160 and D163 may possibly correlate to the *S. grossii* event immediately below the top of the black shales offshore Helgeland. In D160 it occurs together with common *Gochteodinia villosa.*

Oligosphaeridium diluculum, known onshore only from the *stenomphalus* Zone (Davey 1982), is also present. The topmost records of *Dingodinium spinosum* and *Scriniodinium pharo* in D170 are consistent with a latest Ryazanian age (upper part of *Bojarkia mesezhnikovi* Zone) as claimed by Zakharov et al. (1981) for D171. *S. pharo* ranges into earliest Valanginian strata whereas *D. spinosum* probably does not occur above the Ryazanian (Duxbury 1977). Reworked Upper Triassic and Middle Jurassic forms occur in D170 and D171.

Sample E19 from just below the Dragneset/Nybrua formational boundary contains a distinctive Valanginian assemblage with *Pseudoceratium pelliferum, Phoberocysta neocomica, Oligosphaeridium complex* and *Gochteodinia villosa. Systematophora palmula* and *G. villosa* subsp. *multifurcata* are dominant in D174 and

E18, respectively. The latter is indicative of the Lower Valanginian.

The recovery in the upper part of the Nybrua Formation is poor. Samples E10 and F9 are barren. E11, F1 and E5 contain only age undiagnostic Lower Cretaceous species. The presence of *Lagenorhytis delicatula* (Fig. 8j) in F13 supports a Valanginian age at this level (Duxbury 1977). F13 is located within an interval with *Buchia sublaevis* present in most samples and a left valve very close to *Buchia crassicollis* in sample F14 (Zakharov, Surlyk & Dalland 1981). They stated that these two species do not occur together below the Upper Valanginian.

Chlamydophorella trabeculosa in sample F19 points to a late Early Hauterivian or younger age from this level (Duxbury 1977, Davey 1979, Piasecki 1981). *Gonyaulacysta fastigiata* is additional post-Valanginian evidence. Due to the recovery of an Upper Hauterivian – Lower Barremian assemblage with *Muderongia staurota* and *M. tetracantha* in F21 and the lack of Barremian evidence in F19, a Hauterivian age is likely for this sample. According to our experience *Aptea anaphrissa* (common in F21) in northern areas probably has a somewhat longer range than claimed by Duxbury (1977) and Davey (1979). The cooccurrence in Andøya with *M. tetracantha* supports this.

Odontochitina operculata in sample E3 indicates a Barremian, probably Late Barremian or younger age. In the Barremian stratotype Renéville & Raynaud (1981) found only scattered specimens of this in the Lower Barremian, whereas they recorded it consistently in the Upper Barremian. We cannot exclude an Aptian age for this sample.

The recovery in sample E1 from the lower part of Nordelva Member is consistent with a late Barremian-Aptian age. Sample G1 from the Hellneset Member is located about 165 m above E1 and is out of scale in Fig. 6. It contains *Muderongia asymmetrica, Palaeoperidinium cretaceum, Apteodinium granulatum* and *Batioladinium micropodum* and common *Chlamydophorella trabeculosa, Cribroperidinium muderongense* and *Canningia* cf. *colliveri.* This assemblage is most likely Aptian in age although the evidence is not conclusive.

Discussion

Most workers have used the term 'Late Cimmerian regional Unconformity' in the North Sea for the Kimmeridge Clay/Valhall Formation boundary. The 'unconformity' represents everything from a latest Ryazanian or earliest Valanginian facies change, possibly including a small hiatus in the Danish part of the Central Graben (Birkelund, Clausen, Hansen & Holm 1983, Jensen, Heilmann-Clausen & Michelsen 1985) to a Kimmeridgian – Barremian (Johnson 1975) or even longer non-sequence in parts of the northern North Sea.

Rawson & Riley (1982) claimed that although a condensed sequence or a hiatus may occur at basin margins or above structural highs over most of the North Sea, the base of the Valhall Formation is conformable with underlying strata. Hesjedal & Hamar (1983) found no unconformity in the Norwegian-Danish Basin and centrally in the Central Graben. But condensed sequences or non-deposition occur towards the end of the Ryazanian at the flanks of the Central Graben (Hamar, Fjæran & Hesjedal 1983).

In areas with continuous sedimentation, Rawson & Riley (1982) and Hesjedal & Hamar (1983) thought that the base of the Valhall Formation represents an isochron. The abrupt change seen on seismic profiles and in lithology may be caused by a latest Rayzanian transgression. Rawson & Riley (1982) also stressed the importance of eustatic sea-level changes for understanding Lower Cretaceous sedimentation.

In the Sklinnabanken area, black shales were deposited in the Upper Ryazanian prior to a regression which led to non-depostion and some erosion down into *tzikwinianus* Zone beds. Renewed sedimentation of marls seems to have started in latest Ryazanian. The depositional pattern is thus a close parallel to that seen at basin margins and structural highs in the North Sea.

Zakharov, Surlyk & Dalland (1981), on the basis of negative evidence, claimed that Lower and lower Upper Ryazanian were not represented in the Andøya section. Our data suggest that the Ryazanian sequence may be more complete. We have not been able to document any definite intra Ryazanian break in sedimentation, but there may well be one between samples D163 and D164. The unmappable unconformity in Figure 6 of Dalland (1981) below the few metres of Upper Ryazanian shales may be related to this level. These shales may well have been deposited simultaneously with the intraformational conglomeratic limestone interval 11.00–10.80 m in core 7B.

In Jameson Land (East Greenland) the *kochi* Zone sediments (Hesteelv Formation) include both black shales (coarser marginally in the basin), a sandy shell conglomerate and light massive or crossbedded sandstones at the top (Surlyk, Callomon, Bromley & Birkelund 1973). This sequence is slightly too old for being equivalent to the hiatus in other areas. Deposition of *kochi* Zone sediments in Jameson Land may therefore have taken place in a relatively small basin which was gradually filled by sediments of increasing coarseness.

Deposition of clay in Andøya in the uppermost Ryazanian *mesezhnikovi* Zone continued across the Ryazanian/Valanginian boundary. Samples D172, D173 and E19 from the uppermost part of Ratjønna Member are Valanginian in age.

Later in the Valanginian, deposition of sand commenced in Andøya. Valanginian sandstones are also known from Forth Approaches Basin (Devils Hole Formation), Wollaston Forland (Surlyk 1978), Trænabanken and Kong Karls Land (Blüthgen 1936). Surlyk linked his sandstones to the major transgression at the Ryazanian/Valanginian transition, but according to our evidence at least some of the sandstone unit in Andøya correlates with the late Valanginian – early Hauterivian hiatus on Sklinnabanken.

Lower Cretaceous redbrown hematitic mudstones occur both in East Greenland (Rødryggen Member of Surlyk (1978) in Wollaston Forland), in Andøya (Skjermyrbekken Member of Dalland (1975)), in Trænabanken, Sklinnabanken and Haltenbanken. Surlyk interpreted Rødryggen Member as deposited in an oxidized environment on a submarine crest of a tilted fault-block. He assigned a Middle – Late Valanginian age.

Zakharov, Surlyk & Dalland (1981) found *Buchia sublaevis* in similar beds in Andøya. In northern Siberia this species ranges into the earliest Hauterivian *bojarkensi* Zone (Saks & Shulgina 1974).

Chlamydophorella trabeculosa in the uppermost part of Skjermyrbekken Member in Andøya may according to evidence from eastern England (Davey 1979) suggest a mid Hauterivian or younger age. A transgression at about this level (*Simbirskites inversum* Zone) is in northwest Europe documented by mixing of boreal and Tethyan ammonites (Kemper, Rawson & Thieuloy 1981). The Hauterivian shale in Milne Land (East Greenland) of Piasecki (1979) in an otherwise sandy sequence may have been deposited during this same transgressive phase.

In Sklinnabanken we have assigned a Late Hauterivian – Early Barremian age for the lower part of clayey redbeds whereas they are Early Aptian in the Ling sub-basin and middle Albian in the Rødby Formation of the North Sea (Rawson & Riley 1982). This shows that similar depositional environments were developed at different times in different areas. Such sediments were probably not only deposited on the tilted fault-block crests of Surlyk (1978). They may also well be related to transgressions at basin margins in periods when sediment supply was low (Sklinnabanken). Both the Middle – Late Valanginian redbeds of Wollaston Forland, the Late Valanginian – Hauterivian of Andøya, the Late Hauterivian – Barremian of Sklinnabanken and the mid Albian redbeds of the North Sea may be associated with transgressions.

Palaebiogeographically the Ryazanian dinocyst floras from Sklinnabanken are closely related to those from the North Sea area. The diversity in the Ryazanian assemblages of Andøya is reduced compared to that of Sklinnabanken and may suggest it is an assemblage transitional between North Sea assemblages and the low diversity *borealis* assemblage from the Ryazanian of Arctic Canada (Brideaux & Fisher 1976, Brideaux 1976). *Paragonyaulacysta borealis* is present both at Sklinnabanken and Andøya.

Ryazanian assemblages from Tromsøyflaket seem to have characters in common with those from Andøya, but are poorly preserved.

Håkansson, Birkelund, Piasecki & Zakharov (1981) found a low diversity from poor to diverse dinocyst assemblages around this same stratigraphic level in Svalbard.

Conclusion

Palaeontological studies of a core from Sklinnabanken and of Lower Cretaceous samples from Andøya show that the geology of these areas fit into a geological model governed by eustatic sea level changes and tectonics. Sklinnabanken was more or less unaffected by structural movements and is therefore particularly useful for study of eustatic sea level changes. The latest Ryazanian and mid-Hauterivian rises in sea level are best documented.

Sedimentation at Andøya was more influenced by tectonic activity. The Ryazanian sequence is more complete than hitherto considered. Deposition of marl on some structural highs commenced before deposition of marine Valanginian sand started in some structural basins. The Skjermyrbekken Member at Andøya seems to include both Upper Valanginian and Hauterivian strata. The Upper Hauterivian-Lower Barremian sequence is thin, leading to Upper Barremian-Aptian sediments already in the lower part of the Nordelva Member and continuing into the Hellneset Member.

Ryazanian dinocyst assemblages from Andøya and Tromsøyflaket seem transitional between those recorded in North Sea areas/Sklinnabanken and the '*borealis* assemblage' of Arctic areas.

Acknowledgements. The studied cores were obtained on a NPD scientific licence issued for shallow drilling offshore Helgeland in 1982. Several oil compaines financed this mapping programme. NTNF supported publishing (10.15241). We appreciate the technical assistance and critical reading of colleagues at IKU.

References

Birkelund, T., Clausen, C. K., Hansen, H. N. & Holm, L. 1983: The *Hectoroceras kochi* zone (Ryazanian) in the North Sea Central Graben and remarks on the Late Cimmerian unconformity. *Danm. Geol. Unders. Årbog 1982,* 53–72.

Birkelund, T., Thusu, B. & Vigran J. O. 1978: Jurassic-Cretaceous biostratigraphy of Norway, with comments on the British *Rasenia cymodoce* zone. *Palaeontology 21,* 1, 31–63.

Black, M. 1971: Coccoliths of the Speeton Clay and Sutterby Marl. *Yorkshire geol. Soc. Proc. 38/3,* 381–424.

Black, M. 1972: British Lower Cretaceous coccoliths. I.: Gault Clay. *Monogr. palaeontogr. Soc. (London) 126/1 (Publ. Nr. 534),* 1–48.

Black. M. 1973: British Lower Cretaceous coccoliths. I.: Gault Clay. *Monogr. palaeontogr. Soc. (London), 127 (Publ. Nr. 537),* 49–112.

Blüthgen, J. 1936: Die Fauna und Stratigraphie des Oberjura und der Unterkreide von König Karl Land. *Grimmen (Pomerania),* 75 p.

Bogoslovsky, N. 1897: Der Rjasan-Horisont, seine Fauna, seine stratigraphischen Beziehungen und seine wahrscheinliches Alter. *Mater. Geol. Russland 18,* 157 p. (In Russian).

Brideaux, W. W. 1976: Berriasian dinoflagellate assemblage, Martin Creek, northwestern District of Mackenzie. *Geol. Surv. Can., Paper 76-1C,* 115–130.

Brideaux, W. W. & Fisher, M. J., 1976: Upper Jurassic-Lower Cretaceous dinoflagellate assemblages from Arctic Canada. *Geol. Surv. Can. Bull. 259,* 1–53.

Bugge, T., Knarud, R. & Mørk, A. 1984: Bedrock geology on the mid-Norwegian continental shelf. *In* Spencer, A. M. (ed.), *Petroleum Geology of the North European Margin. Norw. Petrol. Soc.* 271–283.

Burns, D. A. 1976: Nannofossils from the Lower and Upper Cretaceous chalk deposits. Nettleton, Lincolnshire, England. *Rev. Esp. Micropaleontologie 8,* 279–300.

Casey, R. 1973: The ammonite succession at the Jurassic-Cretaceous boundary in eastern England. *In* Casey, R. & Rawson, P. F. (ed.), The Boreal Lower Cretaceous. *Geol. J. Spec. Iss. 5,* 193–266.

Dalland, A. 1975: The Mesozoic rocks of Andøy, northern Norway. *Nor. geol. unders. 316,* 217–287.

Dalland, A. 1979: The sedimentary sequence of Andøya, northern Norway – depositional and structural history. *In* Norwegian Sea Symposium, Tromsø, NNS 26, 1–31. *Norsk Petroleumsforening.*

Dalland, A. 1981: Mesozoic sedimentary succession at Andøy, northern Norway and relation to structural development of the North Atlantic Area. *In* Kerr & Fergusson (ed.), Geology of the North Atlantic Borderlands. *Can. Soc. Petrol. Geol. Mem. 7,* 563–584.

Davey, R. J. 1979: The stratigraphic distribution of dinocysts in the Portlandian (latest Jurassic) to Barremian (Early Cretaceous) of northwest Europe. *AASP Contr. ser., 5b,* 49–81.

Davey, R. J. 1982: Dinocyst stratigraphy of the latest Jurassic to Early Cretaceous of the Haldager no. 1 borehole, Denmark. *Danm. geol. unders., ser. B, 6,* 1–56.

Davies, E. H. 1983: The dinoflagellate Oppel-zonation of the Jurassic-Lower Cretaceous sequence in the Sverdrup Basin, Arctic Canada. *Geol. Surv. Can. Bull. 359,* 59 p.

Deres, F. & Achéritéguy, J. 1980: Biostratigraphie des Nannoconidés. *Centr. Rech. Exploration-Production Elf-Aquitaine, Bull. 4,* 1–53.

Donovan, D. T. 1964: Stratigraphy and ammonite fauna of the Volgian and Berriasian rocks of East Greenland. *Meddr. Grønland 154 (4),* 34 p.

Duxbury, S. 1977: A palynostratigraphy of the Berriasian to Barremian of the Speeton clay of Speeton, England. *Palaeontographica B 160,* 17–67.

Grün, W. & Allemann, F. 1975: The lower Cretaceous of Caravaca (Spain): Berriasian calcareous nannoplankton of the Miravetes section. (Subbetic zone, Prov. of Murcia). *Ecl. Geol. Helv. 68,* 147–211.

Hamar, G. P., Fjæran, T. & Hesjedal, A. 1983: Jurassic stratigraphy and tectonics of the south-southeastern Norwegian offshore. *Geol. Mijnb. 62,* 103–114.

Hesjedal, A. & Hamar, G. P. 1983: Lower Cretaceous stratigraphy and tectonics of the south-southeastern Norwegian offshore. *Geol. Mijnb. 62,* 135–144.

Håkansson, E., Birkelund, T., Piasecki, S. & Zakharov, V. 1981: Jurassic-Cretaceous boundary strata of the extreme Arctic (Peary Land, North Greenland). *Geol. Soc. Denmark Bull. 30,* 11–42.

Jeletzky, J. A. 1965: Late Upper Jurassic and early Lower Cretaceous fossil zones of the Canadian Western Cordiellera, British Columbia. *Geol. Surv. Canada Bull. 103,* 70 p.

Jeletzky, J. A. 1984: Jurassic-Cretaceous boundary beds of Western and Arctic Canada and the problem of the Tithonian-Berriasian stages in the Boreal Realm. *Geol. Ass. Canada Spec. Paper 27,* 175–252.

Jensen, T. F., Heilmann-Clausen, C. & Michelsen, O. 1985: Lower Cretaceous stratigraphy, *In* Michelsen, O. (ed.), Symposium on Jurassic-Lower Cretaceous of the Central Graben November, 7th 1984. *Danm. geol. unders. Internal report no. 6,* 43–56.

Johnson, R. J. 1975: The base of the Cretaceous: A discussion. *In* Woodland, A. (ed.), *Petroleum and the Continental Shelf of North-West Europe. Appl. Sci. Publ.,* vol. 1, 389–399.

Kelly, S. R. A. 1984: Bivalvia of the Spilsby Sandstone and Sandringham Sands (late Jurassic-early Cretaceous) of eastern England. Part 1. *Mon. Pal. Soc. London,* 1–94.

Kemper, E., Rawson, P. R. & Thieuloy, J. P. 1981: Ammonites of Tethyan ancestry in the early Lower Cretaceous of north-west Europe. *Palaeontology 24,* 251–311.

Lahusen, J. 1888: Über die russischen Aucellen. *Trudy Geol. Kom. 8,* 46 p.

Løfaldli, M. & Thusu, B. 1979: Micropaleontological studies of the Upper Jurassic and Lower Cretaceous of Andøya, northern Norway. *Paleontology 22,* 413–425.

Maisey, G. H. & Wøien, H. 1983: Havbunnens overflatelag. Kartblad 6406 Haltenbanken. 1:500000. *Inst. for Kontinentalsokkelunders.,* Norge.

McIntyre, D. J. & Brideaux, W. W. 1980: Valanginian miospore and microplankton assemblages from the northern Richardson mountains, District of Mackenzie, Canada. *Geol. Surv. Can. Bull.* 320, 57 p.

Mesezhnikov, M. S. et al. 1979: Stratigraphy of the Jurassic-Cretaceous boundary layers of the Petshora River Basin. *In* The Upper Jurassic and its boundary with the Cretaceous. *Akad. Nauk SSSR,* 66–72 (In Russian).

Perch-Nielsen, K. 1979: Calcareous nannofossils from the Cretaceous between the North Sea and the Mediterranean. *In* Aspekte der Kreide Europas. *IUGS Series A, 6,* 223–272.

Piasecki, S. 1979: Hauterivian dinoflagellate cysts from Milne Land, East Greenland. *Geol. Soc. Denmark Bull. 28,* 31–37.

Rawson, P. F. & Riley, L. A. 1982: Latest Jurassic-Early Cretaceous events and the "Late Cimmerian unconformity" in North Sea area. *AAPG Bull. 66,* 2628–2648.

Renéville, P. de & Raynaud, J.-F. 1981: Palynologie du stratotype du Barrémien. *Centr. Rech. Explor.-Prod. Elf-Aquitaine, Bull. 5,* 1–29.

Saks, V. N. (ed.) 1972: Jurassic-Cretaceous boundary and Berriasian stage in Boreal Realm. *Nauka, Novosibirsk,* 371 p.

Saks, V. N. & Shulgina, N. I. 1974: Basic problems of the Upper Volgian, Berriasian and Valanginian stratigraphy of the Boreal zone. *Acta Geologica Polonica 24,* 543–560.

Sissingh, W. 1977: Biostratigraphy of Cretaceous calcareous nannoplankton. *Geol. Mijnb. 56* (1), 37–65.

Sissingh, W. 1978: Microfossil biostratigraphy and stage-stratotypes of the Cretaceous. *Geol. Mijnb. 57 (3),* 433–440.

Sokolov, D. N. 1912: Fauna der Mesozoischen Ablagerungen von Andö. *Skr. Nor. Vid. Selsk., Mat.-naturvidensk. Kl. 1, Nr. 6.*

Stradner, H. & Grün, W. 1973: On *Nannoconus abundans* nov. spec. and on laminated calcite growth in lower Cretaceous nannofossils. *Geol. Bundesanst. Wien, Verh. 1973,* 2, 267–283.

Surlyk, F. 1978: Submarine fan sedimentation along scarps on tilted fault blocks (Jurassic-Cretaceous boundary, East Greenland). *Grønl. Geol. Unders. Bull. 128,* 108 p.

Surlyk, F., Callomon, J. H., Bromley, R. G. & Birkelund, T. 1973: Stratigraphy of the Jurassic-Lower Cretaceous sediments of Jameson Land and Scoresby Land, East Greenland. *Grønl. Geol. Unders. Bull. 105,* 76 p.

Surlyk, F. & Zakharov, V. A. 1982: Buchiid bivalves from the Upper Jurassic and Lower Cretaceous of East Greenland. *Palaeontology 25 (4),* 727–753.

Taylor, R. J. 1978: The distribution of calcareous nannofossils in the Speeton Clay of Yorkshire and their biostrtigraphical significance. *Yorkshire Geol. Soc. Proc. 42,* 195–209.

Taylor, R. J. 1982: Lower Cretaceous (Ryazanian to Albian) calcareous nannofossils. *In* Lord, A. R. (ed.) *A Stratigraphic Index of Calcareous Nannofossils,* 40–80. Ellis Morwood Ltd.

Thierstein, H. R. 1973: Lower Cretaceous calcareous nannoplankton biostratigraphy. *Geol. Bundesanst. Wien, Abh. 29,* 1–52.

Zahiri, A. 1981: Phytoplankton of Barremian type section from Angles, south east France. *Iranian Petr. Inst. Bull. 83,* 1–34.

Zakharov, V. A. 1981: Buchiidae (Bivalvia) and biostratigraphy of the boreal Upper Jurassic and Neocomian. *Nauka,* Moscow, 270 p. (In Russian).

Zakharov, V. A., Surlyk, F. & Dalland, A. 1981: Upper Jurassic – Lower Cretaceous *Buchia* from Andøy, northern Norway. *Nor. Geol. Tidsskr. 61,* 261–269.

Ørvig, T. 1953: On the Mesozoic field of Andøya. 1. Notes on the Ichthyosaurian remains collected in 1952, with remarks on the age of the vertebrate-bearing beds. *Acta Borealia, A. Scientia, Nr. 4* (Tromsø).

Ørvig, T. 1960: The Jurassic and Cretaceous of Andøya in Northern Norway. *Nor. geol. unders. 208,* 344–350.

Explanation of Figs. 7, 8, 9, 10, 11, 12, 13, 14 and 15.

Fig. 7

a	Apteodinium conjunctum	7B, Ryazanian	15,85 m	PMO 113.309/1 Z30	500 X
b	Apteodinium granulatum	7, U.Haut.-L.Barr.	5,12 m	PMO 113.310/1 V36	500 X
c	Dingodinium spinosum	7B, Ryazanian	11,47 m	PMO 113.311/1 H38/4	800 X
d	Occisucysta sp. A Davey 1982	7B, Ryazanian	21,95 m	PMO 113.312/1 R35/2	800 X
e	Chlamydophorella nyei	7, reworked	2,20 m	PMO 113.313/1 F38/3	800 X
f	Dingodinium spinosum	7B, Ryazanian	18,33 m	PMO 113.314/1 H22	800 X
g	Chlamydophorella trabeculosa	7, U.Haut.-L.Barr.	4,20 m	PMO 113.315/1 P25	800 X
h	Chlamydophorella membranoidea	7B, Ryazanian	21,95 m	PMO 113.316/1 Z29	800 X
i	Chlamydophorella trabeculosa	7, U.Haut.-L.Barr.	4,20 m	PMO 113.315/2 D34/1	800 X

Fig. 8

a	Apteodinium cf. reticulatum	7, U.Haut.-L.Barr.	5,12 m	PMO 113.362/1 R34/2	500 X
b	Apteodinium cf. reticulatum	7, U.Haut.-L.Barr.	5,00 m	PMO 113.317/1 U20	500 X
c	Cribroperidinium sp.	Andøya, Valanginian	E18	PMO 113.318/1 R13/1	500 X
d	Occisucysta tentoria	7B, Ryazanian	23,32 m	PMO 113.319/1 O21	500 X
e	Cribroperidinium granulatum	Andøya, Ryazanian	D157	PMO 113.320/1 F27/2	500 X
f-g	Gonyaulacysta perforobtusa	7, U.Haut.-L.Barr.	4,20 m	PMO 113.315/3 D23/3	800 X
h	Leptodinium sp.	7B, Ryazanian	25,60 m	PMO 113.321/1 R32/2	800 X
i	Gonyaulacysta diutina	7B, Ryazanian	21,95 m	PMO 113.312/2 L 35	800 X
j	Lagenorhytis delicatula	Andøya, Valanginian	F13	PMO 113.322/1 K39/2	500 X

Fig. 9

a	Trichodinium ciliatum	7B, U.Haut.-L.Barr.	5,00 m	PMO 113.323/1 J28	800 X
b	Cribroperidinium muderongense	Andøya, Valanginian	E11	PMO 113.324/1 O39/3	500 X
c	Occisucysta sp. A Davey 1982	7B, Ryazanian	18,25 m	PMO 113.325/1 F 35/2	500 X
d	Cribroperidinium sepimentum	Andøya	E5	PMO 113.326/1 S27/4	500 X
e	Cribroperidinium perforans	7B, Ryazanian	21,95 m	PMO 113.312/3 X33	800 X
f	Apteodinium sp. A Davey 1982	7B, Ryazanian	21,95 m	PMO 113.312/4 F17/2	800 X
g	Occisucysta sp. A Davey 1982	7B, Ryazanian	21,95 m	PMO 113.312/5 Q37	800 X
h	cf. Gonyaulacysta sp. A Davey 1979	7B, Ryazanian	18,33 m	PMO 113.314/2 Q20	800 X

Fig. 10

a	Canningia cf. colliveri	Andøya, U.Barr.-Apt.	G1(E)	PMO 113.327/1 T26/1	500 X
b	Sentusidinium cf. pilosum	7	4,10 m	PMO 113.328/1 Z21/1	500 X
c	Kallosphaeridium agglutinatum	Andøya	D171	PMO 113.329/1 O34	500 X
d	Apteodinium sp.	Andøya	F19	PMO 113.330/1 U47	500 X
e	Canningia cf. colliveri	Andøya, U.Barr.-Apt.	G1(E)	PMO 113.327/2 Q34/3	500 X
f	Canningia cf. colliveri	Andøya, U.Barr.-Apt.	G1(A)	PMO 113.331/1 D41	500 X
g	Cleistosphaeridium sp. (note shape of archeopyle and bifurcate process in the upper left)	7B, Ryazanian	28,28 m	PMO 113.332/1 U25	500 X
h	Cleistosphaeridium sp.	7B, Ryazanian	28,28 m	PMO 113.332/2 P22/3	500 X
i	Canningia attadalica	Andøya, U.Barr.-Apt.	E1	PMO 113.333/1 Q33/1	500 X
j	Muderongia cf. staurota	Andøya	F13	PMO 113.322/2 B40/2	300 X
k	Cleistosphaeridium sp.	7B, Ryazanian	25,60 m	PMO 113.321/2 R35/2	500 X
l	Sentusidinium sp.	7B, Ryazanian	15,66 m	PMO 113.334/1 L31/3	800 X
m	Muderongia asymmetrica	Andøya, U.Barr.-Apt.	G1(E)	PMO 113.327/3 R33/2	300 X
n	?Chytroeisphaeridia sp.	7B, U.Haut.-L.Barr.	5,00 m	PMO 113.335/1 D35	800 X
o	Muderongia simplex	7, U.Haut.-L.Barr.	4,20 m	PMO 113.315/4 J19	670 X
p	?Chytroeisphaeridia sp.	7B, U.Haut.-L.Barr.	5,00 m	PMO 113.335/2 V26	800 X

Fig. 11

a	Sentusidinium sp.	7B, Ryazanian	24,76 m	PMO 113.336/1 F35/2	800 X
b	?Leberidocysta sp.	Andøya, U.Barr.-Apt.	E1	PMO 113.333/2 C25/1	500 X
c	Canningia compta	7B, Ryazanian	18,33 m	PMO 113.337/1 G25/2	800 X
d	Fromea complicata	Andøya, U.Barr.-Apt.	G1(A)	PMO 113.331/2 W39	500 X
e	Sentusidinium sp.	7B, Ryazanian	15,66 m	PMO 113.334/2 W14/4	800 X
f	Sentusidinium sp.	7B, Ryazanian	21,95 m	PMO 113.312/6 Z28	800 X
g	Cleistosphaeridium sp.	7B, Ryazanian	11,57 m	PMO 113.338/1 E39	500 X
h	Sentusidinium sp.	7B, Ryazanian	25,60 m	PMO 113.321/3 S33	800 X

i	Fromea sp.	7B, Ryazanian	25,60 m	PMO 113.321/4 E15	500 X
j	Cassiculosphaeridia reticulata	7, U.Haut.-L.Barr.	4,20 m	PMO 113.339/1 Y22/3	800 X
k	Undescribed dinocyst	7B, Hauterivian	10,10 m	PMO 113.340/1 Y29/1	800 X
l	Cassiculosphaeridia sp.	Andøya, U.Barr.-Apt.	E3 m	PMO 113.341/1 D38/1	500 X
m	Fromea amphora	Andøya, U.Barr.-Apt.	G1(A)	PMO 113.331/3 L42	500 X

Fig. 12

a	Batioladinium radiculatum	7B, Ryazanian	23,32 m	PMO 113.319/2 K35	800 X
b	Pareodinia sp.	7B, Ryazanian	24,76 m	PMO 113.342/1 Q22/2	800 X
c	Paragonyaulacysta borealis	Andøya, Valanginian	E18	PMO 113.343/1 F28/4	500 X
d	Batioladinium radiculatum	7B, Ryazanian	23,32 m	PMO 113.344/1 Q14/2	670 X
e	Batioladinium pomum	7B, Ryazanian	19,55 m	PMO 113.345/1 C19/1	800 X
f	Paragonyaulacysta sp.	Andøya, Ryazanian	D163	PMO 113.346/1 B31/2	500 X
g	Batioladinium micropodum	Andøya, U.Barr.-Apt.	G1(E)	PMO 113.327/4 G35	500 X
h	Pareodinia verrucosa	7B, Ryazanian	18,33 m	PMO 113.314/3 E24/3	800 X
i	Batioladinium micropodum	Andøya, U.Barr.-Apt.	G1(A)	PMO 113.331/4 U23	500 X
j	Paragonyaulacysta borealis	7B, Ryazanian	18,33 m	PMO 113.314/4 Z38/1	800 X
k	Stephodinium spinulosum	7B, U.Haut.-L.Barr.	5,00 m	PMO 113.335/3 S20/3	800 X
l	Batioladinium micropodum	Andøya, U.Haut.-L.Barr.	F21	PMO 113.347/1 H31/2	500 X

Fig. 13

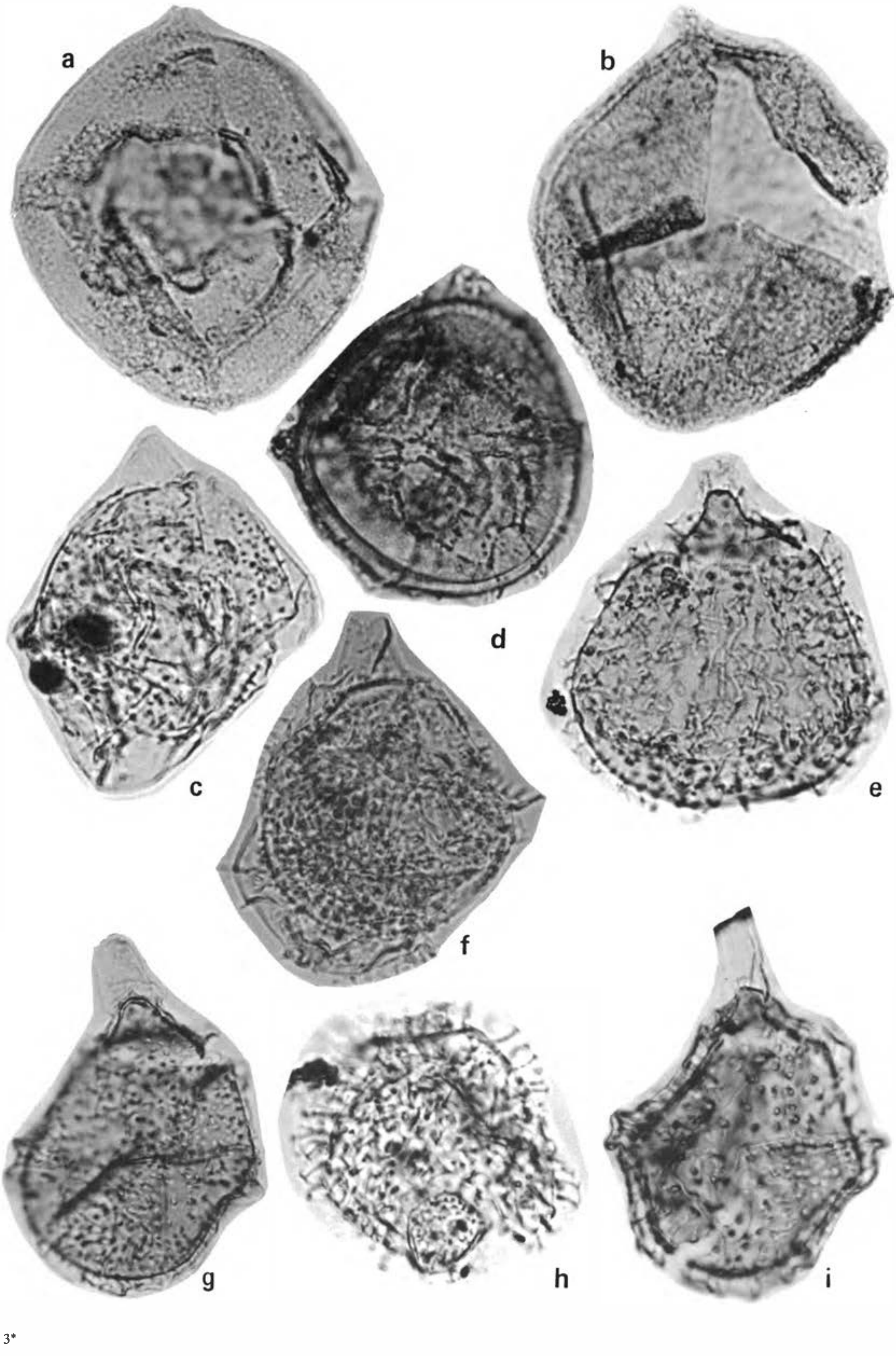
a	Callaiosphaeridium asymmetricum	7, U.Haut.-L.Barr	4,20 m	PMO 113.348/1 R37/3	800 X
b	Oligosphaeridium complex	7, reworked	2,20 m	PMO 113.349/1 C34/4	500 X
c	Cleistosphaeridium separatum	7B, Ryazanian	13,40 m	PMO 113.350/1 W38	800 X
d	Cyclonephelium distinctum	7, U.Haut.-L.Barr.	5,00 m	PMO 113.317/2 C29/4	800 X
e	Solisphaeridium sp.	7B, Ryazanian	18,25 m	PMO 113.351/1 X31/4	800 X
f	Lithodinia sp.	Andøya, U.Barr.-Apt.	G1(A)	PMO 113.331/5 U23/2	500 X
g	Cicatricosisporites sp.	7B, Ryazanian	23,32 m	PMO 113.319/3 X16	800 X
h	Woody fragment bored by fungi	7B, Hauterivian	10,10 m	PMO 113.340/2 J41/2	500 X

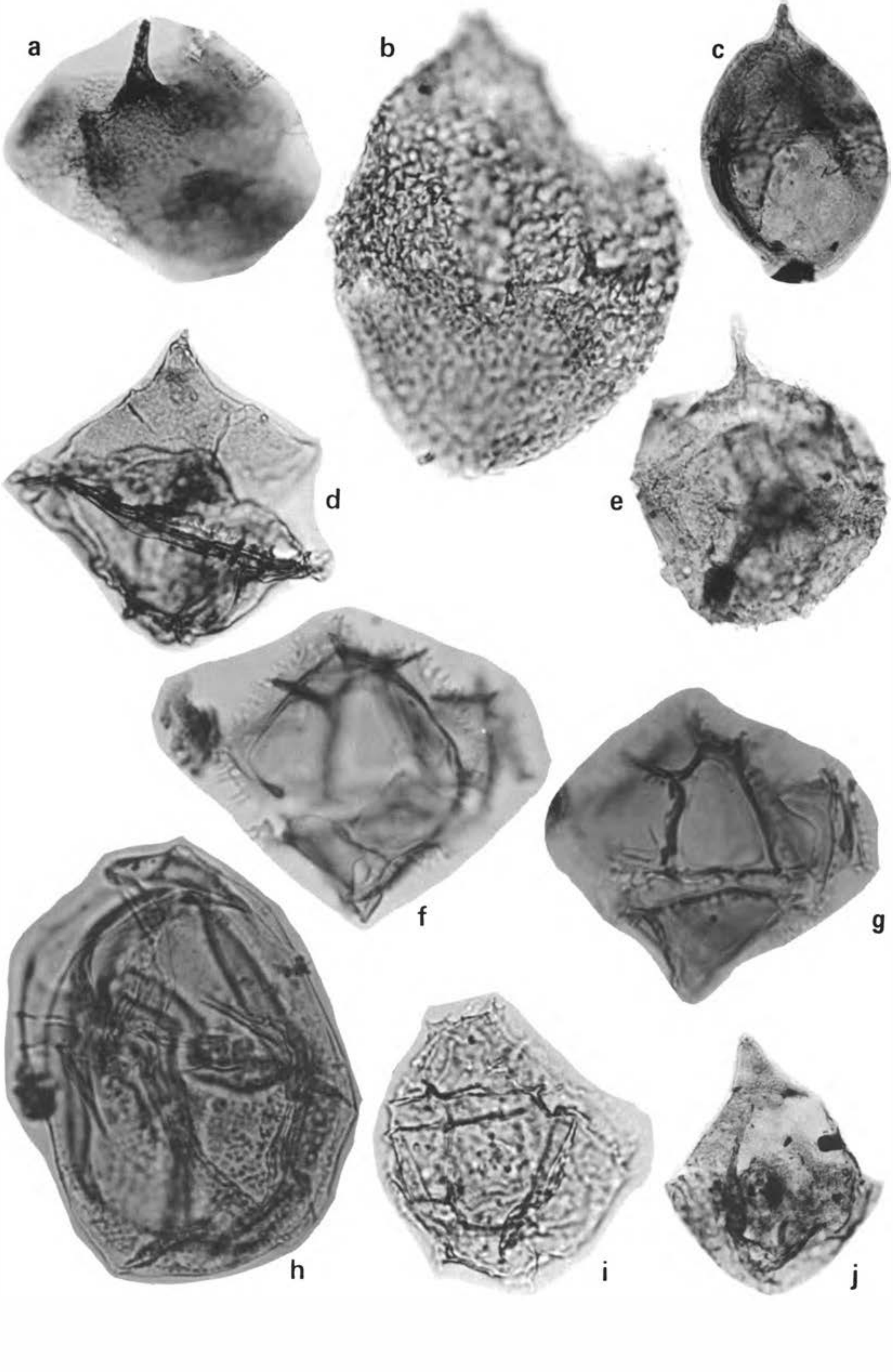
Fig. 14

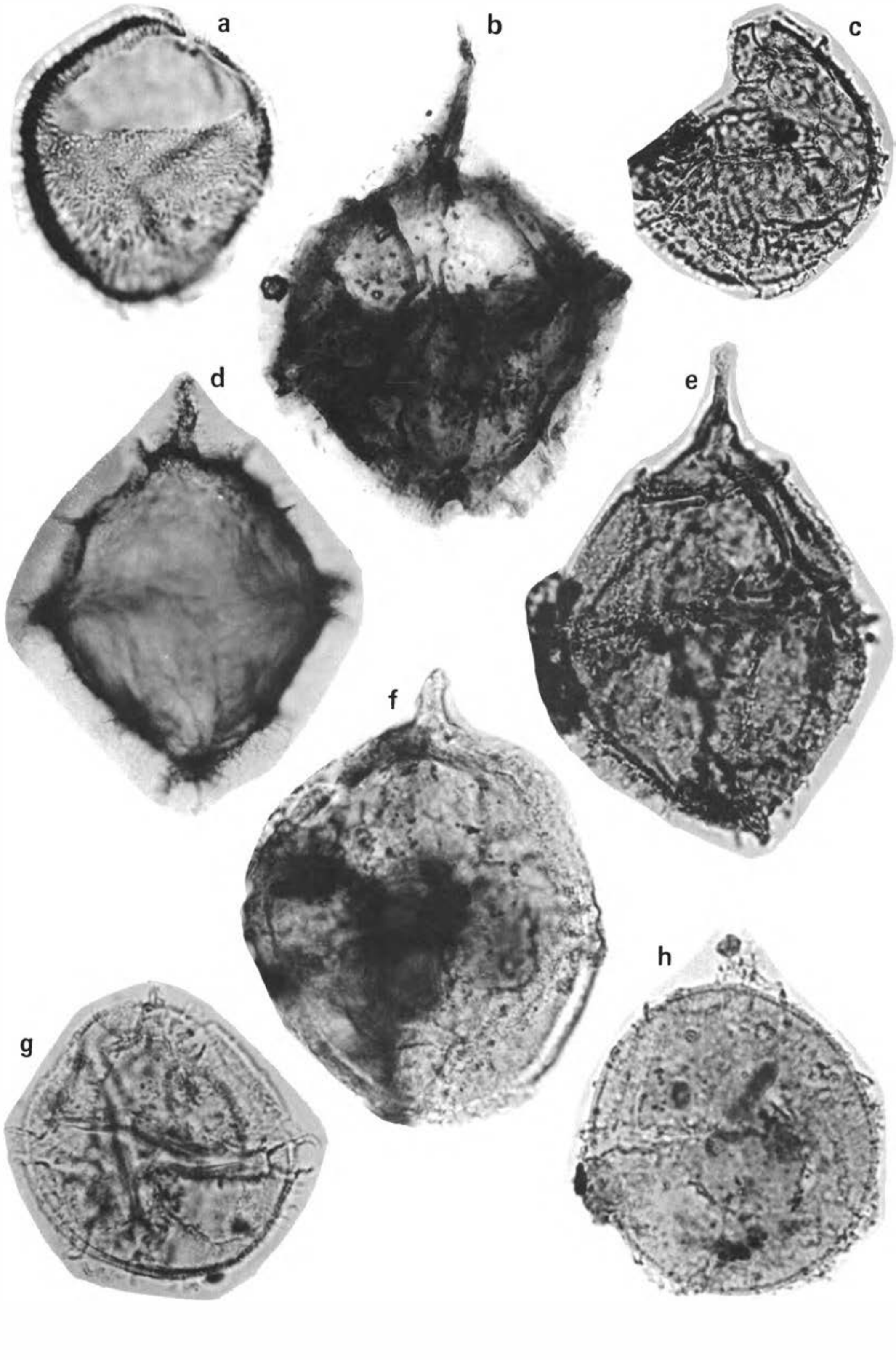
a	Stiphrosphaeridium arbustum	7B, Ryazanian	18,25 m	PMO 113.351/2 E30	500 X
b	Systematophora palmula	Andøya, Valanginian	E18	PMO 113.318/2 V25/1	500 X
c	Systematophora palmula	7B, Ryazanian	16,65 m	PMO 113.352/1 X14/3	500 X
d	Protoellipsodinium spinosum	7, U.Haut.-L.Barr.	4,20 m	PMO 113.315/5 Q22	800 X
e	Systematophora palmula	Andøya, Valanginian	D174	PMO 113.353/1 W22/4	500 X
f	Oligosphaeridium diluculum	7B, Ryazanian	15,66 m	PMO 113.354/1 R27/1	500 X
g	Kleithriasphaeridium porosispinum	7B, Ryazanian	18,33 m	PMO 113.314/5 V21/3	500 X
h	Systematophora palmula	7B, Ryazanian	15,85 m	PMO 113.355/1 M36/4	500 X
i	Systematophora silyba	7, U.Haut.-L.Barr.	5,00 m	PMO 113.317/3 Y24	800 X
j	Systematophora sp. 1 Davey 1982	7B, Ryazanian	25,60 m	PMO 113.321/4 V20/2	500 X
k	Aptea anaphrissa	Andøya, U.Haut.-L.Barr.	F21	PMO 113.356/1 P20/1	500 X
l	Kleithriasphaeridium porosispinum	7B, Ryazanian	11,57 m	PMO 113.357/1 K29/2	500 X

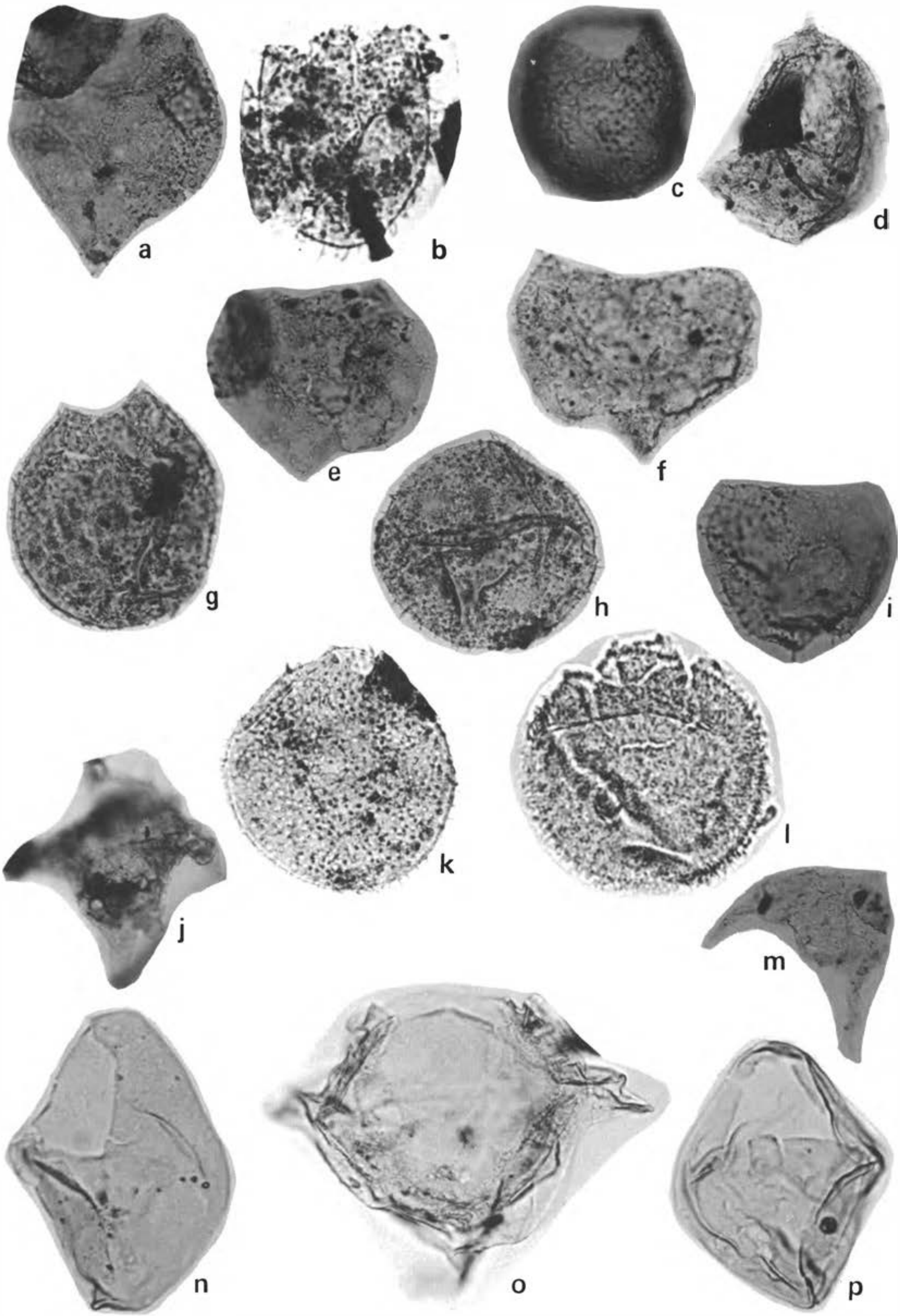
Fig. 15

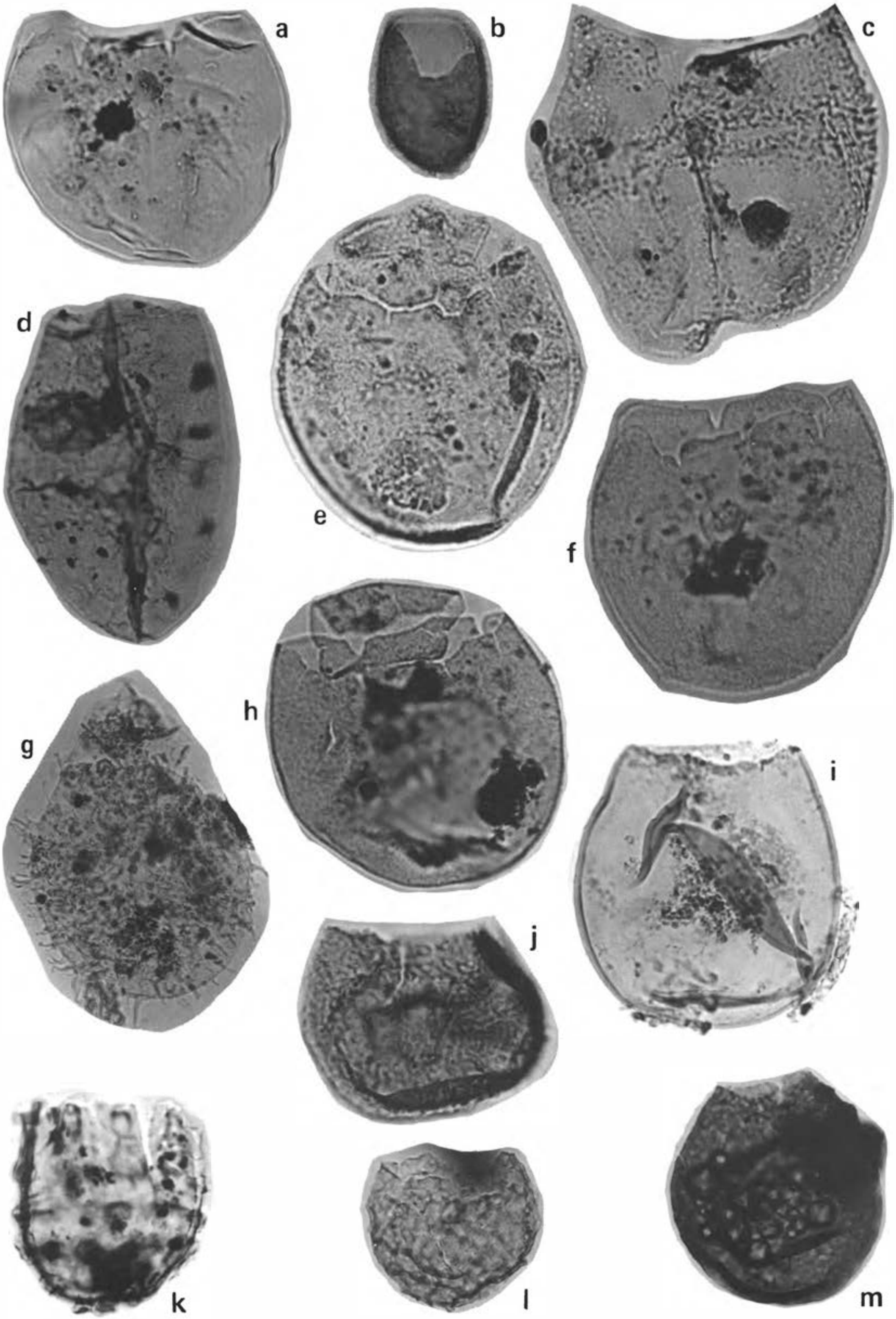
a	Systematophora palmula	7B, reworked	5,25 m	PMO 113.3581 Z18	500 X
b	cf. Surculosphaeridium sp. 1 Davey 1982	7B, Ryazanian	18,25 m	PMO 113.351/3 W31/3	500 X
c	Exiguisphaera plectilis	Andøya, U.Barr.-Apt.	E1	PMO 113.333/3 X28/2	500 X
d	Systematophora sp. 2 Davey 1982	7B, Ryazanian	16,65 m	PMO 113.352/2 W13/2	800 X
e	Cleistosphaeridium ancoriferum	7, U.Haut.-L.Barr.	4,20 m	PMO 113.315/6 J28/4	800 X
f-g	Cleistosphaeridium huguoniotii	Andøya	E5	PMO 113.359/1 N40/3	500 X
h	Stiphrosphaeridium dictyophorum	Andøya, prob. Ryaz.	D156	PMO 113.360/1 H29/2	500 X
i	Cymatiosphaera pachytheca	7B, Ryazanian	16,65 m	PMO 113.361/1 G34	800 X
j	Botryococcus	7B, Ryazanian	16,65 m	PMO 113.361/2	800 X
k	Tasmanites	7B, Ryazanian	16,65 m	PMO 113.361/3 F33/3	800 X

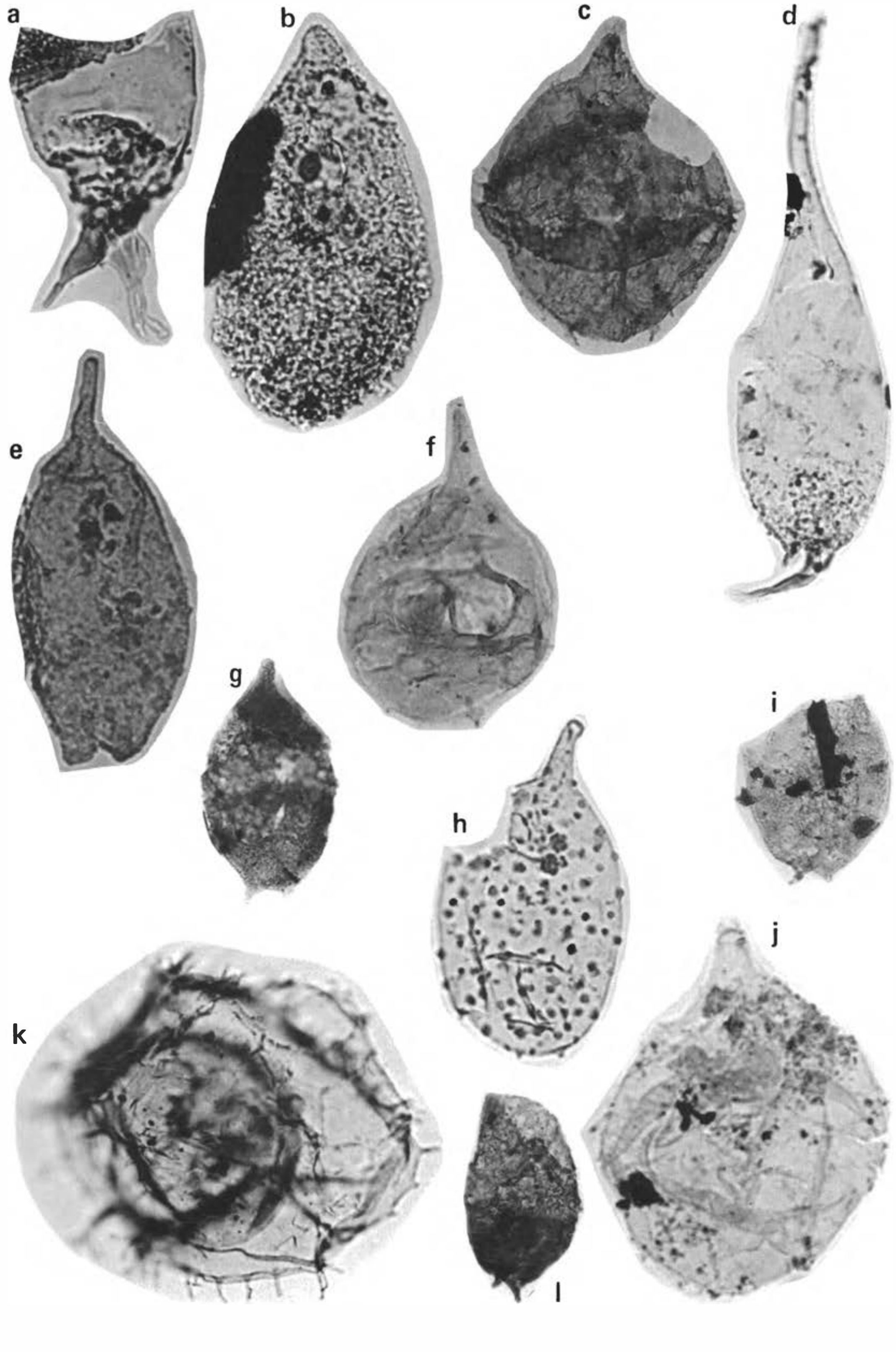

a
b
d
c
e
f
g
h
i

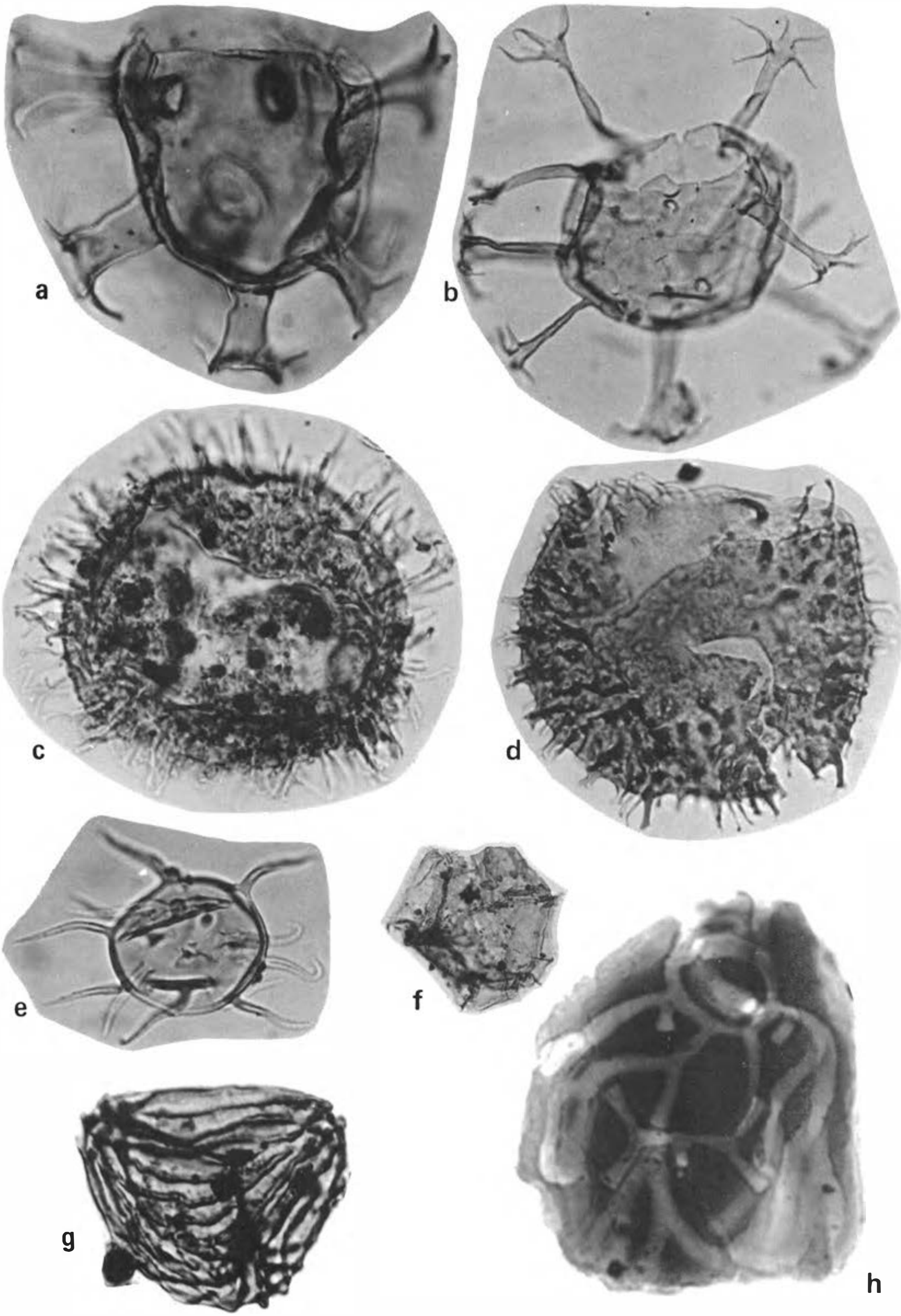

a
b
c
d
e
f
g
h
i
j

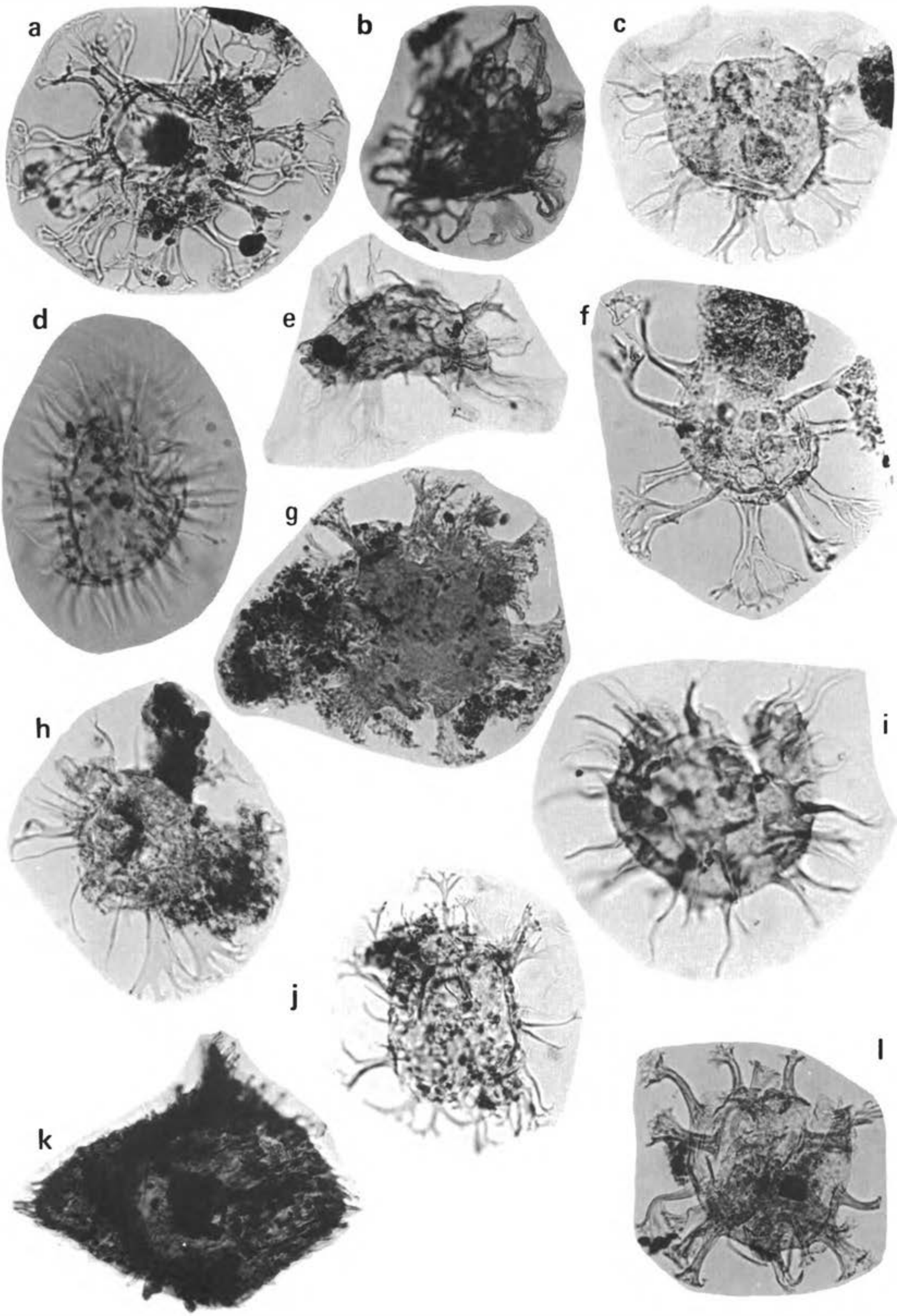

a
b
c
d
e
f
g
h

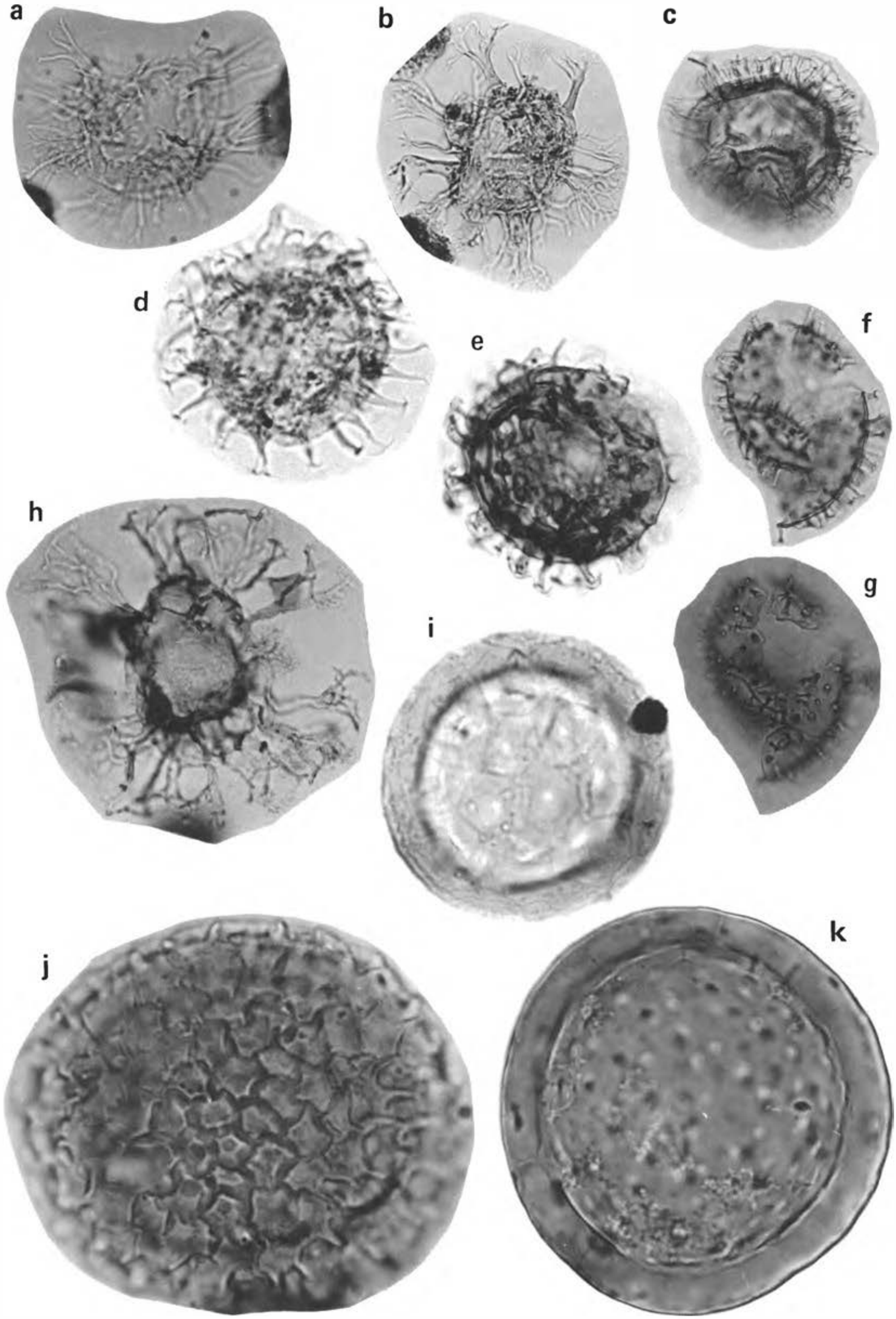

a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p




a
b
c
d
e
f
g
h
i
j
k
l


a
b
c
d
e
f
g
h


a
b
c
d
e
f
g
h
i
j
k
l


a
b
c
d
e
f
h
g
i
j
k