Systematic palaeontology and biostratigraphy of two Early Cretaceous condensed sections from the Barents Sea

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Bivalve, brachiopod and cirripede faunas from the latest Jurassic and Early Cretaceous Barents Sea boreholes 7320/3-U-1 and 7425/9-U-1 are systematically described and illustrated. Microfossils have also been studied and the cores are dated on the basis of the fossil recovery. The bivalve *Buchia* whose zonal sequence has been used for correlation of boreal marine sections is the most important biostratigraphic marker group in the condensed Boreal Berriasian-Hauterivian intervals of these cores. A new species of cirripede *Zeugmatolepas? borealis* Collins sp. nov. and dinoflagellate cyst *Muderongia aequicornus* Århus sp. nov. are described.

The Late Jurassic fine-grained clastics of core 7320/3-U-1 are overlain by about 3 m of grey dolomitic limestone of Valanginian and Hauterivian age. The lowermost part of 7425/9-U-1 is represented by a latest Volgian-earliest Berriasian fossiliferous greyish green marl. It is followed by a reddish brown fossiliferous claystone of Berriasian and perhaps partly Valanginian age. Core 7425/9-U-1 also contains a mainly Valanginian greyish green marly limestone which changes into a dark grey to black limestone of Early Barremian age in its upper part. The sedimentological change from condensation to dark grey clay deposition took place in the middle Barremian *H. rude-fissicostatum* ammonite Zone in 7425/9-U-1 and probably slightly earlier in 7320/3-U-1. This was commenced at about the same time as deposition of the inaccurately and only indirectly dated fluvio-deltaic Festningen Sandstone Member on Spitsbergen. The dark claystone may thus be a distal equivalent to this sandstone unit.

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In large parts of the Barents Sea the Jurassic/Cretaceous boundary is represented by an unconformity with Lower Cretaceous sediments prograding on older strata, often on Volgian black shales. The two coreholes studied here (7320/3-U-1 and 7425/9-U-1, see Fig. 1) were drilled by the drilling ship 'Bucentaur' in 1985 as part of the Norwegian Continental Shelf and Petroleum Technology Research Institute's (IKU's) Barents Sea Mapping Program. 7425/9-U-1 located on the structurally high Bjarmeland Platform (see Gabrielsen et al. 1990) and on such highs the Boreal Berriasian to early Barremian is condensed and incomplete. The cores both produced macrofossils and the fauna and microflora are described here together with a presentation of the lithological logs and a biostratigraphic interpretation where also foraminifera data are taken into consideration.

Because of the Boreal nature of the fauna it is not possible to use directly the standard Tethyan stage names. Until the Jurassic-Cretaceous Boundary Working Group (IGCP) makes precise correlation between the regions, the terms Volgian and Boreal Berriasian (rather than Ryazanian) are recommended.

Parts of these condensed sections are equivalent to a 15 m thick white sandy bioclastic limestone consisting mainly of bivalve debris in the lower part of the Tordenskjoldberget Member (as defined by Smith et al. (1976) in section D 833 on Tordenskjoldberget on Kongsøya, Kong Karls Land), whereas thicker siliciclastics occur on Spitsbergen and in wells in the basins of the southwestern Barents Sea. This shows that tectonics played an important role in facies distribution, but nevertheless the occurrence of Valanginian and Hauterivian limestones on structural highs both in the Barents Sea and further south on the Norwegian shelf seems to be the result of a sea-level rise. The transition from the condensed interval to the overlying claystones
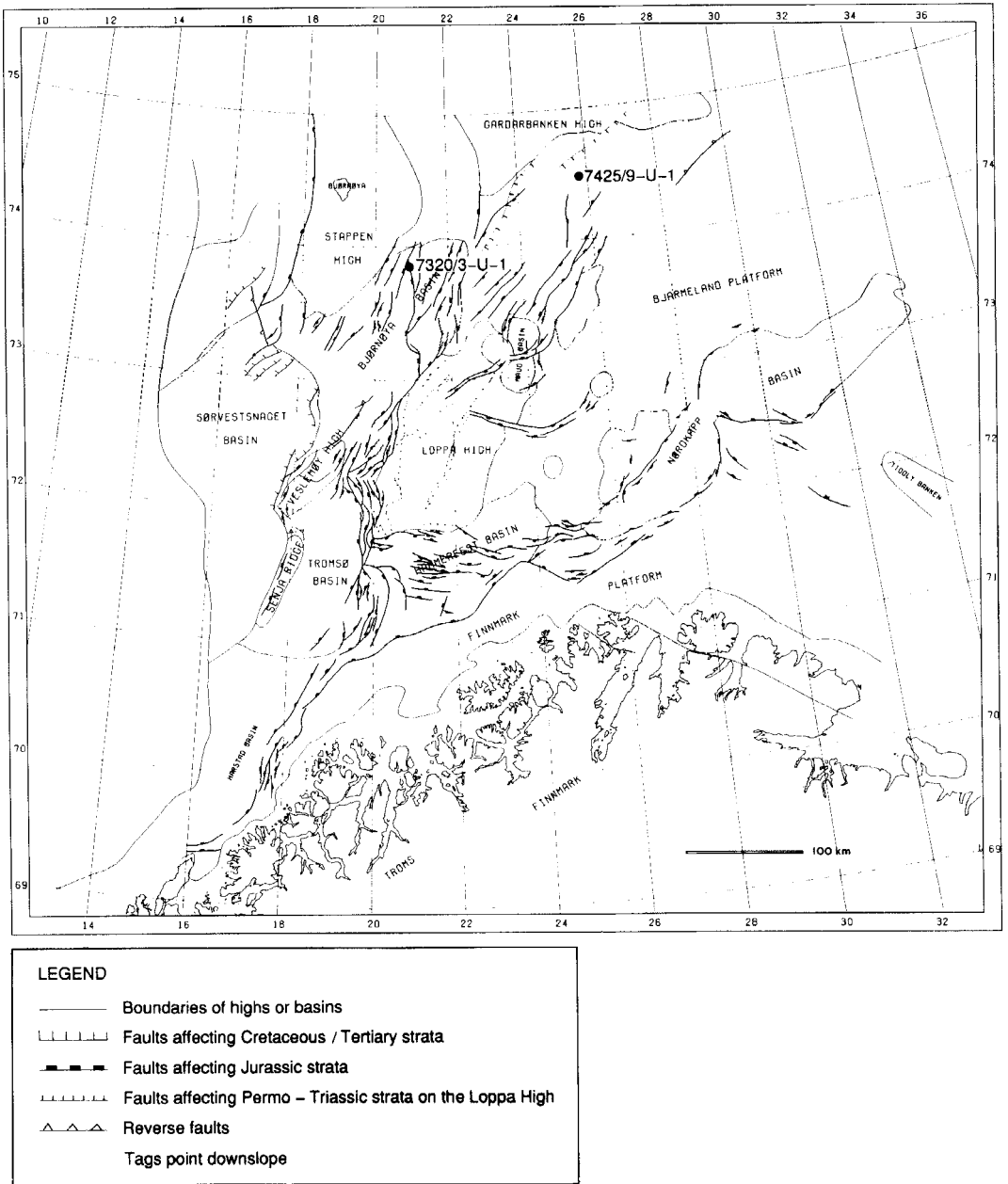
Fig. 1. Locations of the two studied coreholes. Map modified after Gabrielsen et al. (1990).

will be dealt with in a separate paper where data from additional shallow cores are included.

Macrofossil studies of Barents Shelf and adjacent areas (S.R.A.K)

Early Cretaceous macrofossil data, including those from the Jurassic-Cretaceous boundary, from the Barents Sea floor are very limited. Nagy (1973) described but did not illustrate mollusca, including buchiid bivalves, belemnites and ony-chitids from grab samples taken on Svalbard-banken. However, in adjacent Svalbard the sequence has been fairly well documented. The

most important illustrated systematic studies relating to the present study have been by Stolley (1912), Frebold (1930), Frebold & Stoll (1937) and Sokolov & Bodylevsky (1931), mainly in the Isfjorden region, Birkenmajer & Pugaczewska (1975) in Torell Land, Frebold (1929) and Birkenmajer et al. (1982) in Sabine Land, Blüthgen (1936) on Kong Karls Land and Yershova (1983) in the Svalbard Archipelago. South of the Barents Sea there is only limited exposure of Jurassic-Lower Cretaceous strata on Andøya (Birkelund et al. 1978; Zakharov et al. 1981). The biostratigraphy has been slightly revised by Aarhus et al. (1986). To the east of the Barents Sea Sokolov (1908) has described buchias from Timan-Pechora and Spitsbergen; Tullberg (1881) initially described the rich loose block fauna of Novaya Zemlya whose stratigraphy has been most recently revised by Cherkesov & Burdykina (1981). The Jurassic-Cretaceous boundary sections on Frans Josef Land do not provide comparable faunas. To the west, in the Wandel Sea Basin, Håkansson et al. (1981) have described the Jurassic-Cretaceous boundary strata of Peary Land, North Greenland. In East Greenland the *Buchia* sequence was illustrated by Surlyk & Zakharov (1982). Further south the Boreal bivalve faunas of the Jurassic-Cretaceous boundary in eastern England have been described by Kelly (1984). Kelly (1990) has also reviewed the *Buchia* sequence in Europe.

Buchia and the Jurassic-Cretaceous boundary (S.R.A.K.)

By far the most significant macrofossil relating to the present study is the bivalve *Buchia* which has been the subject of a major monographic revision and stratigraphic assessment by Zakharov (1981), on whose work this article relies heavily. Zakharov (1981, table 3) proposed a full sequence of eight *Buchia* biozones for the Russian Platform, but only recorded four of them for the Early Cretaceous of the arctic islands around the Barents Sea. A revised version of the table was given by Surlyk & Zakharov (1982, table 3). The *Buchia* zones that are confirmed from the Barents Sea boreholes are the *B. okensis* and *B. keyserlingi* zones. The *B. volgensis*, *B. unschensis* and *B. sublaevis* zones are only provisionally identified. The Barents Sea *Buchia* zonal sequence is compared to that of northern Siberia in Fig. 5. For comparison with other regions see the tables of Zakharov (1981) and Surlyk & Zakharov (1982).

The *Buchia* zonal sequence in comparison to ammonite zones in Svalbard is being assessed currently by the author. The distribution of *Buchia* species in comparison to ammonite zones in Svalbard has been given by Yershova (1983). She divided the genus into more species than used by Zakharov (1981) and all species recognized in the present work have also been identified by her from Svalbard.

Buchia okensis has been recommended by Zakharov (1987) as the best bivalve for the recognition of the Jurassic-Cretaceous boundary in Boreal regions. Its association on the Russian Platform, North and West Siberia and East Greenland with the ammonite *Hectoroceras kochi* provides an important correlation event of the Boreal Berriasian. Zakharov (1981) regarded the *B. okensis* Zone as appearing in mid-*Chetaites sibericus* Zone and lasting until the middle of the succeeding *H. kochi* Zone. Hoedemaeker (1987), however, correlated the *B. okensis* Zone with only the upper part of the *H. kochi* Zone and the lower part of the Tethyan *Berriasella paramimouna* Subzone. He regarded the base of the Cretaceous as somewhat below (three zones) this level at the boundary between the *Pseudosubplanites grandis* and the *Subthurmannia subalpina* Subzones. Zakharov's broader concept of the *B. okensis* Zone commences only half a zone above Hoedemaeker's concept of the base of the Berriasian in the Boreal Realm at the base of the *Chetaites sibiricus/Praetollia maynci* Zone.

Description of core 7320/3-U-1 (205500.8E 735115.2N). – See Fig. 2 (N.Å. on the basis of data from colleagues at IKU).

36.2–33.3 m

The lowermost 2.9 m of the core consist of a grey clayey and sandy siltstone with wood fragments and numerous 1–5 mm thick horizontal fine sand and silt laminations. Some mainly horizontal burrows 1–3 mm in diameter occur. Faecal pellets 0.2–0.5 mm in diameter are commonly pyritized and/or sideritized, probably during early diagenesis, and a larger siderite nodule was also penetrated.

Glauconite occurs as a few 0.2–0.5 mm green grains and possibly replaces faecal pellets. Chert is observed in a few laminations and in concretions up to 3 mm in diameter.

The unit is fairly homogeneous with respect to natural γ-radiation except for positive K and U anomalies in the uppermost decimetres of the
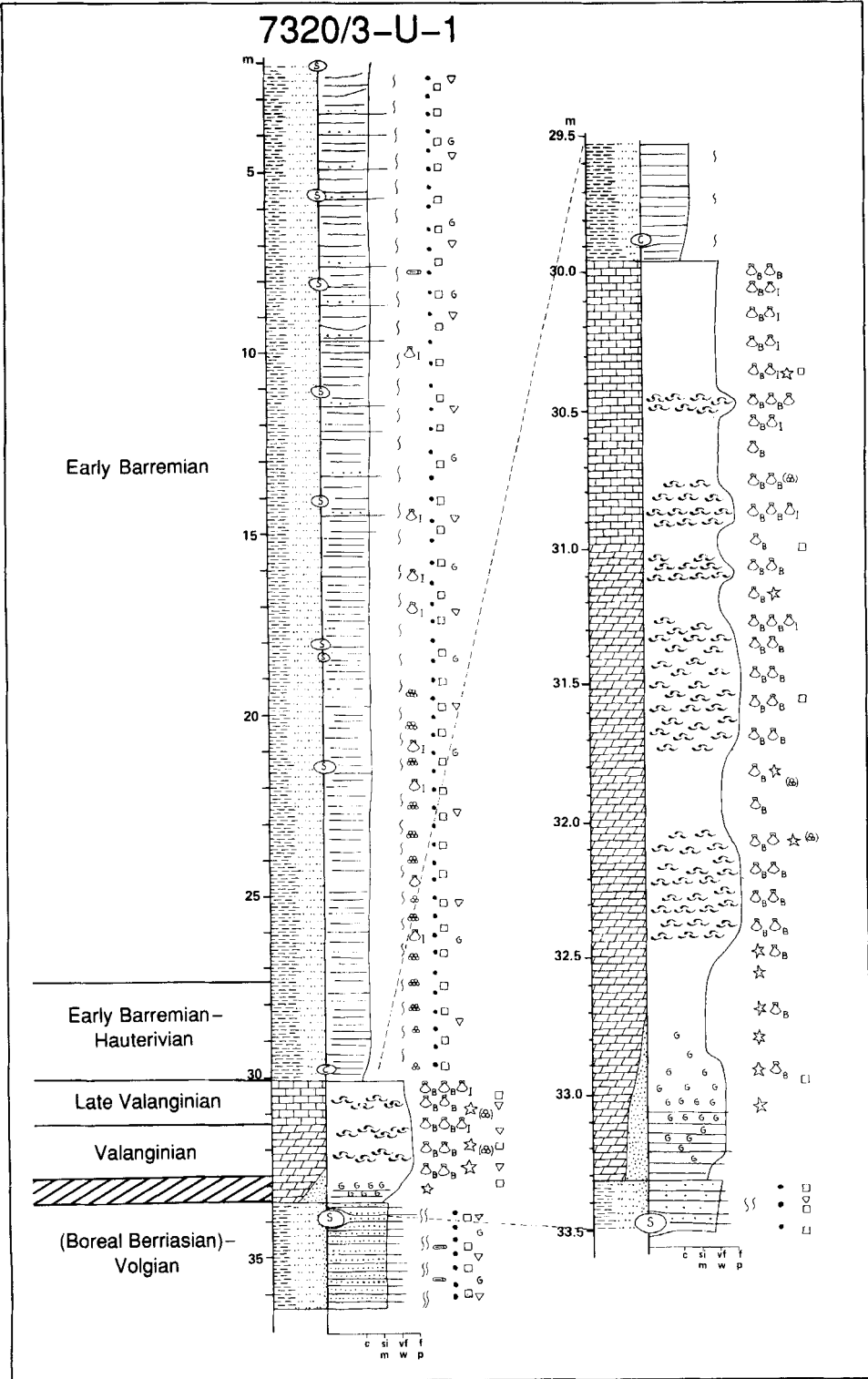
7320/3-U-1

Fig. 2. Sedimentological log core 7320/3-U-1, prepared by Geir Elvebakk. For legend see Fig. 4.

unit. TOC values in 7 samples vary between 1.6 and 4.3 wt% (mean 2.7%), with lowest values above 34 m. The kerogen is of very poor hydrogen type IV up to 34.2 m where a strong increase in hydrogen index is seen.

33.3–29.95 m

The next 3.3 m thick grey carbonate interval consists of 2.3 m of dolomitized limestone followed by 1 m of limestone. The transition from the clastic interval below is abrupt and the lower 0.25 m of the dolomite is horizontally laminated and gradually changes into a wackestone. Glauconite mainly in the form of glauconitized faecal pellets occurs together with medium sized sand grains in the lower 0.7 m of the dolomite. The glauconite may contribute to 30% of the rock in the richest horizons.

Most of the interval consists of intermingling wackestones and packstones. The packstones are very rich in both fragmented and unfragmented material of *Buchia*. In the wackestones the proportion of *Buchia* is low relative to the presence of foraminifera, fragments of echinoderms and the bivalve *Inoceramus*.

Chert occasionally partly replaces both micrite and fossil fragments. The average whole rock TOC content is 0.2 wt%.

29.95–0 m

This upper part of the core consists of dark grey silty claystone to clayey sandy siltstone except for the lowermost 0.5 m which is developed as a black shale poor in quartz and feldspar and rich in mica/ illite. In the lower part of the unit horizontally laminated silty and clayey alternations occur. From around 16 m and upwards very fine grained sandstones occur at the base of thin fining upwards beds. The income of sandy material seems to be associated with an increased content of albite as compared to alkali feldspar.

Bioturbation mainly occurs as 0.5–2 mm diameter horizontal burrows, although they may also be vertical and/or up to 1 cm in diameter. Elliptical to spherical faecal pellets of 0.2–1 mm diameter often comprise approximately 10% of the rock. These are sideritized, pyritized or glauconitized.

Siderite also occurs as early diagenetic concretions approximately 3–5 cm in diameter. The amount of macrofossils in the rock is low, but some *Inoceramus* fragments occur.

TOC values generally increase upwards to 20 m from where they are fairly constant. The average for the whole unit is 3.2 wt%. Rock-Eval data indicate an upward change in kerogen type from a hydrogen-poor type III kerogen to a slightly more hydrogen-rich type III, especially above 15 m.

Biostratigraphy of core 7320/3-U-1. – See Fig. 3 (N.Å., S.R.A.K.).

36.20–33.50 m Volgian – (Boreal Berriasian)

Four samples from this interval were processed for palynology, and were found to contain the low diversity *Pareodinia borealis* dinoflagellate cyst assemblage. Samples from the lower part of the interval are dominated by tasmanitids, *Sirmiodinium grossii*, representatives of the *Gonyaulacysta cretacea/helicoidea* group and a variety of *Tubotuberella apatela* similar to *Tubotuberella uncinata* (Brideaux 1977) Davies 1983. Some of the specimens of *T. apatela* bear a few small spines along plate boundaries particularly antapically, resembling *Tubotuberella dangeardi* subsp. *primitiva* Sarjeant 1982, proving the need for revision of this complex. *T. uncinata* has previously been recorded from the Barremian and *T. dangeardii* subsp. *primitiva* from the Bathonian. Poorly preserved specimens of *Cribroperidinium* spp. with variably developed horns are the dominant palynomorphs recorded at 33.50 m. Some of them may be referred to the *C. granulatum/ granuligerum/globatum* complex.

The recorded assemblages from this interval are not very age significant. Tasmanitids are particularly common in the late Portlandian i.e. Late Volgian in the North Sea Basin (Davey 1982), but in the Middle Volgian on Spitsbergen. Representatives of the *G. cretacea/helicoidea* group have not been found consistently and commonly below the Volgian on Spitsbergen. The absence of *Gonyaulacysta jurassica* and *Pareodinia capillosa* also favours a Volgian dating, although this evidence is negative. *P. capillosa* occurs consistently in the latest Kimmeridgian *sensu gallico* in the area.

At 36.20 m several specimens of *Cribroperidinium* cf. *mamilliferum* (Gitmez 1970) have been observed. Gitmez found this form in the basal Kimmeridgian of Normandy, but we have recorded it only in latest Kimmeridgian *sensu gallico* in the Barents Sea borehole 7230/5-U-2, which does not penetrate the Volgian.
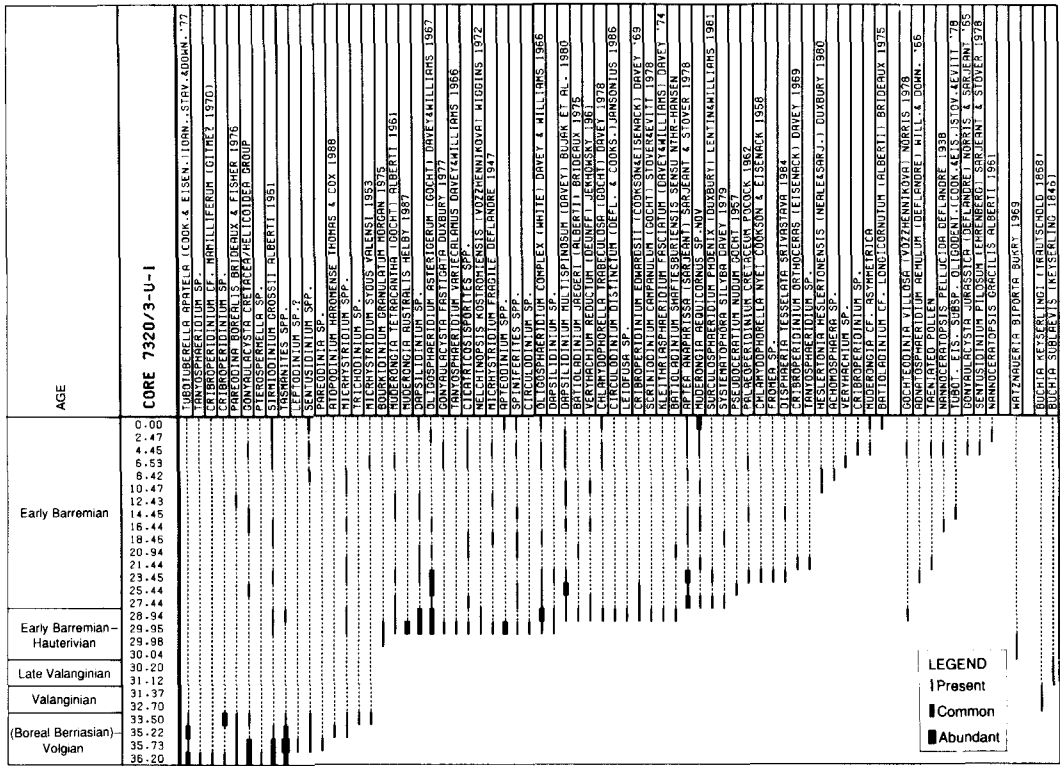
Fig. 3. Palaeontological range chart core 7320/3-U-1.

32.70–31.37 m Valanginian

Buchia keyserlingi occurs throughout the interval which has not yielded palynomorphs. In East Greenland (Surlyk & Zakharov 1982), on Andøya (Birkelund et al. 1978; Zakharov et al. 1981) and the Russian Platform (Zakharov 1981) the species was reported as most abundant in the Early Valanginian. Zakharov (1987, p. 146, table 2) tabled most numerous specimens in his late Early Valanginian *B. keyserlingi* Zone. *B. keyserlingi* also ranges up into the Early Hauterivian, especially in northern Germany and eastern England.

31.12–30.20 m Late Valanginian

B. sublaevis has been found from 31.12 to 30.20 m. The species is most typical of the Late Valanginian of Andøya, Norway (Zakharov et al. 1981), East Greenland (Surlyk & Zakharov 1982) and the Russian Platform (Zakharov 1981), but extends from Early Valanginian to earliest Hauterivian.

30.04–27.44 m Hauterivian – Early Barremian

The presence of rare and damaged representatives of the nannofossil *Watznaueria biporta* at 30.04, 29.99 and 29.98 m suggests an age not earlier than Hauterivian at these depths.

Relatively diverse dinoflagellate cyst assemblages occur in the dark claystone from immediately above the limestone and upwards. *Nelchinopsis kostromiensis* has been recorded in the two lowermost samples at 29.95 and 28.94 m. Duxbury (1977) and Riley & Fenton (1984) claimed that this species does not range above the Hauterivian, in contrast to Heilmann-Clausen (1987) and Leereveld (pers. comm. 1988) who reported it also from the earliest Barremian *S. variabilis* Zone and as high as the middle Barremian *H. rude-fissicostatum* Zone, respectively. *Muderongia australis* is common at 29.95 m.

27.44–0 m Early Barremian

The presence of *Aptea anaphrissa* in most samples from 27.44 m to the top (common in the lower

part) favours a late Early Barremian dating. Dux-
bury (1977) and Davey (1979) found *A.
anaphrissa* in uppermost Lower and middle Bar-
remian strata, whereas Duxbury (1980) reported
it exclusively from top Lower Barremian, but
there is some confusion due to a former three-
fold division of this stage. Mutterlose & Harding
(1987) recorded *A. anaphrissa* exclusively in the
middle section of the Hauptblätterton of claypit
Gott, northern Germany, which according to
them is an offshore anoxic warmwater facies.
These beds contain a belemnite fauna with
Aulacoteuthis spp. and correspond to the late
Early Barremian *fissicostatum* Zone (lower part
of *H. rude-fissicostatum* Zone).

*Description of core 7425/9-U-1 (254619.3E
742925.3N).* – See Fig. 4 (N.Å. on the basis of
data from Geir Elvebakk and others).

64.54–63.84 m
Lithologically this 14.5 m long core can be divided

into four units. The lowermost 0.7 m thick part
consists of a greyish green homogeneous marl
(wackestone) with abundant fragmented and
unfragmented shells of *Buchia* and fragmented
Inoceramus in a micritic matrix. Terrigenous mat-
ter may amount to more than 60 wt% and TOC
content to an average of 0.3%.

63.84–58 m
The overlying, about 5 m thick unit comprises
reddish brown, very fossiliferous, silty claystone
with occasional reduction spots. Its base is sharp.
Complete and fragmented specimens of the
bivalve genera *Buchia* and *Inoceramus* are the
most common fossils, but brachiopods, cirri-
pedes, gastropods, belemnites, echinoderm frag-
ments, foraminifera and wood fragments have
also been recognized.

58–53.5 m
The unit gradually changes into the greyish green
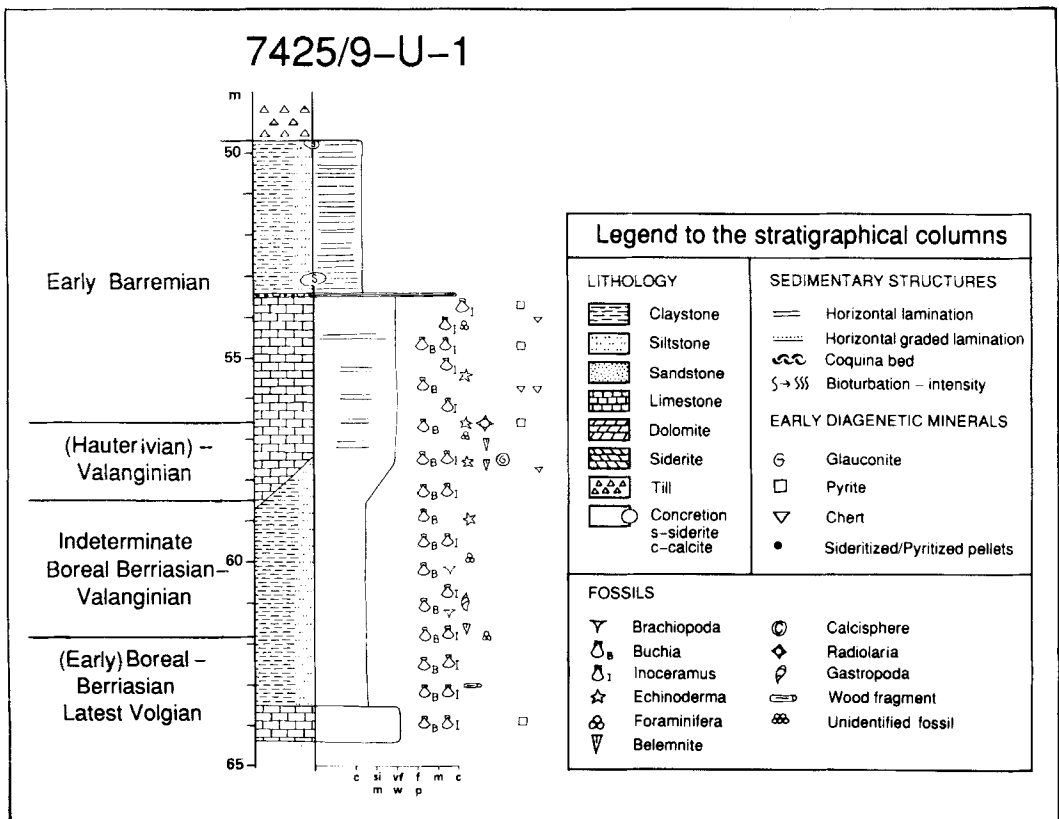marly limestone of the next unit and the transition

Fig. 4. Sedimentological log core 7425/9-U-1, prepared by Geir Elvebakk.

zone is mottled. Colour changes often follow the outlines of shells, suggesting that colour differences are due to diagenesis. Light greyish/ greyish green mottling occurs in the lower 2.5 m of this unit, whereas the upper couple of metres consist of dark grey to black limestone. This limestone may be stromatolitic in part due to lamination of calcite and dark brown to black material of possible algal origin. The interval in general is lean in organic matter with an average TOC content of only 0.06%.

The amount and diversity of calcareous fossils

and fragments in the unit is high. *Buchia* is the most common fossil in the lower part whereas *Inoceramus* is dominant in the upper part. Echinoderm fragments and foraminifera occur throughout the unit and belemnites and calcispheres have been observed in the lower part. Much of the shell material is bored, probably by sponges. Diameter and shape of the borings vary.

53.5–49.72 m

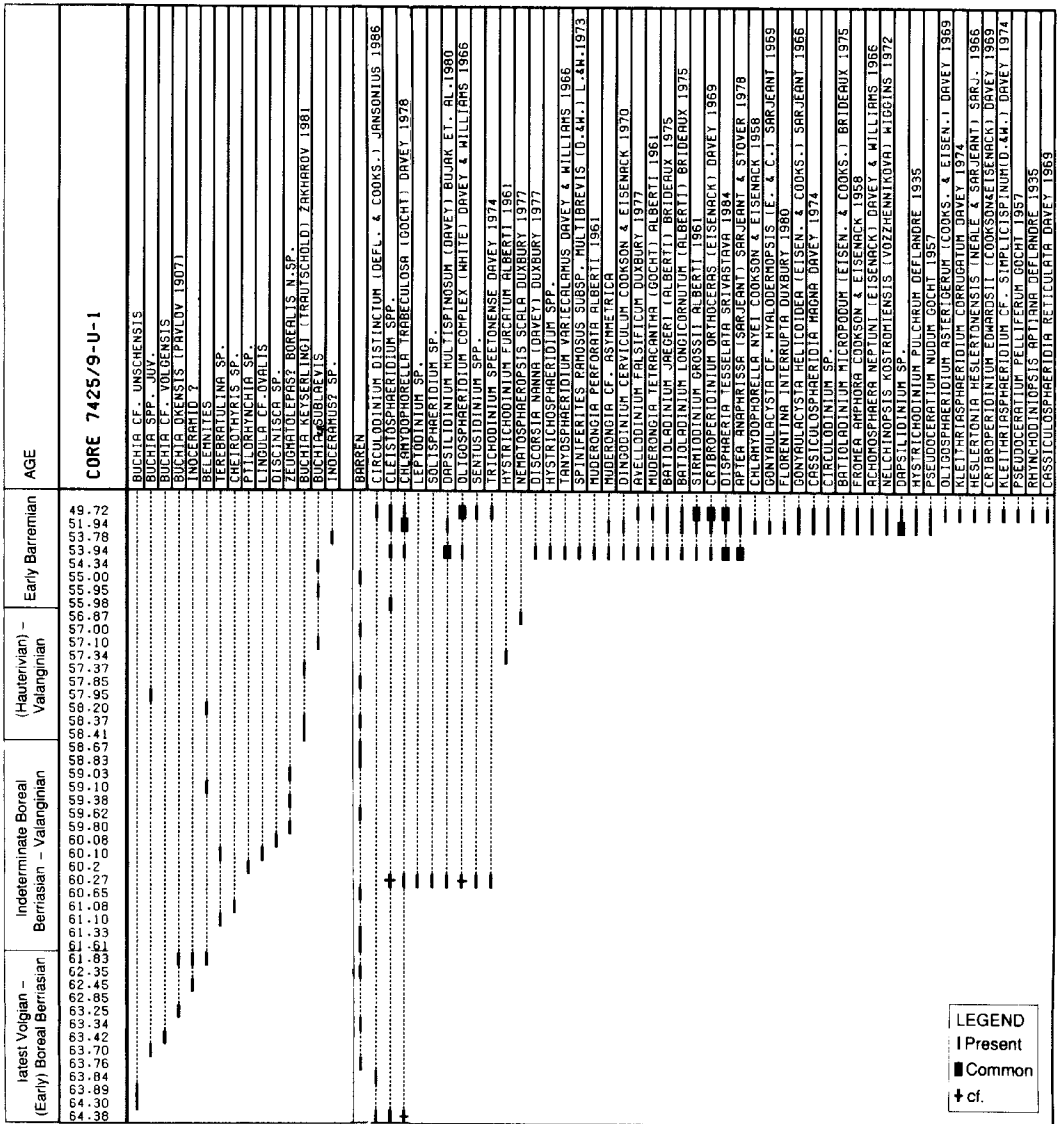The transition is abrupt to the overlying grey silty

Fig. 5. Macrofaunal and palynological range chart core 7425/9-U-1.

claystone, represented by 3.8 m of core. A 3 cm thick lag deposit of coarse sand containing some glauconite is developed between the units. Description is hampered by extreme fragmentation of the rock. Thin lamination occurs, but locally, burrows 1–2 mm in diameter destroy this. Yellowish brown siderite concretions up to 15 cm thick are observed. The rock has a fair to good organic matter content with an average TOC content of 1.0 wt%. Rock-eval data show that the samples contain a hydrogen-poor type III/IV kerogen. The most organic-rich examined sample from 51.94 m with a TOC content of 2.4% has a more hydrogen-rich type III kerogen.

Biostratigraphy of core 7425/9-U-1. – See Figs. 5 and 6 (S.R.A.K., N.Å.).

64.54–61.83 m latest Volgian – (Early) Boreal Berriasian
Buchia cf. *unschensis* (Pavlov) occurs at 64.30–63.89 m and suggests a late Late Volgian to earliest Early Boreal Berriasian age. Low diversity assemblages of foraminifera and dinoflagellate cysts are present and are not very age diagnostic. The dinocyst assemblages consist of small spinose species, probably reflecting some environmental restriction.

Buchia cf. *volgensis* was recognized from a single specimen at 63.42 m. *B. volgensis* is a more widespread Boreal Berriasian indicator than *B. okensis*, which occurs between 63.25 and 61.83 m. *B. okensis* is most typical of the late Early Boreal Berriasian (Zakharov 1987), where it often occurs in association with the ammonite zonal index *Hectoroceras kochi*. In Barents Sea core 7430/10-U-1 the uppermost specimens determined as *B.* cf. *okensis* have been found 10 cm above the last records of *Lenticulina sossipatrovae* and the first records of *Marssonella oxycona* (Skarbø pers. comm.). Bartenstein & Bettenstaedt (1962) claimed that *M. oxycona* is suggestive of a Valanginian or younger age, but our evidence complicates this. Also in 7425/9-U-1 *M. oxycona* appears slightly below the disappearance of *B. okensis* (at 62.50 and 61.83 m, respectively).

Lenticulina spp. dominate the foraminifera assemblages at 63.76 and 63.38 m. Basov & Ivanova (in Saks 1972) reported some new species of *Lenticulina* to appear in the Berriasian of the Urdyuk-Khaya and the Boyarka sections, northern Siberia, but a detailed correlation with Siberia is impossible at this stage. Nagy (pers. comm.)

correlated a similar foraminifera assemblage from a thin interval at the base of the Rurikfjellet Member in the Agardhfjellet section, Spitsbergen, to the Berriasian of Siberia, but a younger age cannot be excluded.

61.83–58.41 m indeterminate Boreal Berriasian-Valanginian
Only one of the seven samples prepared for palynology from this interval was productive, containing a poor and low diversity dinocyst assemblage without precise biostratigraphic significance. The bivalve fauna includes only epifaunal or reclining filter feeders. Juveniles with clearly preserved prodissoconchs numerically dominate the age undiagnostic disarticulated *Buchia* fauna. Cirripede plates described below are found between 61.05 and 59.28 m.

58.41–57.37 m (Early) Valanginian
Buchia keyserlingi (Trautschold) occurs from 58.41–57.37 m. The species is a typical Boreal Early Valanginian to Early Hauterivian indicator, but most characteristic in the late part of the Early Valanginian (Zakharov 1987). The interval is therefore most likely to be Early Valanginian. A single poorly preserved specimen of the dinoflagellate cyst *Hystrichodinium furcatum* has been recorded at 57.34 m. According to Riley & Fenton (1984), this species has a total stratigraphic range of late Valanginian to early Barremian.

57.10 m Late Valanginian – (Early Hauterivian)
Buchia cf. *sublaevis* (Keyserling) occurs at this depth and is most likely evidence of a Late Valanginian age (see above). Records of similar forms at 55.95 and 54.34 m are stratigraphically problematic.

56.62–49.72 m Early Barremian
The foraminifera fauna, with the first record of *Gavelinella barremiana* at 56.62 m, indicates that most of the upper limestone unit in this core is Barremian in age. *Uvigerina moesiana* appears at 55.70 m. Skarbø (pers. comm.) has noted the income of these two species in the same sample in the lower part of a limestone interval in Barents Sea core 7430/10-U-1, 0.25 m above the first record of the dinocyst *A. anaphrissa*. The uppermost record of *Buchia sublaevis* at 55.95 m is conflicting and problematic evidence (see above). Inoceramids occur throughout the core, but between
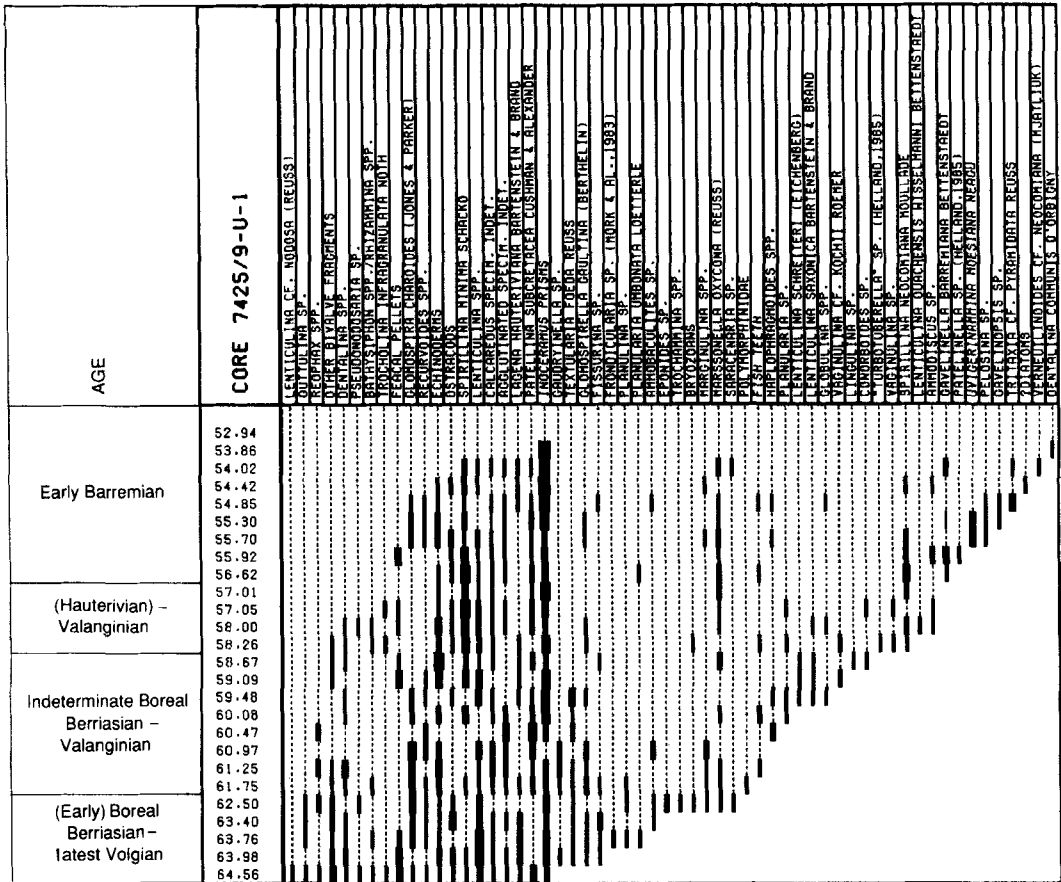
Fig. 6. Range chart prepared by Oddvar Skarbø showing distribution of foraminifera etc. in core 7425/9-U-1.

53.85 and 53.78 m much larger shell fragments of this group are common. The necessary characters for species determinations have not been observed and the fauna therefore cannot be used for age interpretation.

A relatively diverse dinoflagellate cyst assemblage occurs at 53.94 m, about 0.5 m below the top of the limestone interval. *Aptea anaphrissa*, *Dapsilidinium multispinosum* and *Disphaeria tesselata* dominate the assemblage. According to Duxbury (1980), *A. anaphrissa* is a late Early Barremian marker (see above).

Nelchinopsis kostromiensis is rare, with single specimens recorded at 51.94 and 49.72 m, showing that *N. kostromiensis* and *A. anaphrissa* have overlapping ranges in this core. This is in contrast to the observations by Duxbury (1977) and Riley & Fenton (1984) who claimed that *N. kos-*

tromiensis does not range above the Hauterivian. But the species is rare in the upper part of its range. Since *A. anaphrissa* often has an acme occurrence in the lowermost part of its range (e.g. in the commercial Tromsøyflaket wells 7120/9-1 at 1,761 m, in 7120/12-2 at 1,500 and 1,475 m and in 7120/12-3 at 1,810 m), this may be the best practical palynological criterion for distinguishing Hauterivian and Barremian strata, although the acme occurrence is probably situated in the middle Barremian *H. rude-fissicostatum* ammonite zone according to the literature (see above).

The presence of *Rhynchodiniopsis aptiana* (synonymous with *R. fimbriata* and *Gonyaulacysta anglese*) is in accordance with the range reported by Srivastava (1984). He found the taxon throughout the Barremian stage in the stratotype and some paratype sections in contrast to Zahiri

(1981), who reported it only from the lowermost Barremian.

Systematic palaeontology

Systematic annotations as indicated by the symbols preceding the year in each synonymy entry follow the Richter system as modified by Matthews (1973). Synonymy entries of buchiid bivalves are only included where they supplement the principal work of Zakharov (1981), or have been figured or described from Svalbard. Citings are not mentioned unless significant. The figured material is held in the collection of Paleontologisk Museum, Oslo (PMO).

Bivalves (S.R.A.K.)

Class Bivalvia Linné, 1758
Subclass Pteriomorphia Beurlen, 1944
Order Pterioida Newell, 1965
Suborder Pectinina Waller, 1978
Superfamily Buchiacea Waller, 1978
Family Buchiidae Cox, 1953
Genus *Buchia* Rouillier, 1845

Buchia cf. *unschensis* (Pavlov 1907)
Fig. 7A–C

 1931 *Aucella* cf. *unschensis* Pavlov; Sokolov & Bodylevsky, p. 42 (Festningen, Spitsbergen, Valanginian).
cf. 1983 *Buchia unschensis* (Pavlov); Yershova, p. 25, pl. 27, fig. 4 (Agardhbukta, Spitsbergen, *nodiger* Zone, Late Volgian).
cf. 1983 *Buchia unschensis* (Pavlov); Zakharov et al., p. 176, pl. 23, figs. 4–6 (northern central Siberia, Late Volgian).
cf. 1989 *Buchia unschensis* (Pavlov); Paraketsov & Paraketsova, p. 230, pl. 9, fig. 4 (northern U.S.S.R., Late Berriasian).

Type. – Lectotype: designated by Jeletzky (1966), A. P. & M. V. Pavlov Museum, Moscow, No. VI, 34/153, Late Volgian, *?nodiger* Zone, River Unzha, near Ogarkov, Kostromsk Oblast, U.S.S.R.

Material. – Borehole 7425/9-U-1 at 64.30–63.89 m.

Diagnosis. – Small to medium size, trigonal outline, moderate to close spaced commarginal folds with fine lamellae. Growth curve curvoid to orthoid.

Remarks. – These specimens are not well preserved. However, they are the only bivalve

indicators of a possible Jurassic age in this borehole. The species was originally recorded from Spitsbergen by Sokolov & Bodylevsky (1931). Zakharov (1981, p. 116) recognized *B. unschensis* from the *Craspedites okensis* to *Hectoroceras kochi* Zones in northern central Siberia and in the Pechora Basin on the Russian Platform in strata of possibly the *Craspedites subditus* Zone to those bearing *Hectoroceras*. Håkansson et al. (1981, p. 24) recorded the species from the Late Volgian and Early Ryazanian of Peary Land, North Greenland. Jeletzky (1984) also identified the species in the Late Tithonian (i.e. Late Volgian – earliest Boreal Berriasian) of Arctic Canada. The present occurrence is most likely to be Early Boreal Berriasian, but it is also possible that it may be latest Volgian as recorded from Svalbard by Yershova (1983).

Stratigraphic range. – *C. subditus* Zone, Late Volgian to *H. kochi* Zone, Early Boreal Berriasian.

Buchia okensis (Pavlov 1907)
Fig. 7E–L

v. 1931 *Aucella okensis* Pavlov; Sokolov & Bodylevsky, p. 40, pl. 1, figs. 10, 11 (Festningen, Spitsbergen, Janusfjellet Formation, Boreal Berriasian).
 1937 *Aucella* sp. cf. *okensis* Pavlov; Frebold & Stoll, p. 29 (Festningen, Spitsbergen, Janusfjellet Formation, Boreal Berriasian).
v. 1981 *Buchia okensis* (Pavlov); Zakharov, p. 116, pl. 31, figs. 1–3; pl. 32, figs. 1–4; pl. 33, figs. 1–2; pl. 34, figs. 1–3; pl. 35, figs. 1–4 (R. Boyarka and Paksa, northern central Siberia, Boreal Berriasian).
. 1981 *Buchia okensis* (Pavlov); Håkansson et al. p. 24, pl. 4, figs. 3–8; pl. 5, figs. 1–3 (Peary Land, North Greenland, Boreal Berriasian).
. 1982 *Buchia okensis* (Pavlov); Surlyk & Zakharov, p. 740, pl. 75, fig. 1 (South Jameson Land, East Greenland, Boreal Berriasian).
. 1983 *Buchia okensis* (Pavlov); Yershova, p. 34, pl. 26, fig. 26 (Agardhbukta, Svalbard, throughout the Berriasian).
. 1983 *Buchia okensis* (Pavlov); Zakharov et al., p. 176, pl. 24, figs. 1–2 (northern central Siberia, Berriasian).
. 1984 *Buchia okensis* (Pavlov); Jeletzky, p. 203, pl. 3, fig. 2a-d (SW British Columbia, Boreal Berriasian).
. 1986 *Buchia okensis* (Pavlov); Zakharov & Lebedev, p. 94, pl. 11, figs, 2,3 (western Siberia, Boreal Berriasian).
. 1987 *Buchia okensis* (Pavlov); Zakharov, p. 147 (Berriasian; defines base of Cretaceous in the Boreal and Subtethyan realms). (See Zakharov 1981, p. 116, for full synonymy.)
. 1989 *Buchia okensis* (Pavlov); Paraketsov & Paraketsova, p. 228, pl. 10, figs. 1–5 (northeastern U.S.S.R., Late Berriasian).

Type. – Lectotype designated by Pozhariskaya (1971, p. 118), original of Pavlov (1907, pl. 1,
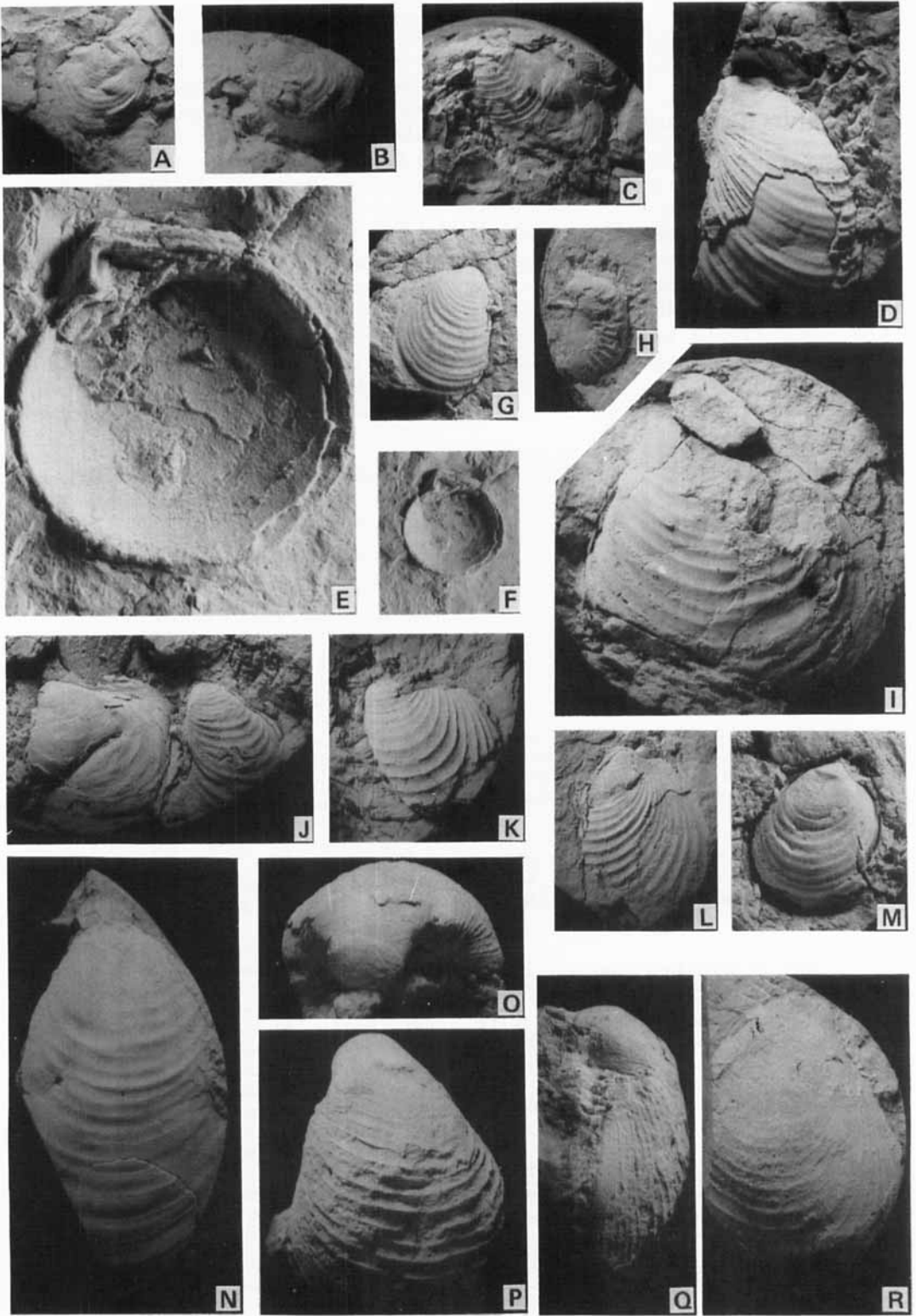
fig. 11a-c), M. V. and A. P. Pavlov Museum, Moscow, Ryazan Horizon, R. Pekhorka, Ulyanovsk Oblast, U.S.S.R.

Material. – Borehole 7425/9-U-1 at 63.25–61.83 m.

Diagnosis. – Medium to large size buchiid with strong commarginal folds, moderately compressed, broad valves, umbo of left valve moderately projecting. Growth curve curvoid to obliquoid.

Remarks. – The species is most typical of the Early Boreal Berriasian on the Russian Platform where it occurs in association with *Hectoroceras kochi* (Zakharov 1981, p. 121). The same association is described from Peary Land, North Greenland (Håkansson et al. 1981). It also occurs in East Greenland where it is recorded by Surlyk & Zakharov (1982, p. 740) as rarely occurring in the Muslingeelv Member of the Hesteelv Formation. But the basal conglomerate of this same member yielded abundant specimens of this species to the author in 1973. However, it is not known in the *H. kochi* Zone from eastern England. *B. okensis* is widely distributed in the Northern Hemisphere (see Zakharov, 1981, fig. 62). Jeletzky (1984, fig. 5) considered the species *sensu stricto* appeared at the true Tithonian-Berriasian boundary in Western British Columbia, but also recognized *B.* n. sp. aff. *okensis* occurring considerably earlier within the Late Tithonian. However, on the central Russian Platform the species is recorded from the Late Volgian (Zakharov 1981, table 3) where it is associated with *B. uncitoides* and in Svalbard it ranges throughout the Berriasian overlapping with *B. keyserlingi* (Yershova 1983).

Stratigraphic range. – *H. kochi* to *B. mesezhnikovi* Zones, Boreal Berriasian.

Buchia cf. *volgensis* (Lahusen 1888)
Fig. 7D

cf. 1983 *Buchia volgensis* (Lahusen); Yershova, p. 34 (Svalbard, Berriasian, up to *spasskensis* Zone).
cf. 1989 *Buchia volgensis* (Lahusen); Paraketsov & Paraketsova, p. 229, pl. 11, figs. 1–3 (northeastern U.S.S.R., Early Valanginian).
cf. 1990 *Buchia volgensis* (Lahusen); Kelly, p. 138, pl. 2, fig. 2 (eastern England, Berriasian, *S. icenii* Zone).
(See Zakharov (1981) and Kelly (1984) for full synonomy of species.)

Types. – Syntypes from the Boreal Berriasian of Kashpir, Simbirsk, Starayan and Ryazan. Lectotype: designated Glazunova (1973), Gorni Museum, Leningrad, No. 11/40, Kashpir, Kuybyshev Oblast, U.S.S.R.

Material. – Borehole 7425/9-U-1 at 63.42 m.

Diagnosis. – Medium to large, tall buchiid, with low regular commarginal folds. Growth curve orthoid to inversoid.

Remarks. – *B. volgensis* is a longer ranging Boreal Berriasian indicator than *B. okensis*, which becomes most abundant in the Late Boreal Berriasian, but also occurs in the Early Boreal Berriasian. The species is widely recorded from the Boreal Berriasian of Spitsbergen (Yershova 1983). It is particularly widespread on the Russian Platform (Zakharov 1981), Andøy, Norway (Birkelund, et al. 1978; Zakharov et al. 1981), East Greenland (Surlyk & Zakharov 1982), ?Peary Land, North Greenland (Håkansson et al. 1981), and eastern England (Kelly 1984). (See

Fig. 7.
A–C: *Buchia* cf. *unschensis* (Pavlov 1907)
A, PMO 116.481, right valve, 63.89 m, ×1.5; B, PMO 116.482, left valve, 64.03 m, ×1.5; C, PMO 116.483, left valve, 64.30 m, ×1.
D: *Buchia* cf. *volgensis* (Lahusen 1888)
PMO 116.484, left valve, 63.42 m, ×1.
E–L: *Buchia okensis* (Pavlov 1907)
E, PMO 116.485, right valve interior, 63.25 m, ×3; F, same specimen, PMO 116.485, ×1; G, PMO 116.486, right valve, 63.02 m, ×1.25; H, PMO 116.487, left valve, anterior view, 62.74 m, ×1; I, PMO 116.488, left valve, 62.50 m, ×1; J, PMO 116.489, left valves, 62.25 m, ×1.5; K, PMO 116.490, left valve, 61.83 m, ×1; L, PMO 116.491, right valve, 62.40 m, ×1.
M–R: *Buchia keyserlingi* (Trautschold 1868)
M, PMO 116.492, right valve, 58.41 m, ×1.5; N, PMO 116.493, left valve, 57.37 m, ×1.5; O, P, Q, PMO 116.494, left valve, dorsal, lateral and anterior views, 57.62 m, ×1; R, PMO 116.495, left valve, 57.52 m, ×1.
All specimens from Barents Sea Borehole 7425/9-U-1. Depths given in metres below sea floor. All specimens in external lateral view unless stated otherwise.
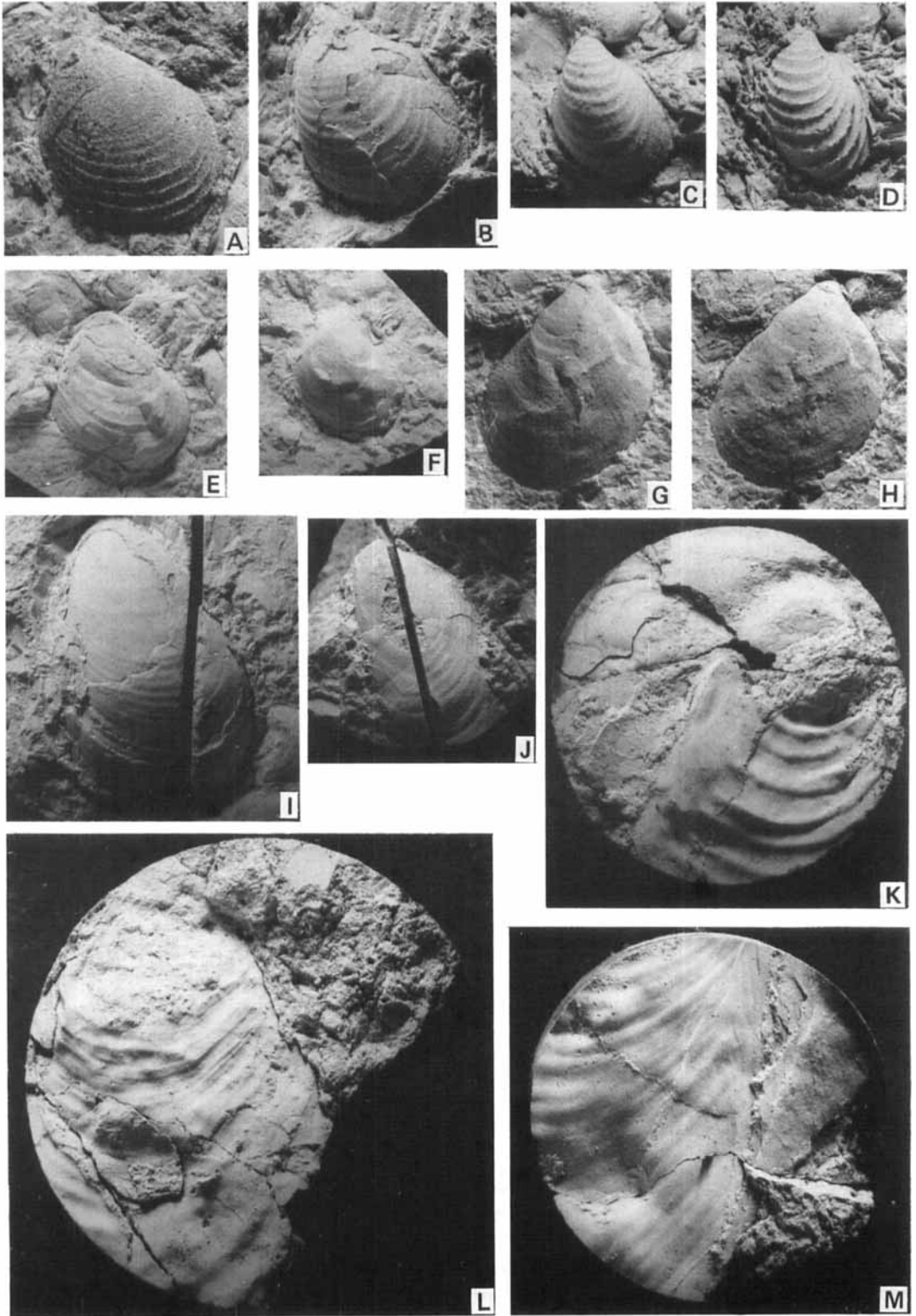
Zakharov 1981, fig. 66, and Kelly 1984, p. 60, for more widespread geographical distribution.)

Stratigraphic range. – Boreal Berriasian.

Buchia keyserlingi (Trautschold 1868)
Fig. 7M-R, Fig. 8A–D

v. 1930 *Aucella keyserlingi* Lahusen; Frebold, p. 43, pl. 15, fig. 1 (Festningen, Spitsbergen, Janusfjellet Formation, Valanginian).

1931 *Aucella keyserlingi* Lahusen; Sokolov & Bodylevsky, p. 43 (Festningen, Spitsbergen, Janusfjellet Formation, Valanginian).

v. 1936 *Aucella keyserlingi* Lahusen; Blüthgen, p. 13, pl. 2, fig. 2 (Johnsenberget, Kong Karls Land, Early-Middle Valanginian).

1937 *Aucella keyserlingi* Lahusen; Frebold & Stoll, p. 28 (Festningen, Spitsbergen, Janusfjellet Formation, Valanginian).

v. 1981 *Buchia keyserlingi* (Trautschold); Zakharov, p. 141, pl. 50, figs. 2–5; pl. 51, figs. 1–7; pl. 52, figs. 1–3; pl. 53, figs. 1–3; pl. 54, figs. 1–2; pl. 55, figs. 1–4 (Svalbard, British Columbia, Russian Platform, northern central Siberia, Valanginian).

? 1981 *Buchia* sp. indet. cf. *keyserlingi* (Lahusen); Håkansson et al., p. 26, pl. 5, fig. 6 (Peary Land, North Greenland, Valanginian).

. 1981 *Buchia keyserlingi* (Trautschold); Zakharov et al., p. 264, pl. 2, figs. 3, 4 (Andøy, Norway, Early Valanginian).

v. 1982 *Buchia keyserlingi* (Trautschold); Surlyk & Zakharov, p. 741, pl. 76, figs. 2, 3; pl. 77, fig. 1 (Wollaston Forland, East Greenland, Early Valanginian).

. 1983 *Buchia keyserlingi* (Lahusen); Kemper, p. 366, pl. 1, figs. 7, 8 (Axel Heiberg and Ellesmere Islands, Canadian Arctic, Late Valanginian).

. 1983 *Buchia keyserlingi* (Lahusen); Bogdanova in Luppov et al., p. 77, pl. 11, figs. 9–15; pl. 12, figs. 1–3 (Manguyschlak, southern U.S.S.R., Early Valanginian).

. 1983 *Buchia keyserlingi* (Lahusen); Yershova, p. 34, pl. 37, fig. 2 (Svalbard, Late Berriasian (Beds with *Tollia* and *Bojarkia*) to late Early Valanginian (*ramulicosta* Zone)).

. 1983 *Buchia keyserlingi* (Trautschold); Zakharov et al., p. 176, pl. 23, figs. 4–6 (northern central Siberia, Early Valanginian).

. 1986 *Buchia keyserlingi* (Trautschold); Zakharov &

Lebedev, p. 95, pl. 14, figs. 8, 9 (western Siberia, late Early Valanginian).

1987 *Buchia keyserlingi* (Trautschold); Zakharov, p. 150 (Boreal and Subtethyan regions, Early Valanginian to Early Hauterivian).

(See Zakharov 1981 for full synonymy.)

Type. – Holotype by monotype, Gorni Museum, Leningrad, No. 266/46, River Yusy, Volga River Basin. Originally figured by Keyserling (1846, pl. 16, fig. 6) as *Aucella concentrica* var. *rugosa*.

Material. – Borehole 7320/3-U-1 at 32.70–31.37 m; 7425/9-U-1 at 58.41–57.37 m.

Diagnosis. – Inflated, moderately sized buchiid, commarginal ribs regular, but sometimes smooth. Left valve beak weakly to moderately projecting. Growth curve inversoid.

Remarks. – The species is a typical Boreal Valanginian indicator, and is widely recognized in Svalbard. It is most abundant in the Early Valanginian of East Greenland (Surlyk & Zakharov 1982), Andøy, Norway (Birkelund et al. 1978; Zakharov et al. 1981), and the Russian Platform (Zakharov 1981). The species, however, does range up into the Late Valanginian where it occurs with, but is subordinate to, *B. sublaevis* (Keyserling) and also into the Early Hauterivian, the latter occurrence especially in northern Germany and eastern England. Yershova (1983) recorded *B. keyserlingi* as early as the latest Late Berriasian.

Stratigraphic range. – Latest Berriasian to Early Hauterivian.

Buchia sublaevis (Keyserling 1846)
Fig. 8G–I

v. 1931 *Aucella sublaevis* Keyserling; Sokolov & Bodylevsky, p. 45, pl. 2, figs. 6, 7 (Festningen, Spitsbergen, Janusfjellet Formation, Valanginian).

Fig. 8.
A–D: *Buchia keyserlingi* (Trautschold 1868)
A, PMO 116.496, latex cast of left valve, 31.37 m, ×2; B, PMO 116.497, left valve, 31.42 m, ×2; C, PMO 116.498, internal mould, left valve, 31.79 m, ×2; D, PMO 116.498, same specimen, latex cast, ×2.
E,F,J: *Buchia* cf. *sublaevis* (Keyserling 1846)
E, PMO 116.499, left valve, 55.95 m, ×1.5; F, PMO 116.500, left valve, 57.10 m, ×1.5; J, PMO 116.503, left valve, 54.34 m, ×1.
G,H,I: *Buchia sublaevis* (Keyserling 1846)
G, PMO 116.501, right valve, internal mould, 31.12 m, ×2; H, PMO 116.501, same specimen, latex cast, ×2; I, PMO 116.502, left valve, 30.20 m, ×1.5.
K–M: *Inoceramus?* sp.
K, PMO 116.504, right valve, 53.85 m, ×1; L, PMO 116.505, ?left valve, 53.78 m, ×1.2; M, PMO 116.506, ?right valve, 53.80 m, ×1.
Specimens A–D, G–I from Barents Sea Borehole 7320/3-U-1, E, F, J–M, 7425/9-U-1. Depths given in metres below sea floor. All specimens in external lateral view unless stated otherwise.

1975 *Buchia* cf. *sublaevis* (Keyserling); Pugaczewska in Birkenmajer & Pugaczewska, p. 66, pl. 5, fig. 1 (Treskelen, Spitsbergen, Tirolarpasset Member?, Valanginian?).

v. 1981 *Buchia sublaevis* (Keyserling); Zakharov, p. 149, pl. 56, figs. 1–5; pl. 57, figs. 1–4; pl. 58, figs. 1–4; pl. 59, figs. 1–4 (Russian Platform and northern central Siberia, Late Valanginian to Early Hauterivian).

. 1981 *Buchia sublaevis* (Keyserling); Zakharov et al., p. 264, pl. 2, figs. 5, 6 (Andøy, Norway, Late Valanginian, ?Early Hauterivian).

. 1982 *Buchia fischeriana* (d'Orbigny); Pugaczewska in Birkenmajer et al., p. 124, pl. 41, figs. 1–7 (Myklegardfjellet, Spitsbergen, Rurikfjellet Member, probably Late Valanginian).

v. 1982 *Buchia sublaevis* (Keyserling); Surlyk & Zakharov, p. 742, pl. 76, figs. 2–7 (Kuhn Island and Wollaston Forland, East Greenland, Early and Late Valanginian).

. 1983 *Buchia* sp. (ex gr. *sublaevis* Keyserling); Yershova, p. 43, (Svalbard, early Early Hauterivian).

. 1983 *Buchia sublaevis* (Keyserling); Yershova, p. 38, pl. 39, fig. 2 (Svalbard, Late Valanginian).

cf. 1983 *Buchia sublaevis* (Keyserling); Zakharov et al., p. 176, pl. 27, figs. 1–2 (northern central Siberia, Late Valanginian).

. 1986 *Buchia sublaevis* (Keyserling); Zakharov, p. 95, pl. 11, figs. 12, 13 (western Siberia, Late Valanginian).

. 1989 *Buchia sublaevis* (Keyserling); Paraketsov & Paraketsova, p. 237, pl. 10, figs. 5–7 (northeastern U.S.S.R., Late Valanginian).

. 1990 *Buchia sublaevis* (Keyserling); Kelly, p. 138, pl. 2, figs. 3–5 (Federal German Republic, Early Hauterivian).

(See Zakharov 1981, p. 149, for full synonomy.)

Type. – Syntypes: Gorni Institute, Leningrad, nos. 267/46, 268/46, originals of Keyserling 1846, p. 300, pl. 16, figs. 13–15, Late Valanginian, R. Izhma, tributary of R. Pechora, Shel'skaya, Archangel'sk Oblast, U.S.S.R.

Material. – Borehole 7320/3-U-1 at 31.12–30.20 m.

Diagnosis. – Moderately inflated, with left valve beaks weakly to moderately projecting. Commarginal ornament usually becoming smooth. Growth curve inversoid.

Remarks. – The specimens figured by Pugaczewska (in Birkenmajer & Pugaczewska 1975) were from loose concretions, thus the precise age cannot be established. The specimens that she figured (in Birkenmajer et al. 1982) as *B. fischeriana* occur very high in the section, probably at the level of the *B. crassicollis/unschensis* assemblage recorded by Pchelina (1967). Yershova (1983) showed the *B. sublaevis* group in Svalbard to extend from the Late Valanginian to Early Hauterivian time. It represents the final appearance of *Buchia*. The specimens have suppressed

to smooth commarginal ornament and certainly lack the very regular, quite strong commarginal ornament of *B. fischeriana*. *B. sublaevis* is most typical of the Late Valanginian of Andøy, Norway (Zakharov et al. 1981), East Greenland (Surlyk & Zakharov 1982) and the Russian Platform (Zakharov 1981) but also extends from Early Valanginian to Early Hauterivian, the latter especially in eastern England and northern Germany.

Stratigraphic range. – Early Valanginian to Early Hauterivian.

Inoceramus? sp.
Fig. 8K–M
Material. – Borehole 7425/9-U-1 at 53.85–53.78 m.

Diagnosis. – Large prismatic shell with broad commarginal folds; a juvenile shell shows subovate outline and moderate obliquity.

Remarks. – The specimens originally described as *I. spitsbergensis* by Stolley (1912, p. 20, pl. 1, figs. 5,6) were in association with *Inoceramus labiatiformis* Stolley and crioceratid ammonites in a block from the 'Ditrupa Sandstein'. *I. labiatiformis* differs from *I. spitzbergensis* by its much narrower umbones and more narrow, oblique shape. Sokolov & Bodylevsky (1931, p. 47) recorded *I.* cf. *spitzbergensis* from bed 32 of the Festningen Section, which they dated as Early Aptian. They also stated that the specimen cited by Zhirmunskiy (1927, p. 104), which was seen by them in the Marine Institute Collections, Leningrad, bore radial ornament and was not an inoceramid. Pchelina (1965) listed *I. spitzbergensis* also in association with *I.* cf. *labiatiformis*, but together with *Arcthoplites* from the Middle Albian of Van Keulenfjorden, Spitsbergen. Pchelina (1967) recorded *Inoceramus* sp. associated with Hauterivian Simbirskitid ammonites in Sørkapp Land, and gave several species from the Albian. In Svalbard Yershova (1983) recorded Early Hauterivian *Inoceramus* sp. and Late Hauterivian *I.* aff. *aucella* Trautschold and *I.* sp. ex. gr. *colonicus* (Anderson). She also identified *I. spitzbergensis* Stolley and *I. labiatiformis* from Aptian and *I. anglicus* from the Middle Albian. The present borehole specimens are left in open nomenclature and the age cannot be precisely given at this stage.

Brachiopods (M.R.S.)

Articulate and inarticulate brachiopods have been recovered from the calcareous reddish brown silty claystone unit of core 7425/9-U-1 of indeterminate Berriasian-Valanginian age (between 61.50 and 60.08 m depth). The brachiopods are not numerous and are generally poorly preserved, being crushed and/or incomplete. A number of distinctive shell morphologies are present, however, which do allow some generic assignations. The lack of abundant and suitably preserved material does not allow full taxonomic description of this material. The internal structures that are available for study (of *Terebratulina* sp. and *Cheirothyris* sp.) are due to fortuitous preservation.

Representatives of the genera *Lingula*, *Discinisca*, *Terebratulina* and *Cheirothyris* are recorded for the first time from the northern high latitudes, providing new information on Early Cretaceous brachiopod palaeobiogeography. A single valve referred to the rhynchonellid genus *Ptilorhynchia*, an element of the distinctive northern Siberian brachiopod fauna described by Dagys (1968), has been identified.

Only a few brachiopods have been recovered from core 7425/9-U-1 and the chances of recovering and identifying large 'Siberian' terebratulids (e.g. *Siberiothyris* and *Taimyrothyris*) from a 54 mm diameter core would be remote.

The possibility of homoeomorphy between the Barents Sea articulate brachiopods and the genera to which they are assigned has to be considered.

Specimen numbers prefixed B. are present in the collections of the Department of Palaeontology, British Museum (Natural History), London.

Phylum Brachipoda Duméril, 1806
Class Inarticulata Huxley, 1869
Order Lingulida Waagen, 1885
Superfamily Lingulacea Menke, 1828
Family Lingulidae Menke, 1828
Genus *Lingula* Bruguière, 1797

Lingula cf. *ovalis* J. Sowerby
Fig. 11A

Material. – One complete and two fragmentary valves at 60.10 m. Dimensions (approximate) of complete specimen (Fig. 11A): length 4.2 mm, width 2.6 mm. Approximate dimensions of incomplete external mould: length 4.5 mm, width 3.1 mm.

Elongate-oval outline, rounded anterior margin. Prominent beak, gently rounded hingeline. Numerous growth lines.

Remarks. – The specimens are small in comparison to *Lingula ovalis* from the Upper Kimmeridge Clay Formation of Dorset, England, but have a similar elongate-oval outline and comparable beak position. We have not been able to compare the specimens from core 7425/9-U-1 directly with juvenile growth line patterns of *Lingula ovalis* J. Sowerby and *Lingula subovalis* Davidson. Such comparison may clarify the affinities of the Barents Sea material. These specimens may be juveniles. They are not preserved in life position.

Records of Early Cretaceous *Lingula* are rare. The genus is typically interpreted in the fossil record as an indicator of shallow-water marginal marine to intertidal environments (e.g. Ferguson 1986). Living species of *Lingula* are found mainly in tropical to subtropical seas. The presence of *Lingula antarctica* Buckman in the Eocene La Meseta Formation of Seymour Island, Antarctica, has been interpreted as indicating that shelf water temperatures were warmer in the southern high latitudes during the Eocene than they are today (Owen 1980; Lee 1986; Wiedman et al. 1988). The occurrence of *Lingula* in core 7425/9-U-1 may allow a similar inference, that water temperatures were warmer in the northern high latitudes during the Early Cretaceous than present-day. In this Barents Sea core, however, *Lingula* occurs in a sequence that contains a characteristic Boreal bivalve *Buchia* (which need not imply 'cold water'). The ecological tolerances of taxa (genera and species) may vary through geological time and this needs to be kept in mind when relating modern and fossil distributions to each other.

Order Acrotretida Kuhn, 1949
Superfamily Discinacea Gray, 1840
Family Discinidae Gray, 1840
Subfamily Disciniscinae Schuchert and Le Vene, 1929
Genus *Discinisca* Dall, 1871

Discinisca sp.
Fig. 11B

Material. – One crushed specimen at 60.08 m. Dimensions of the damaged specimen: length 2.4 mm, width 1.8 mm. The specimen has a cir-

cular outline. At least 12 growth lines can be distinguished. The specimen is attached to the posterior lateral margin of the pedicle valve of an indeterminate terebratulid(?).

Class Articulata Huxley, 1869
Order Rhynchonellida Kuhn, 1949
Superfamily Rhynchonellacea Gray, 1848
Family Rhynchonellidae Gray, 1848
Subfamily Cyclothyridinae Makridin, 1955
Genus *Ptilorhynchia* Crickmay, 1933

Ptilorhynchia sp.
Fig. 11C

Material. – Internal cast of an incomplete pedicle valve at 60.20 m. Dimensions of the specimen: length 7.9 mm, width 7.8 mm. The specimen is crushed and incomplete. It has a sub-triangular outline with a rounded anterior commissure. In lateral profile the specimen is very gently convex except in the umbonal area (posterior third of length), where the maximum convexity is developed. The internal cast is smooth, with the traces of a few growth lines visible. A shallow sulcus extends from the umbo to the anterior commissure, where the sulcus is approximately 2 mm in width. Two parallel straight muscle scars (c. 2 mm long) are present in the umbonal area. A hinge tooth appears to be present where the cast is damaged in the umbonal area, suggesting that it is a pedicle valve.

Remarks. – The shape of the outline and the smooth shell and sulcus suggested by the internal cast are characters displayed by *Ptilorhynchia* and some species of *Lacunosella*. The valve is most likely to be the pedicle valve of a *Ptilorhynchia*.

The outline of the sulcate valve is comparable to *P. glabra* Dagys recorded from the Valanginian of northern Siberia (Dagys 1968). Two other species from northern Siberia, *P. seducta* Dagys (Berriasian-Hauterivian) and *P. obscuricostata* Dagys (Lover Volgian), also have broadly sulcate pedicle valves but with costae developed towards the anterior commissure. Costae have not been seen on the specimen recovered from core 7425/9-U-1, but due to its probable juvenile status these would not be expected. It is not possible to provide a specific identification for the specimen apart from commenting on its similarity to the above species. The internal structures of the specimen are unknown.

Ptilorhynchia is currently recorded from Jur-

assic and Cretaceous northern high latitudes of the Boreal Realm (Dagys 1968; Owen 1972) and also from Cretaceous southern high latitudes (Thomson & Owen 1979). If Thomson & Owen's (1979) record of *Ptilorhynchia australis* from the Lower Aptian of Alexander Island, Antarctic Peninsula, is a true *Ptilorhynchia*, it suggests that either the genus had a bipolar distribution, or a cosmopolitan distribution (it should therefore be found in mid- and low palaeolatitudes), possibly migrating from northern to southern high latitude regions. The record of *Ptilorhynchia* from the Lower Cretaceous of Mexico (Sandy in press) suggests a cosmopolitan distribution and a North-South migration for the genus.

The internal structures of the type species *P. plumasensis* Crickmay 1933, originally described from the Jurassic of California, are not yet known in detail. Knowledge of these would be valuable in understanding the relationship between the occurrences of the genus in Siberia, British Columbia, Mexico and Antarctica.

Order Terebratulida Waagen, 1883
Suborder Terebratulidina Waagen, 1883
Superfamily Cancellothyridacea Cooper, 1973
Family Cancellothyrididae Thomson, 1926
Subfamily Cancellothyridinae Thomson, 1926
Genus *Terebratulina* d'Orbigny, 1847

Terebratulina sp.
Fig. 11D, E

Material. – *Terebratulina* sp. Interior of a brachial valve at 61.10 m. Dimensions: length 3.2 mm, width 3.1 mm.

Brachial valve interior (Fig. 11D, depth 61.10 m), the brachidium is not preserved. The socket is visible on the left-hand side. A euseptoidum approximately 1 mm in length is present. The interior of the valve is relatively smooth. The traces of a few of the costae can be seen along the length of the specimen but are most noticeable at the margin of the specimen where they are expressed as grooves on the valve interior.

Terebratulina? sp. Internal cast of brachial(?) valve at 60.10 m. Dimensions (approximate) of incomplete specimen: length 3.0 mm, width 3.5 mm. The specimen has a circular outline apart from the posterior hinge-line which is straight. An estimated 17 costae are present at the margin of the damaged specimen. It can be estimated that approximately 20 costae were originally present.

Terebratulina? sp. Valve exterior (Fig. 11E, depth 60.10 m). Dimensions: length 3.3 mm, width 3.0 mm. The specimen has a subcircular outline, tapering posteriorly to a sub-straight hinge-line. The umbo protrudes posteriorly beyond the hinge-line, suggesting a pedicle valve. Costae radiate from the neanic stage of the valve. Eighteen costae are present at the margin of the valve, some originating from the bifurcation of other costae. The intersection of growth lines and costae leads to the development of concentrically arranged isolated rugae.

Remarks. – The specimens from core 7425/9-U-1 may be juveniles or representatives of micromorphic brachiopod species. Contemporaneous genera sharing similar external and internal morphological characters include *Symphythyris* Smirnova and *Cruralina* Smirnova. The specimens lack the posterior elongation of *Symphythyris*. In the brachial valve interior (Fig. 11D) there is no sign of the ventrally concave hinge-plate-like structures on the inner side of the socket ridges seen in *Cruralina* (as illustrated by Nekvasilová 1978, plate IV), or of their former attachment. Two small scars are present where the brachidium has broken off.

The relatively coarse costae on the internal cast (*Terebratulina?* sp., depth 60.10 m) and the circular outline of its valve are atypical of *Terebratulina*, which tends to have relatively smooth valve interiors (e.g. Cooper 1973). In the absence of additional material and details of the brachidium the specimen is tentatively referred to *Terebratulina*.

Suborder Terebratellidina Muir-Wood, 1955
Superfamily Zeilleriacea Allan, 1940
Family Zeilleriidae Allan, 1940
Genus *Cheirothyris* Rollier, 1919

Cheirothyris sp.
Fig. 11F

Material. – Interior of a single brachial valve at 61.08 m. Dimensions of the incomplete valve: length 4.2 mm, width 4.3 mm. The valve has four characteristic prominent carinae which extend anteriorly. The anterior commissure appears to be rectimarginate. Marginal grooves are preserved along part of the anterior commissure. At least five regularly spaced growth lines are present. A median septum can be traced for two-thirds of the length of the valve, the brachidium is not preserved. Shell endopunctation is

well marked. The right-hand deltidial plate of the pedicle valve appears to be in place, sticking out and resembling a socket tooth.

Remarks. – The specimen of *Cheirothyris* from core 7425/9-U-1 may be an immature specimen or belong to a diminutive species. It is smaller than adult specimens figured by Gerasimov (1955) and Makridin (1964) or specimens of the type species *Cheirothyris fleuriausa* (d'Orbigny) in the British Museum (Natural History), London (specimens reach over 20 mm in length, e.g. B. 37312, B. 86223). The possible immature status of the specimen could account for the long median septum which would become relatively shorter as the valves grew longer and/or the septum became partially resorbed.

Cheirothyris has previously been recorded from the Jurassic of the Russian Platform. The Pechora Basin may have acted as a migration route for *Cheirothyris* between the Russian and Svalbard Platforms, suggesting a South-North pattern of colonization.

The brachiopod genera *Cheirothyris* (Late Jurassic-Early Cretaceous), *Cheirothyropsis* (Jurassic) and *Tetractinella* (Triassic) provide a classic example of homoeomorphy (e.g. Rudwick 1970, p. 110). Another homoeomorphic brachiopod to add to this list is represented by a single specimen from the Upper Cretaceous Flysch Zone of Austria (F. A. Middlemiss Collection). The specimen is from Dambachgraben, Austria, probably Campanian in age and appears to be a homoeomorph of *Cheirothyris* (Middlemiss pers. comm.; pers. observ.).

Stratigraphic range. – Gerasimov (1955) and Makridin (1964) record species of *Cheirothyris* from the Jurassic of the U.S.S.R. This is the first record of the genus from the Cretaceous.

Cirripedes (J.S.H.C.)

Hitherto, only two species of cirripedes, *Archaeolepas decora* Harbort (1905) and *Zeugmatolepas? hausmanni* (Koch & Dunker 1837) have been described from the Lower Cretaceous. The new species described here is the first to be described from the Berriasian and may be compared with *Z.? hausmanni*.

Capitular and lateral valves occur spasmodically through 59.38–59.03 m of core 7425/9-U-1. The valves are very fragile, frequently shattering as the core-thickness was reduced. The moulds,
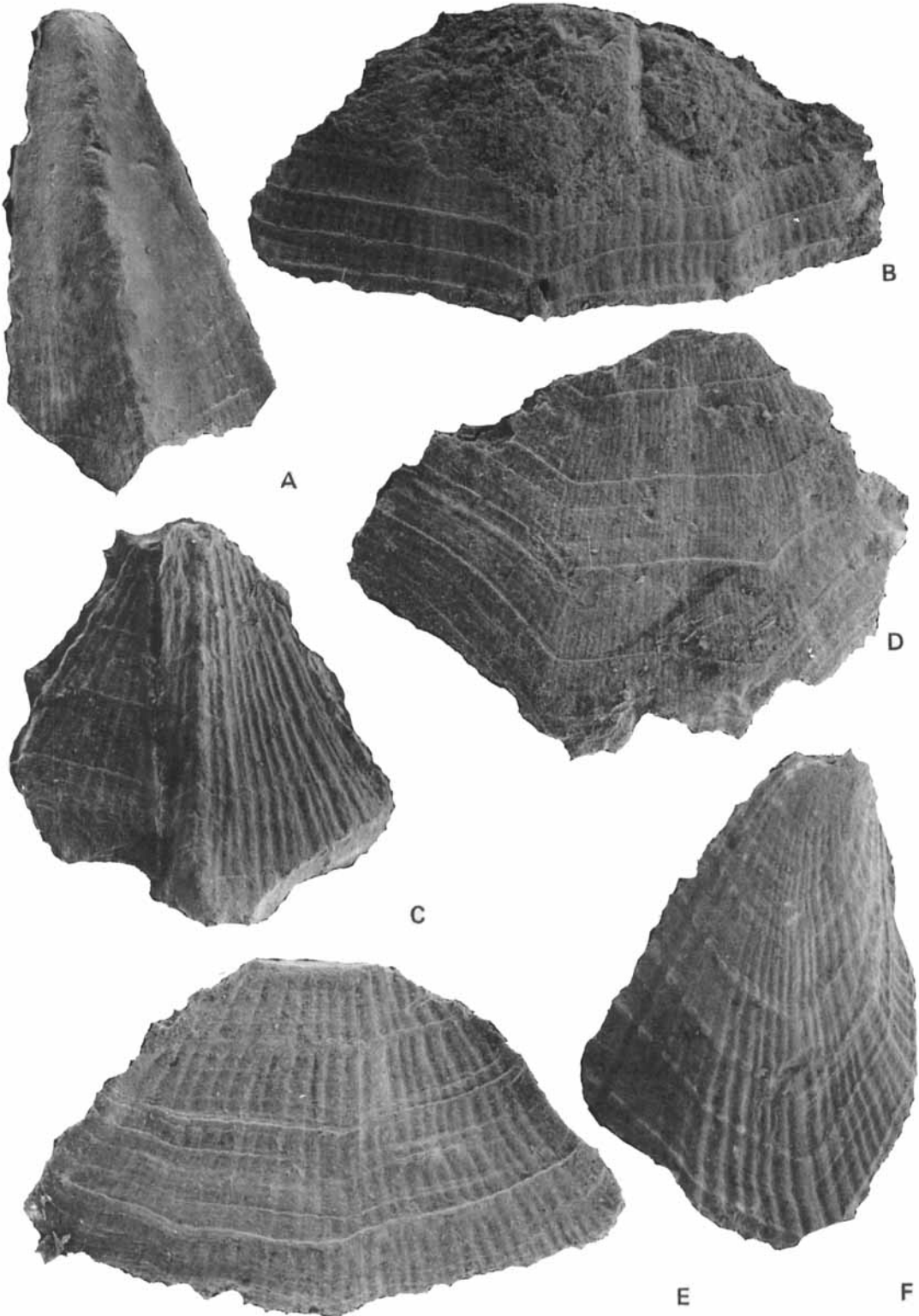
however, are sufficiently well preserved to allow adequate description of inner surface details where not otherwise available. Predominant valves are terga, followed by scuta, rostra and then single examples of a carina and several different lateral valves. This proportion of valves would seem to compare favourably with the presence of valves of various Gault species in a similar bulk sample. Unfortunately, the carina, an apical fragment, is not sufficiently well preserved to be selected as type.

Series Cirripedia Burmeister, 1834
Order Thoracica Darwin, 1851
Suborder Lepadomorpha Pilsbry, 1907
Family Scalpellidae Pilsbry, 1916
Genus *Zeugmatolepas* Withers, 1913

Type species. – Zeugmatolepas mockleri Withers 1913 by original designation.
Range. – Late Jurassic – Late Cretaceous.

Zeugmatolepas? borealis sp. nov.
Fig. 9A–F, Fig. 10A–F

Derivation of name. A northern species.

Diagnosis. – A *Zeugmatolepas* with the umbo of the scutum apical and the basal tergal angle moderately rounded. Tergum with the upper and lower carinal margin rounded or forming an obtuse angle, the apico-basal ridge is developed basally.

Material. – All specimens from borehole 7425/9-U-1. Holotype, a right scutum (Fig. 9F) from 59.38 m. Paratypes, 3 terga, carina, rostrum, 7 latera or lower latera, ?peduncle plate from 59.8 m, 3 terga, rostrum from 59.03 m, 3 scuta from 59.28 m, 7 terga, 2 scuta from 59.35 m, 2 terga, 1 lateral valve from 59.37 m.

Scutum (Fig. 9F) is subtrapezoidal in outline, moderately convex transversely and slightly curved towards the tergum. The width is about two thirds of the length. The umbo is apical and the curved apico-basal ridge, which is only a little wider than the ornamental ridges, is not produced

at the tergo-basal angle. The occludent margin is slightly arched in the lower part and forms almost a right angle with the weakly sinuous lower margin. The tergal margin is weakly convex to almost straight and the tergo-lateral angle is bluntly rounded. The lateral margin is straight, as long as the tergal margin, and forms a right angle with the basal margin. The ridges of the surface ornament are coarser on the occludent side of the apico-basal ridge and themselves become coarser towards the occludent margin. Some ridges bifurcate, others are intercalated at an early growth-stage. Intermediate stages of growth are marked by very faint lines, whereas temporary terminal stages are marked by rather broad shingle-like ridges knotting the apicobasal ones.

On the inner surface a moderately deep adductor muscle pit is overlain by another pit – some internal moulds show only a very shallow division between these two pits. Several growth ridges line the tergal edge; the occludent edge is sharp to within a short distance of the apex.

Tergum (Fig. 10B, C) is sub-rhomboidal in outline, thin, rather bowed towards the carinal side and about one third as long as wide. The apicobasal ridge, situated about two thirds from the carinal margin, is obscure, but broadly developed basally and there is a shallow depression on the carinal side of it. The occludent margin is weakly concave, shorter than the scutal margin, raised and bounded by a depression; the scutal angle is broadly rounded. The scutal margin is sinuous in its upper half and in its lower half almost straight to the broadly rounded basal angle. The convex upper part of the carinal margin is rather longer than the concave lower part and the carinal angle is generally broadly rounded, though may be sharp. The longitudinal ridges are much flatter and broader than those on the scutum; a somewhat stronger ridge extends from the apex to about midway along the scutal margin. The knotted arrangement of the growth-lines appears only on the carinal side and its full development is retarded to a late growth-stage.

Fig. 9.
Zeugmatolepas? borealis Collins sp. nov. Barents Sea Borehole 7425/9-U-1 at depth 59.38–59.03 m.
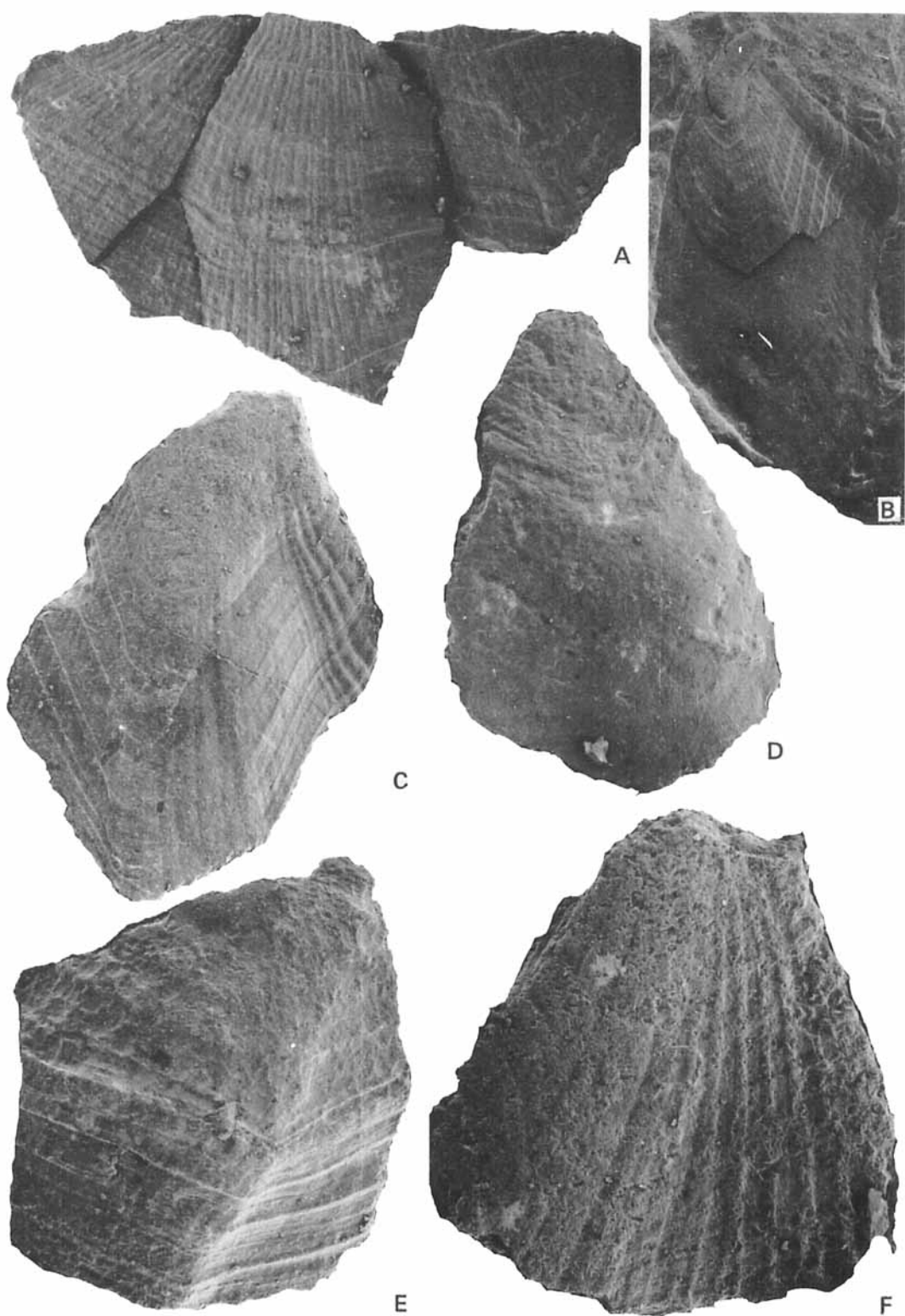A: Paratype, PMO 116.470 (Stub SK18); apical portion of carina, ×36.
B: Paratype, PMO 116.478 (Stub SK20); lower latus L3, ×33.
C: Paratype, PMO 116.471 (Stub SK18); rostrum, ×24.
D: Paratype, PMO 116.472 (Stub SK18); lower latus L4, ×36.
E: Paratype, PMO 116.473 (Stub SK18); lower latus L3, ×43.
F: Holotype, PMO 116.475 (Stub SK19); scutum, ×20.

On the inner surface a broad area of the upper carinal and occludent edges is marked with growth-lines; no ridges pending from the apex on the occludent side have been observed.

Carina (Fig. 9A). A fragmentary apical portion seen only from the photograph; narrow, flat to concave on either side of a broadly rounded median ridge. The basal angle is acute and the apex rounded. Weak growth lines are knotted at the intersection with rather stronger apicobasal ridges.

Rostrum (Fig. 9C) is equilaterally triangular, almost as wide as high and strongly convex transversely with a strong apicobasal ridge; the apex is rounded. The lateral margins are weakly convex apically and concave basally; the basal margin is nearly straight with sharp basilateral angles. The surface ornament of coarse ridges is similar to that of the scutum; the growth lines are vague.

Latus 1 (Fig. 10D) is almost isoceles-triangular in outline with the basal margin rounded; a small portion of the apical area shows the growth lines in chevron.

Latus 2 (Fig. 10F) is almost equilaterally triangular in outline with the apex rounded; the basal margin forms almost a right angle to one side and is moderately rounded on the other towards which the apicobasal ridges are directed; the ridges are almost absent (?eroded) on the inflected side and rather broad, sometimes bifurcate on the other. The valve figured by Withers (1935, pl. 3, fig. 5s, after Koch & Dunker 1837) is very similar, but from the opposite side of the capitulum.

Latus 3 (Fig. 9B, E) ?left and right valves, in outline subtriangular with the apex rounded and more or less medial, the height is about two thirds of the width. Of the two weak apicobasal 'ridges' one is rather nearer one side, reducing the length of that part of the basal margin, the growth lines are deflected upwards on the opposite side. Ridges similar to those on the scutum form the surface ornament.

Latus 4 (Fig. 9D) is rather damaged along the lateral margins; about twice as wide as high with

the apex a little to one side of the midline causing a slight difference in length of the lateral margins. The longer margin is convex towards the base and the basal margin is divided by apicobasal 'ridges' into three parts each with a concave margin, the part on the side of the longer lateral margin equals the length of the median part. The surface ornament is more prominent on the median and 'short' side of the valve.

Latus 5 (Fig. 10E) is subtriangular in outline with the surface strongly deflected to one side of an apicobasal ridge; on the deflected side the lateral margin is convex and the basal margin slightly upturned. A fragment of another form (Fig. 10A) partially overlaps the basal part of a right scutum.

A possible peduncle plate has the outer surface sharply inclined with the base in which is a distinct pit; vertical ridges on the outer surface are continued partway onto the base.

Discussion. – In ornament and broad outline the scuta and terga of *Z.? borealis* are not unlike those of the Jurassic *Z. concinna* (Morris 1845) from the Oxford Clay of central England. Of known Cretaceous species *Z.? borealis* is closest to *Z.? hausmanni*, which has been recorded from the Lower Cretaceous Hilston of Germany (Harbort 1905) and Speeton Clay of England. The scutum of *Z.? hausmanni* which also retains the apical position of the umbo is much smoother than that of *Z.? borealis* and on the inner surface has a ridge limiting the pit above the adductor muscle pit. The underside of the tergum of *Z.? hausmanni* has 3–4 short apical ridges on the occludent side which appear not to be developed in *Z.? borealis*. The rostrum of *Z.? borealis* is essentially similar to that considered by Withers (1935, p. 82) to belong to *Z.? hausmanni*, but differs in having a rather more triangular base and stronger median ridge.

But for two exceptions the lateral valves here assigned to *Z.? borealis* show the greatest deviation to any figured by Withers (1928, 1935) in *Zeugmatolepas;* 'latus 1', herein, approaches a

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Fig. 10.

Zeugmatolepas? borealis Collins sp. nov. Barents Sea Borehole 7425/9-U-1 at depth 59.38–59.03 m.

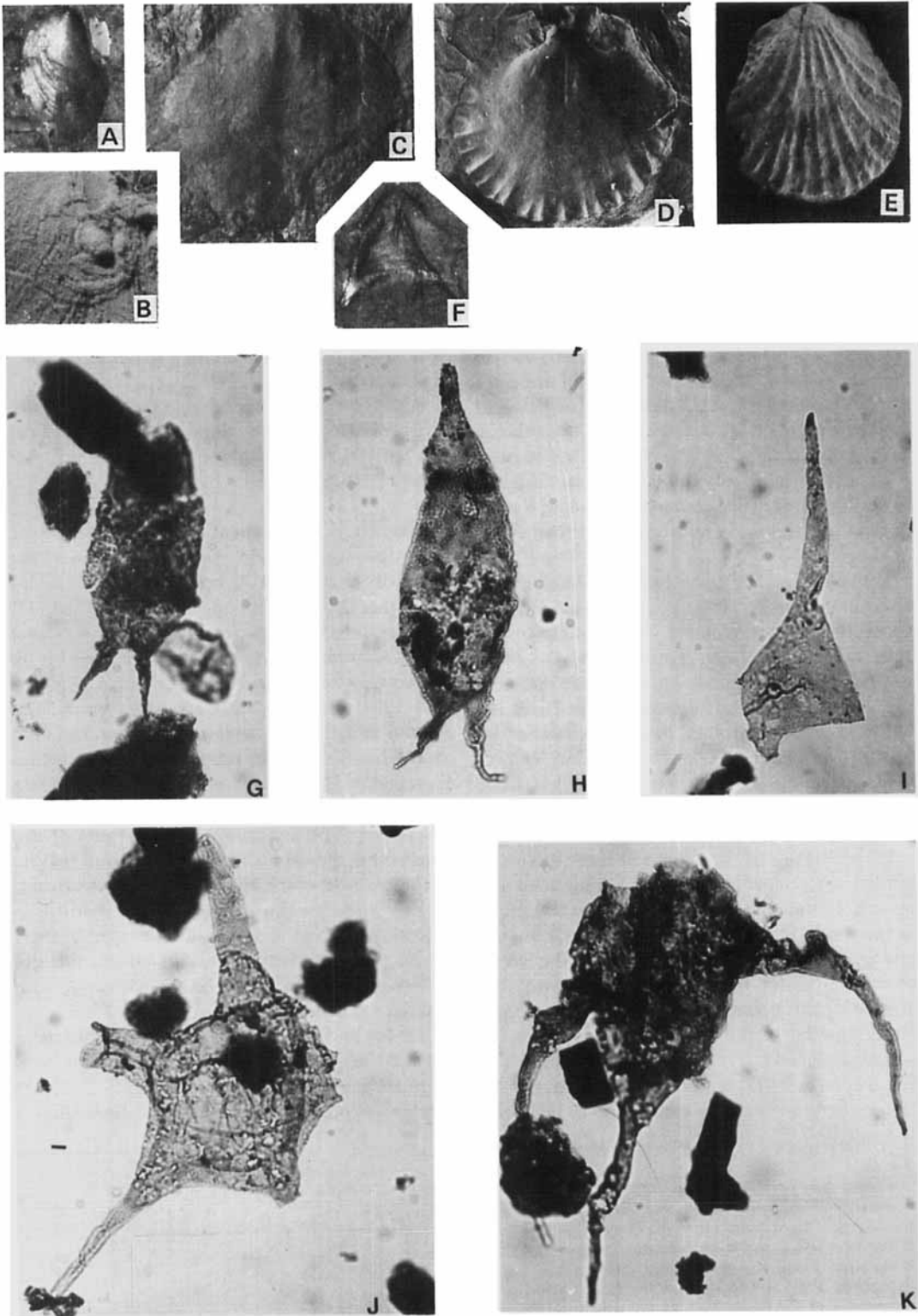A: Paratype. PMO 116.479 (Stub SK20); latus overlapping right scutum, ×24.

B: Paratype. PMO 116.469 (Stub SK17); left tergum, ×30.

C: Paratype. PMO 116.480 (Stub SK20); left tergum, ×22.

D: Paratype. PMO 116.476 (Stub SK19); latus 1, ×20.

E: Paratype. PMO 116.474 (Stub SK18); latus 5, ×30.

F: Paratype. PMO 116.477 (Stub SK19); latus 2, ×33.

typical upper latus, while 'latus 2' approaches that figured by Koch & Dunker as remarked above. The others are peculiar in having a tripartite basal margin.

Dinoflagellate cysts (N.Å.)

Muderongia Cookson & Eisenack emend. Stover & Evitt 1978

Type species. – Muderongia macwhaei Cookson & Eisenack emend. Stover & Evitt 1978

Muderongia aequicornus sp. nov.
Fig. 11J, Fig. 12B, G, H (holotype)

Derivation of name. – With reference to the equal lengths of the right and left lateral horn and also to the two equal antapical horns.

Material. – Borehole 7320/3-U-1 at 27.44–0 m. A few specimens recorded per slide from seven samples, but more commonly in one sample from the top of the core.

Description. – Proximate cyst, cornucavate. Endophragm rounded, more or less protruding into the five horns. The apical and two straight antapical diverging horns are about 50 µm long and gently tapering throughout their length. Stout, blunt lateral horns, in the order of 15 µm long with paracingular notches. Operculum usually detached. Paraplates not discernible.

Remarks. – In spite of the often difficult distinction of species within this genus, the morphology of this species shows little variation in core 7320/3-U-1.

Muderongia testudinaria Burger 1980 and *Muderongia asymmetrica* Brideaux 1977 are the most similar species, but both have relatively long postcingular extensions of their cingular horns. The antapical horns of *M. asymmetrica* are of unequal length.

Stratigraphic range. – Known only from the Lower Barremian.

Muderongia australis Helby 1987
Fig. 12C

1958 *Muderongia macwhaei* Cookson & Eisenack, p. 41, pl. 6, figs. 1, 4 (partim).
1975 *Muderongia* sp. cf. *M. macwhaei* Cookson & Eisenack; Wall & Evitt, pl. 3, figs. 1, 2, 4, 5, text-fig. 9.
1980 *Muderongia* sp. cf. *M. macwhaei* Cookson & Eisenack; Wiseman, pl. 1, fig. 2.
1980 *Muderongia simplex* Alberti; Morgan, pl. 19, figs. 8, 9, 10 (partim).
1984 *Muderongia macwhaei* Cookson & Eisenack; Jain & Khowaja-Ateequzzaman, pp. 37–38, pl. 1, figs. 1, 3; pl. 2, figs. 1, 2, 4, 5; pl. 3, figs. 3–9.
1987 *Muderongia australis* Helby, pp. 300–303, figs. 2, 3, 5.

Holotype. – Geological Survey of Western Australia, Perth. Investigator-1, 1,419 m. Slide F 11824, co-ordinates L07.1+07.2. Fig. 2A–C.

Material. – Common at 29.95 m in borehole 7320/3-U-1. 7430/10-U-1. Present in the uppermost part of the Rurikfjellet Member, Janusfjellet, Spitsbergen, where it is common 10 m below the top of the member, but also present somewhat lower in the section in the Hauterivian *S. versicolor* ammonite Zone.

Remarks. – This species belongs to a plexus including *M. macwhaei* Cookson & Eisenack 1958, *M. staurota* Sarjeant 1966 and *M. australis* Helby 1987. Helby (1987) distinguished a form included in *M. macwhaei* by Cookson & Eisenack and named it *M. australis*. Jain & Khowaja-Ateequzzaman (1984) illustrated the variation in the plexus, but their forms are more similar to *M. australis* and *M. staurota* than to the holotype of

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Fig. 11.
A–F: Brachiopods from core 7425/9-U-1, Barents Sea.
Undifferentiated Boreal Berriasian-Valanginian. Depth and magnification as indicated.
A: *Lingula* cf. *ovalis* J. Sowerby. PMO 116550, 60.10 m, ×5.
B: *Discinisca* sp. PMO 116551, 60.08 m, ×10.
C: *Ptilorhynchia* sp. PMO 116552, 60.20 m, ×5.
D: *Terebratulina* sp. PMO 116553, 61.10 m, ×10. Interior of brachial valve.
E: *Terebratulina?* sp. PMO 116554, 60.10 m, ×10.
F: *Cheirothyris* sp. PMO 116555, 61.08 m, ×5. Interior of brachial valve.
G–K: Dinoflagellate cysts from cores 7320/3-U-1 and 7425/9-U-1, Barents Sea. Lower Barremian. ×500. Depth as indicated.
G: *Batioladinium shaftesburiensis* sensu Nøhr-Hansen, PMO 116556. 7320/3-U-1, 28.94 m. Slide Ox₁, England finder W22/1.
H: *B. shaftesburiensis* sensu Nøhr-Hansen. PMO 116557. 7320/3-U-1, 20.94 m. Slide Ox₃, England finder C40.
I: *Pseudoceratium nudum* Gocht 1957. PMO 116558. 7425/9-U-1, 49.72 m. Slide Ox₁, England finder F21/4.
J: *Muderongia aequicornus* sp. nov. PMO 116559. 7320/3-U-1, 4.45 m. Slide Ox₂, England finder Y27.
K: *Muderongia tetracantha* (Gocht) Alberti 1961. PMO 116560. 7320/3-U-1, 23.45 m. Slide Ox₁, England finder M25/4.
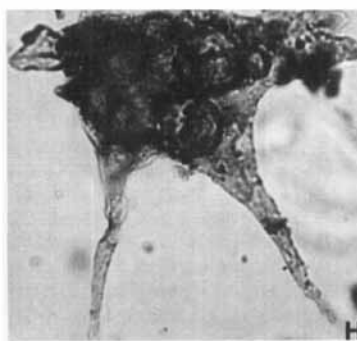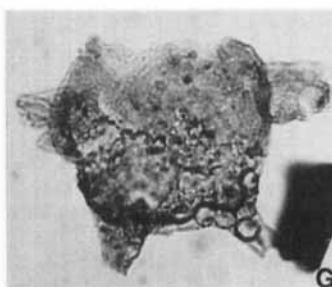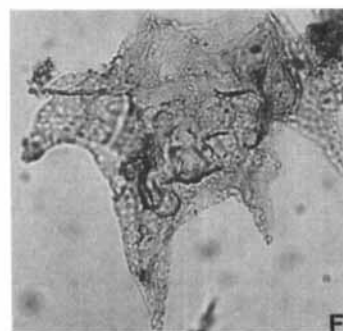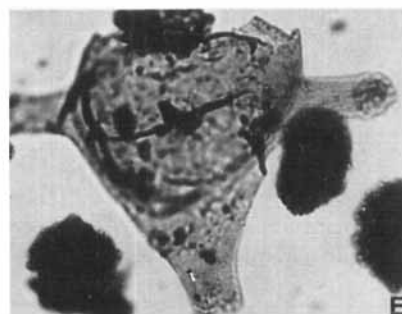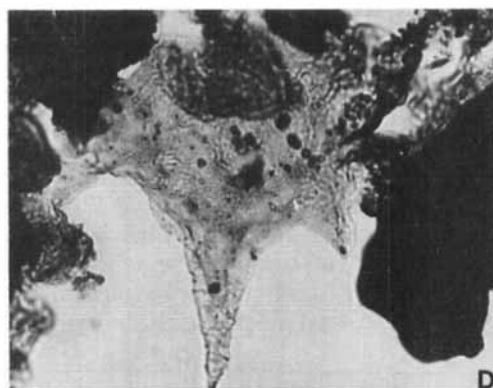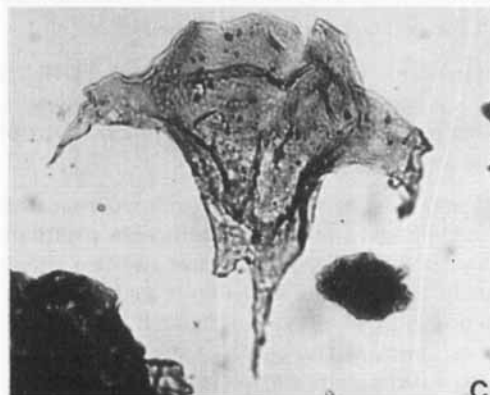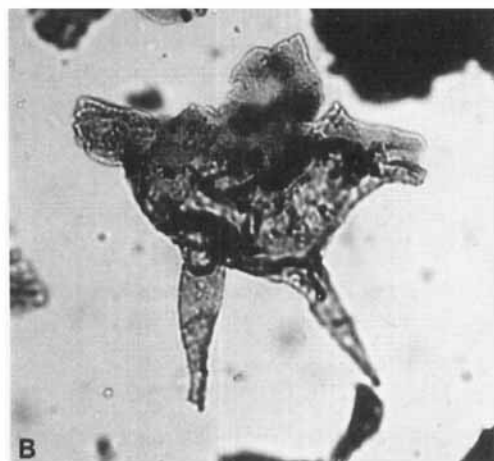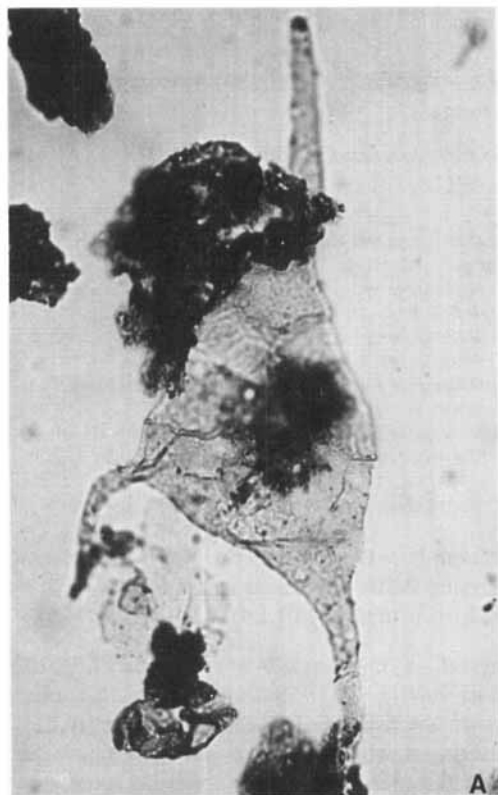
M. macwhaei. Their Pl. 2, fig. 9 resembles *M. tetracantha.* No specimens with the extreme lateral horns of the holotype of *M. macwhaei* have been observed in our material.

Stratigraphic range. – This species occurs in the Hauterivian and Barremian of Australia and in beds close to the Hauterivian/Barremian boundary in the Barents Sea, Spitsbergen and East Greenland. An acme of this species observed both in the Barents Sea and Spitsbergen and also in East Greenland by Nøhr-Hansen (pers. comm. 1989) may be of stratigraphic importance. This acme is not observed in 7430/10-U-1, where the species occurs consistently in low numbers from 25.10 to 11.94 m (top of the core). In 7425/9-U-1 *M. australis* has not been found.

Muderongia perforata Alberti 1961
Fig. 12E

1961 *Muderongia perforata* Alberti, p. 13, pl. 2, figs. 8, 9.
1974 *Muderongia* cf. *staurota* Sarjeant; Davey & Verdier, p. 644, pl. 91, figs. 4, 8.
1976 *Muderongia simplex* Alberti; Brideaux, pl. 44.2, fig. 1.
1979 *Muderongia simplex* Alberti; Ashraf, p. 136, pl. 6, fig. 10.
1981 *Muderongia perforata* Alberti; Below, pp. 16–17, pl. 2, fig. 7, text-fig. 11.
1983 *Muderongia pariata* Duxbury, pp. 36–37, pl. 2, figs. 5, 8, text-fig. 16.
1987 *Muderongia pariata* Duxbury; Heilmann-Clausen, pl. 1, fig. 6.

Holotype. – Geologischen Institut der Universität Tübingen. Borehole Pirna, Sachsen. Slide A9, Pl. 2, fig. 8.

Material. – Borehole 7425/9-U-1 at 53.94 m.

Remarks. – Alberti described this species as having two antapical horns, one of which can be strongly reduced. His figures, however, do not show more than one antapical horn except the specimen in Pl. 2, fig. 7, which he only with doubt assigned to this species. The lack of two antapical horns led Duxbury to describe his specimens as a new species.

Stratigraphic range. – The species is too rare to be useful for dating in the Lower Cretaceous of the Barents Sea, but does at least occur in the Barremian. In Morocco and England it is also known from the Aptian and Albian and the species seems to be more common in these areas.

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Fig. 12.
Dinoflagellate cysts from Lower Barremian sections in cores 7320/3-U-1 and 7425/9-U-1, Barents Sea. ×500. Depth as indicated.
A: *Pseudoceratium nudum* Gocht 1957. PMO 116561. 7425/9-U-1, 51.94 m. Slide Ox$_2$, England finder M18/1.
B: *Muderongia aequicornus* sp. nov. PMO 116562. 7320/3-U-1, 2.47 m. Slide Ox$_3$, England finder V21.
C: *Muderongia australis* Helby 1987. PMO 116563, 7320/3-U-1, 29.95 m. Slide Ox$_2$, England finder N16.
D: *Muderongia* cf. *asymmetrica* Brideaux 1977. PMO 116561. 7425/9-U-1, 51.94 m. Slide Ox$_2$, England finder G34/4.
E: *Muderongia perforata* Alberti 1961. PMO 116564. 7425/9-U-1, 53.94 m. Slide Ox$_2$, England finder Z22/3.
F: *Muderongia* cf. *asymmetrica* Brideaux 1977. PMO 116561. 7425/9-U-1, 51.94 m. Slide Ox$_2$, England finder K24/3.
G: *Muderongia aequicornus* sp. nov. PMO 116565. 7320/3-U-1, 10.47 m. Slide Ox$_1$, England finder 023/2.
H: *M. aequicornus* sp. nov. Holotype. PMO 116566. 7320/3-U-1, 0 m. Slide Ox$_2$, England finder 024/2.

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