The Klippfisk Formation — a new lithostratigraphic unit of Lower Cretaceous platform carbonates on the Western Barents Shelf

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A new Lower Cretaceous lithostratigraphic unit of the Western Barents Shelf, named the Klippfisk Formation, is formally introduced. The formation represents a condensed carbonate succession deposited on platform areas and structural highs, where it consists of limestones and marls, often glauconitic. The limestones may have a nodular appearance, and fossil debris, which are dominated by *Inoceramus* prisms, may be abundant. The Klippfisk Formation is composed of two members: the Kutling Member defined herein from cores drilled on the Bjarmeland Platform, and the coeval Tordenskjoldberget Member described on Kong Karls Land. The base of the formation is defined by the abrupt decrease in gamma-ray intensity, where the dark shales of the underlying Hekkingen or Agardhfjellet formations are replaced by marls. It is often unconformable. The Klippfisk Formation is of Berriasian to Early Barremian age and appears to be time-transgressive over parts of the Western Barents Shelf (including Kong Karls Land). It passes laterally into the basinal Knurr Formation. On Kongsøya (Kong Karls Land) a thin shale unit, bounded by unconformities, earlier included in the Tordenskjoldberget Member, represents the northernmost extension of the overlying Kolje Formation in the Barents Shelf.

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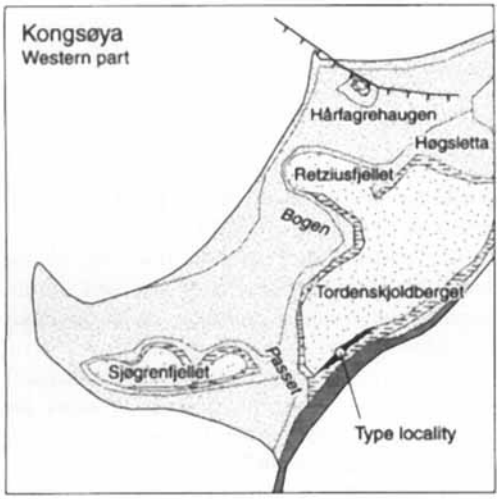
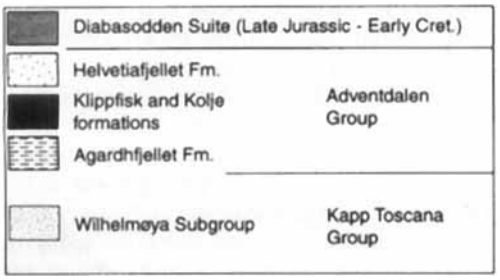
Introduction

Exploration activity during the past twenty years has provided extensive information on the Mesozoic succession on the Western Barents Shelf, and stratigraphic information based on data from exploration wells, boreholes and seismics are reported in a number of published papers, including several in the volumes edited by Collinson (1989), Vorren et al. (1993) and Hanslien (1995). A formal lithostratigraphic scheme for the Mesozoic succession offshore northern Norway has been proposed by Worsley et al. (1988), replacing the informal units used in Berglund et al. (1986) and Sund et al. (1986). Worsley et al. (1988) assigned the Lower Cretaceous to the Nordvestbanken Group, and subdivided the group into three new formations: the Knurr Formation of Berriasian/Valanginian-Early Barremian age, the Kolje Formation of Barremian-Early Aptian age, and the Kolmule Formation of Aptian-Cenomanian age. Lithostratigraphic units for the Lower Cretaceous on Spitsbergen and on Kong Karls Land have been introduced by Parker (1967) and Smith et al. (1976), respectively. During revision of the formal lithostratigraphy of both Svalbard and the Barents Shelf by the Committee on Stratigraphy of Svalbard, Subcommittee on Mesozoic Stratigraphy (Mørk et al. in press), the Nordvestbanken Group is found superfluous and its units are included in the Adventdalen Group as defined on Svalbard by Parker (1967).

Shallow drillings (Rise & Sættem 1994) performed by IKU at several locations on the Western Barents Shelf in the period 1985–1990 (Fig. 1) revealed a condensed unit of Lower Cretaceous marls and limestones. The unit cannot be directly assigned to any of the three previously formally erected Lower Cretaceous formations, although it is broadly time-equivalent and shows relations to the Knurr Formation of Worsley et al. (1988). Biostratigraphy and age-correlations of the unit herein formally introduced as the Klippfisk Formation have been published by Århus et al. (1990) and Århus (1991). However,





recent investigations on nannofossils and dinoflagellates have given new age constrains to some of the cored units discussed by Århus (1991). This new information is presented in the Appendix of this paper. As discussed by Århus (1991), the condensed Lower Cretaceous marl/limestone unit recognised on the shelf can be correlated with the Tordenskjoldberget Member defined on Kongsøya, Kong Karls Land, by Smith et al. (1976). Herein we propose to include the Tordenskjoldberget Member as formal member of the new Klippfisk Formation. A shale unit occurring in only one of the sections of Smith et al. (1976, fig. 13) represents the only remains of a major shale unit which has been variably eroded before the deposition of the overlying Helvetiafjellet Formation (Olaussen et al. pers. commun). This unit was originally included in the Tordenskjoldberget Member by Smith et al. (1976), but it is lithologically similar to the Kolje Formation of the Barents Shelf (Worsley et al. 1988). Biostratigraphy (see below) dates this unit as Barremian, and the unit is under- and overlain with pronounced sequence boundaries which can be followed across the Barents Shelf. Consequently, this shale unit is herein regarded as a part of the Kolje Formation. The lithostratigraphic nomenclature used in this paper follows the 'Rules and recommendations for naming geological units in Norway' (Nystuen 1986). The formal outline generally follows the one used by Worsley et al. (1988), with minor modifications similar to those presented in Isaksen & Tonstad (1989).

Klippfisk Formation (new) (Klippfiskformasjonen)

Name: Named using the Norwegian word for split, salted and dried fish (mainly cod); the name was selected to follow the established Norwegian procedure with naming Cretaceous units in the Barents Sea after fishes whose name begins with a

Fig. 1. Location map of coreholes 7430/10-U-01 (type section of the Klippfisk Formation and Kutling Member), 7231/01-U-01 (reference section of the Klippfisk Formation), 7425/09-U-01 and 7320/03-U-01 on the Western Barents Shelf, and the type locality of the Tordenskjoldberget Member on Kongsøya, Kong Karls Land (Map modified from Mørk et al. in press).

capital K. However, the ordinary list of fish names is exhausted.

Type section: Core 7430/10-U-01, from 34.0 m to 42.9 m (8.9 m fully cored), Bjarmeland Platform, at 74°12′47.79″N, 30°14′44.22″E, Figs. 2 and 3.

Reference section: Core 7231/01-U-01, from 59.9 m to 64.4 m (4.5 m fully cored), coordinates 72°45′12.45″N, 31°07′30.21″E, Figs. 2 and 4.

Thickness: In the type borehole the Klippfisk Formation is 8.9 m thick, and in the reference borehole 4.5 m thick. In borehole 7425/09-U-01 south of the Gardarbanken High the formation is about 5.5 m, and in borehole 7320/03-U-01 in the northern Bjørnøya Basin area the thickness of the formation is 3.3 m (Århus et al. 1990).

Lithology: The formation consists of limestones and marls and is often glauconitic and pyritic. The limestones may have a nodular appearance (Fig. 3) and dominating texture is alternating wackestone and packstone. The lithology varies from biomicrites to sparites dominated by *Inoceramus* prisms. The *Inoceramus* shells and disintegrated prisms are by far the most abundant fossil constituents (Fig. 5a and b), but fragments of other bivalve genera (mainly thin-shelled, Fig 5c), bryozoans, echinoderms, foraminifera and ?calcispheres are also present (Fig. 5d). The lower part of the formation is clay rich and strongly bioturbated. The content of clay minerals decreases upwards and above 39 m a clean limestone occurs. The colour is usually greenish to white or light grey, but locally dark brown to reddish. Some dolomite is present in the lower part of the reference core.

The intense bioturbation which obliterate most sedimentary structures contrasts with the very sparse bioturbation restricted to thin intervals in the underlying Hekkingen Formation. The overlying Kolje Formation is unbioturbated in the type core, but well bioturbated in core 7231/01-U-01. Most trace fossils are hard to identify due to the intense degree of bioturbation. However, in the nodular development in the upper part of the formation *Thalassinoides* is present.

Basal boundary: The base of the formation is defined where dark shales of the underlying formation are replaced by marls. This boundary is often an unconformity and can be seen on petrophysical logs as an abrupt decrease in gamma-ray readings and an increase in velocity upwards from the underlying dark shales.

Upper boundary: The upper boundary of the Klippfisk Formation is usually defined by the transition from carbonates to dark claystones of the overlying Kolje Formation (Barremian) or younger strata. This boundary is reflected on petrophysical logs as an upward increase in gamma-ray readings and a reduction in velocity. In borehole 7425/09-U-01 the upper boundary is recognised by a 3 cm thick lag deposit of coarse sand containing some glauconite (fig. 4 in Århus et al. 1990). On Kong Karls Land the Tordenskjoldberget Member is directly overlain by the claystone of the Kolje Formation.

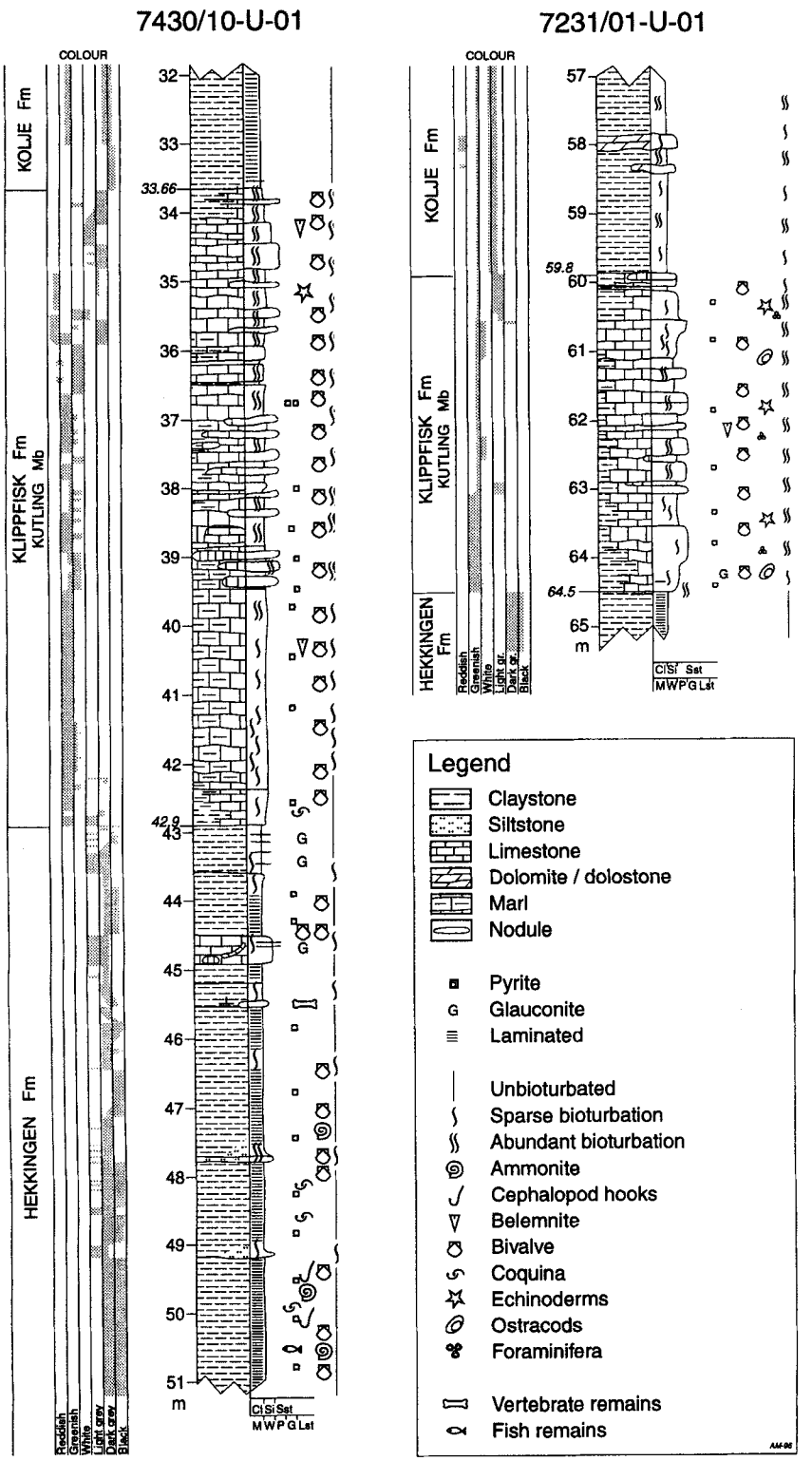
Distribution: The formation is found on platform areas and on structural highs on the western Barents Shelf and Kong Karls Land (Kongsøya). It is recognised in boreholes on the Bjarmeland Platform, Gardarbanken High, northern part of the Bjørnøya Basin and northeastern part of the Nordkapp Basin areas. It is further documented by shallow drilling and sampling in Hopendjupet and in the Olga Basin (Norwegian Petroleum Directorate, IKU Petroleum Research and Norwegian Polar Institute unpubl. data). Lithological units assignable to the Klippfisk Formation are also cored in the Troms III and Nordland VII areas.

Subdivision: The formations consists of two members: The Kutling Member recognised on the western Barents Shelf, and the Tordenskjoldberget Member found on Kong Karls Land (Kongsøya).

Age: The Klippfisk Formation ranges from Berriasian to Early Barremian in age. The formation comprises condensed carbonate deposits and contains several major and minor stratigraphic gaps. The formation is time-transgressive over parts of the Western Barents Shelf, and includes sediments of Boreal Berriasian to Early Barremian age on the Bjarmeland Platform and Valanginian to Lower Barremian strata at sites adjacent to the Bjørnøya Basin and in the northern Nordkapp Basin. An Early Valanginian-Hauterivian age is reported for the Tordenskjoldberget Member on Kong Karls Land.

Depositional environment: The formation probably represents transgressive, shallow marine deposits, which covered platform areas and local structural highs of the Barents Shelf.

Remarks: The Klippfisk Formation is time-equivalent with the Knurr Formation as defined on Tromsøyflaket by Worsley et al. (1988). In contrast to the condensed carbonate succession of the Klippfisk Formation, the Knurr Formation


7430/10-U-01
7231/01-U-01
COLOUR
KOLJE Fm
KLIPPFISK Fm
KUTLING Mb
HEKKINGEN Fm
Reddish
Greenish
White
Light grey
Dark grey
Black
m
Cl Si Set
M W P G Lst
33.66
42.9
59.8
64.5
Legend
Claystone
Siltstone
Limestone
Dolomite / dolostone
Marl
Nodule
Pyrite
Glauconite
Laminated
Unbioturbated
Sparse bioturbation
Abundant bioturbation
Ammonite
Cephalopod hooks
Belemnite
Bivalve
Coquina
Echinoderms
Ostracods
Foraminifera
Vertebrate remains
Fish remains

consists of dark grey to greyish brown claystone with thin limestone and dolomite interbeds. Thin sandstones are also seen in the lower part of the Knurr Formation. In the type well 7119/12-1 the Knurr Formation is 56 m thick, and the formation reach 285 m in the reference well 7120/12-1. The Knurr Formation was deposited in open and generally distal marine environments, while the Klippfisk Formation represents transgressive, shallow marine sediments that were deposited on platform areas and local structural highs on the Barents Shelf.

Kutling Member (new) (Kutlingleddet)

Name: The unit is named after the Norwegian name of a small saltwater fish of the suborder *Gobioidea*.

Remarks: The Kutling Member has the same type and reference sections as the superior Klippfisk Formation and represents the entire Klippfisk Formation where the formation has been cored on the Bjarmeland Platform, northern part of the Bjørnøya Basin and northeastern part of the Nordkapp Basin.

Tordenskjoldberget Member (revised) (Tordenskjoldbergleddet)

Name: Named after Tordenskjoldberget, a mountain on southeastern Kongsøya, Kong Karls Land.

Type section: The type section was described by Smith et al. (1976) on the south face of Tordenskjoldberget on south-eastern Kongsøya (i.e. their section D.833, fig. 13).

Reference sections: Sections S.1414-west and S.1414-east on Tordenskjoldberget, Kongsøya (Smith et al. 1976, fig. 14).

Thickness: The (revised) thickness of the member at the type sections D.833 is 15 m, while the thickness is 20 m at the S.1414-east section and only 1 m at the S1414-west section (sections measured by Smith et al. 1976).

Lithology (revised): At the type section the member consists of calcareous, white and light yellow, loosely cemented, coarse to medium sandstones. According to Smith et al., the calcareous sandstone consists almost entirely of prismatic bivalve shell fragments (*Inoceramus* fragments). The unit characteristically contains abundant large belemnite rostra, but complete bivalve shells, particularly of *Buchia*, are also found (Smith et al. 1976).

Remarks: Smith et al. (1976) subdivided the Tordenskjoldberget Member at the type section into two divisions. The *lower division*, comprising calcareous sandstone, is here retained as the Tordenskjoldberget Member. The *upper division* of Smith et al. consists of 15 m shales and siltstones with dark brown weathering ironstone nodules and is herein included in the Kolje Formation. It should be noted that the *upper division* of Smith et al. (1976) was not recognised at the reference sections S.1414-west and S.1414-east. Here the carbonates of the Tordenskjoldberget Member are directly overlayed by sandstones of the Helvetiafjellet Formation (i.e. the Hårfagrehaugen Member).

Distribution: The Tordenskjoldberget Member is observed *in situ* only over a distance of a little more than a kilometre on the southern slope of Tordenskjoldberget on Kongsøya. The member is also penetrated by shallow drilling and sampling in Hopendjupet and in the Olga Basin (J. G. Verdenius and A. Mørk, written commun).

Age: Valanginian to Hauterivian. Both belemnites, bivalves, nannofossils and palynomorphs suggest a Valanginian to Hauterivian age for the Tordenskjoldberget Member as presently defined, i.e. as equivalent to the *lower division* of Smith et al. 1976 (see review in Doyle & Kelly 1988).

Kolje Formation on Kong Karls Land

On Kong Karls Land the Kolje Formation (Worsley et al. 1988) is only recognised on the south face of Tordenskjoldberget on southeastern Kongsøya in the upper part of the sediments originally placed in the Tordenskjoldberget Member as described by Smith et al. (1976; i.e.

Fig. 2. Sedimentological corelog of the Klippfisk Formation type section in borehole 7430/10-U-01, Bjarmeland Platform and the reference section in borehole 7231/01-U-01, northeastern Nordkapp Basin.

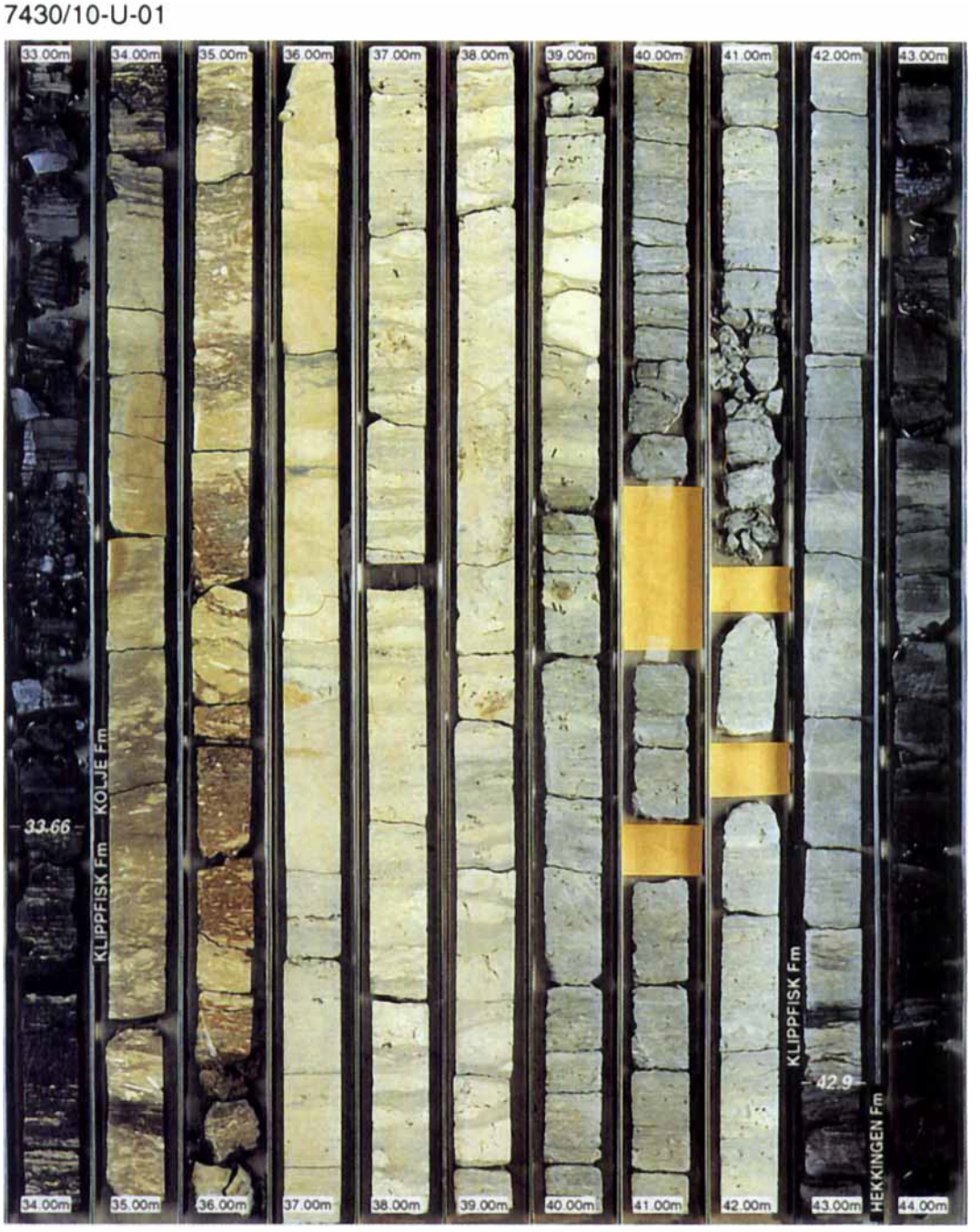


Fig. 3. Core photos from the Klippfisk Formation (Kutling Member) type section, core 7430/10-U-01, Bjarmeland Platform.

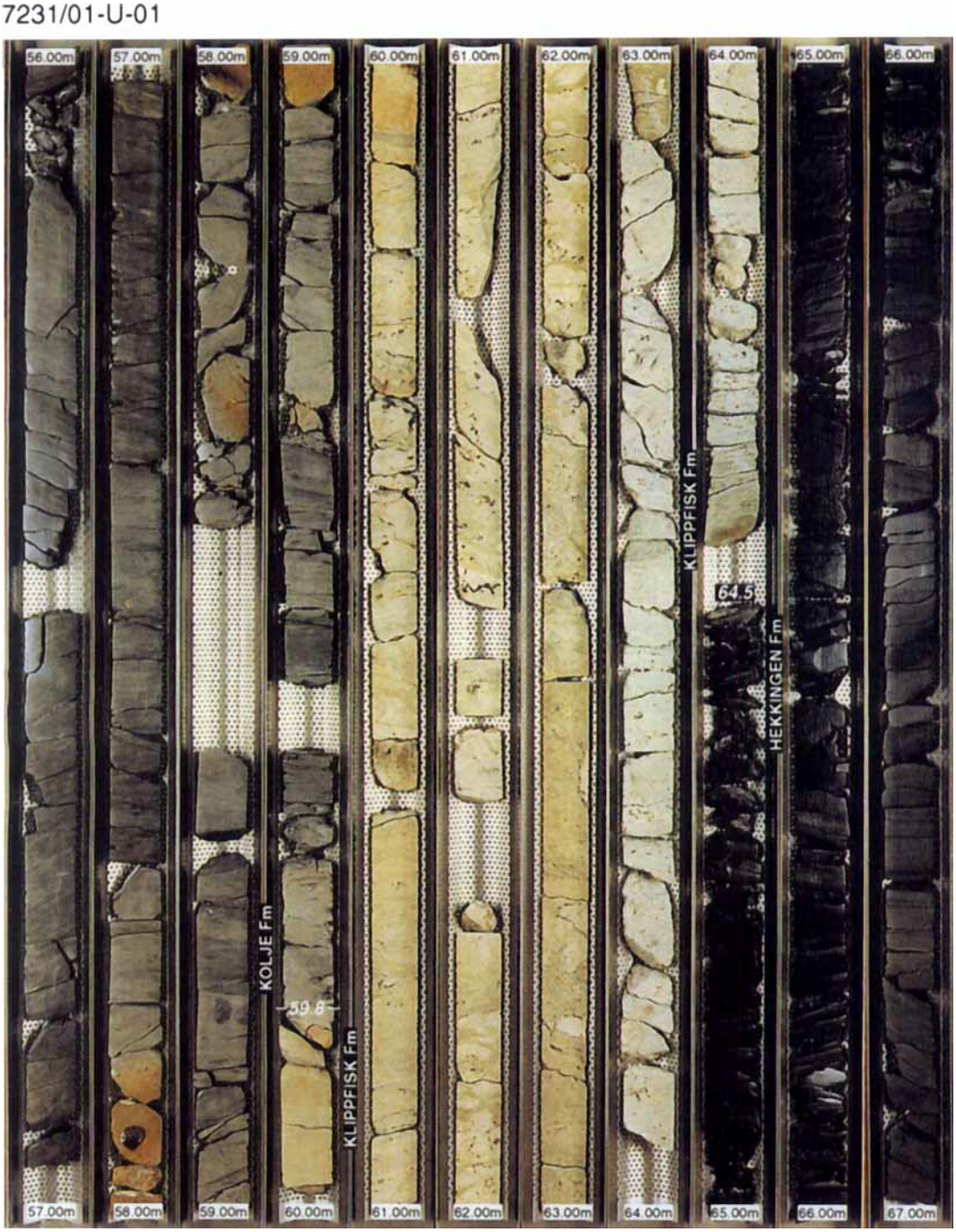


Fig. 4. Core photos from the Klippfisk Formation (Kutling Member) reference section in core 7231/01-U-01, Nordkapp Basin.

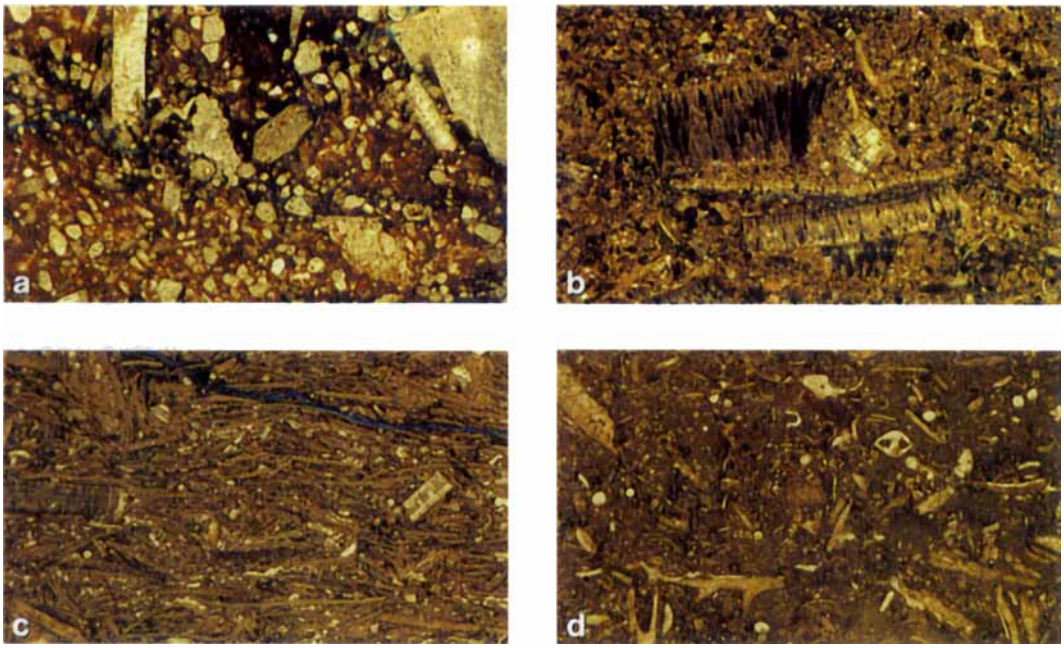


Fig. 5. Photos of thin-sections from the Klippfisk Formation (Kutling Member) type section, core 7430/10-U-01, Bjarmeland Platform: (a) Fossil debris, mainly disintegrated *Inoceramus* prisms in a reddened micrittic matrix (35.32 m, ×20); (b) *Inoceramus* prisms floating in a microsparittic matrix (35.32 m, ×7); (c) Coquina of thin shelled bivalves and a few thicker shelled *Inoceramus* fragments (36.90 m, ×8); (d) Biomicrite with abundant crushed fossil debris (38.44 m, ×7).

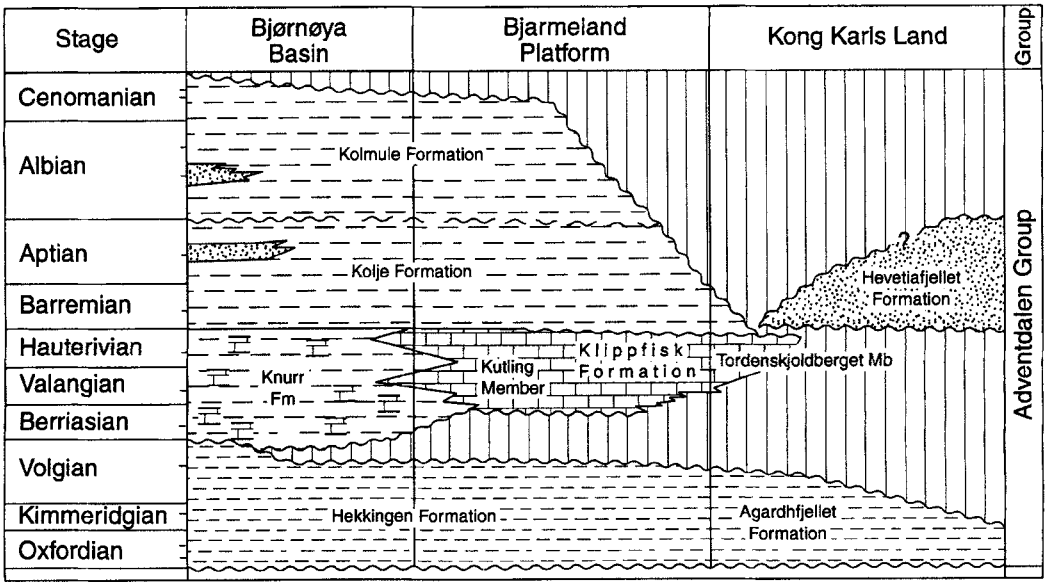


Fig. 6. Lithostratigraphic correlation scheme for the Klippfisk Formation and adjacent units in the Bjørnøya Basin and on the Bjarmeland Platform and Kong Karls Land on eastern Svalbard.

their section D.833, fig. 13), where the formation is 15 m thick. The unit consists of shales and siltstones with dark brown weathering ironstone nodules. This lithology is typical for the Kolje Formation of the Barents Shelf. Age-determinations based on dinoflagellates from this unit suggests a Barremian age (Leereveld & Smelror 1988). There are a similar and contemporaneous transition from a condensed section of Valanginian-Hauterivian carbonates to overlying dark Lower-Middle Barremian shales/claystones as seen elsewhere on the Barents Shelf at the transition from the Klippfisk Formation to the overlying Kolje Formation (Fig. 6). The Kolje formation was also penetrated by shallow and exploration drillings in wide areas of the Barents Shelf and further investigations are needed to describe the regional development of this formation. The unit is of Barremian age, possibly extending into the Early Aptian.

Appendix. Biostratigraphy (Bjarmeland Platform cores and the Tordenskjoldberget section on Kongsøya)

Core 7430/10-U-01

Nannofossil biostratigraphy

A total of 104 samples were analysed, which were taken about 50 cm intervals from the core (Fig. 7). The shales below 43.00 m are essentially barren of nannofossils; a few samples yield dissolution-resistant *Watznaueria*. The relatively high proportion of *Watznaueria britannica* at 57.63 m is suggestive of a Late Jurassic or earliest Cretaceous age. The overlying limestones and marls yield moderately to heavily overgrown assemblages. The siltstones above 33.00 m are only sparsely nannofossiliferous, but occasional samples yield dissolution-modified assemblages.

41.50 m – ?Late Berriasian (albidum Zone). – The presence of possible *Sollasites arcuatus* (poorly preserved) at 41.50 m suggests a latest Berriasian age. This date coincides with the start of carbonate deposition elsewhere.

39.00–41.00 m – Early Valanginian (Paratollia spp. 'Zone'). – *Cretarhabdus angustiforatus* at 40.35 and 40.00 m confirms that a Late Berriasian or younger age has been reached. The absence of *Sollasites arcuatus* from this interval and the first appearance of *Triqueterhabdulus shetlandensis* at 39.57 m indicate a basal Valanginian age. *Micrantholithus speetonensis* was not recorded – this suggests an age in the lower part of the Paratollia spp. 'Zone'. The first appearance of fairly common *Tranolithus gabalus* coincided with the first occurrence of *Triqueterhabdulus shetlandensis* – this event is also recognised in Core 7425/09-U-01, and in the Speeton section.

36.00–39.00 m – 'middle' Hauterivian (regale/inversum Zone – speetonensis Zone. – *Trigueterhabdulus shetlandensis* disappears above 39.00 m, and *Eiffellithus striatus* first appears at 38.04 m – these events indicate a Late Valanginian or younger age. *Calculites* sp. 1, at 37.65 m, is common in the Early Hauterivian (amblygonium-regale Zones) of Speeton, but its full range is not well constrained. *Chiastozygus tenuis* and *Chiastozygus* sp. 1, at 36.10 m, first appear in the mid-late Hauterivian at Speeton. *Perissocyclus plethotretus*, in the same sample, first appears in the 'middle' Hauterivian (inversum Zone). *Zeugrhabdotus* sp. 1, which first becomes common in the late Hauterivian of Speeton, occurs for the first time at 36.10 m. The presence of *Eiffellithus striatus* and abundant *Biscutum salebrosum* up to 36.10 m, and the absence of *Tegulalithus septentrionalis* at this level, indicate an age no younger than speetonensis Zone. The lower part of this interval cannot be dated so confidently, but the absence of common *Cyclagelosphaera margerelii* and *Eprolithus antiquus* make a Late Valanginian-Early Hauterivian age unlikely. Thus sedimentation probably resumed in the 'middle' Hauterivian (regale/inversum Zone), as it did in Core 7425/09-U-01. This interval encompasses the nodular limestone unit, which corresponds with a similar horizon in Core 7425/09-U-01; these nodular beds may be almost exactly equivalent in age – they are

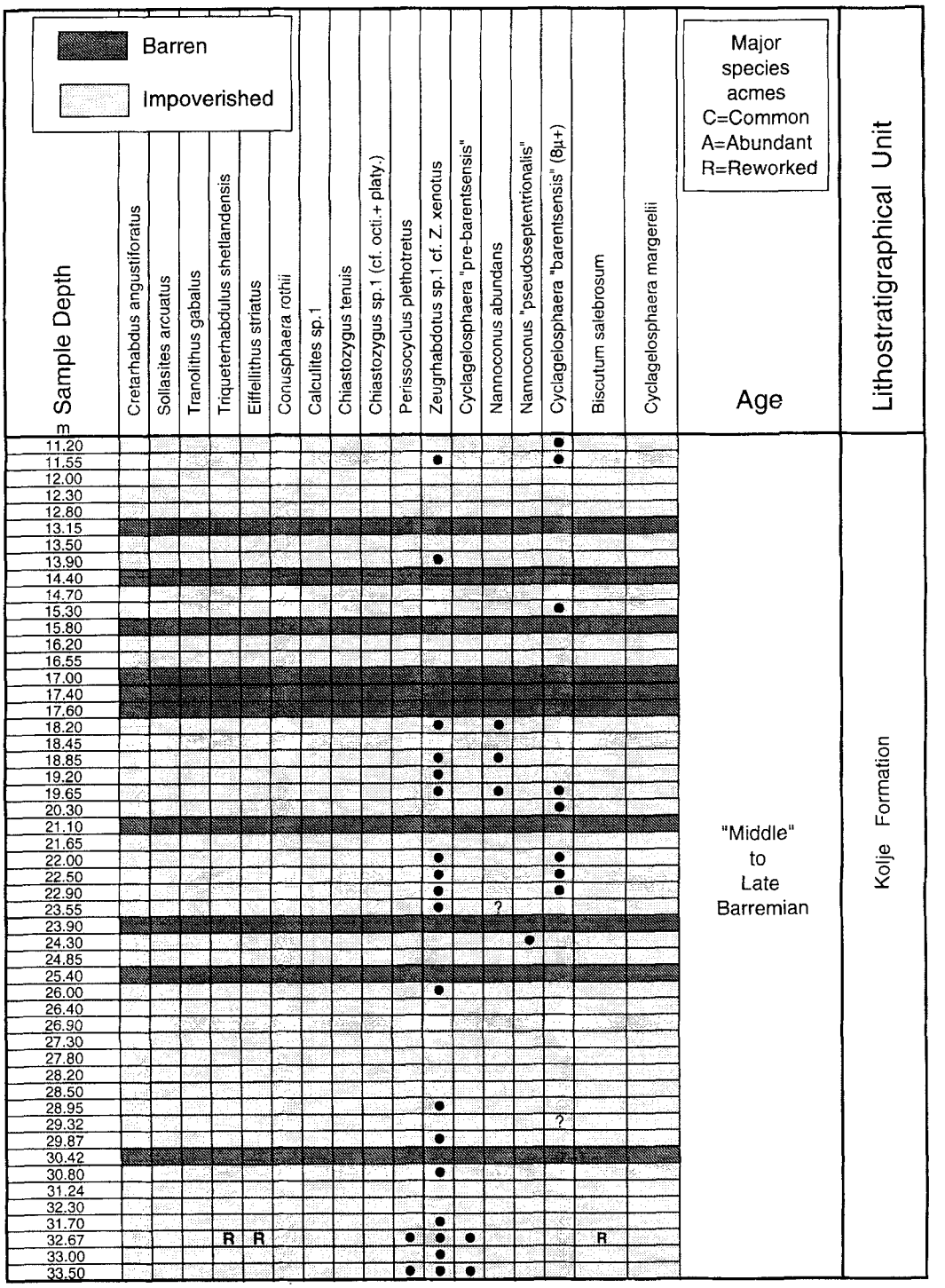


Fig. 7. Continued on next page.

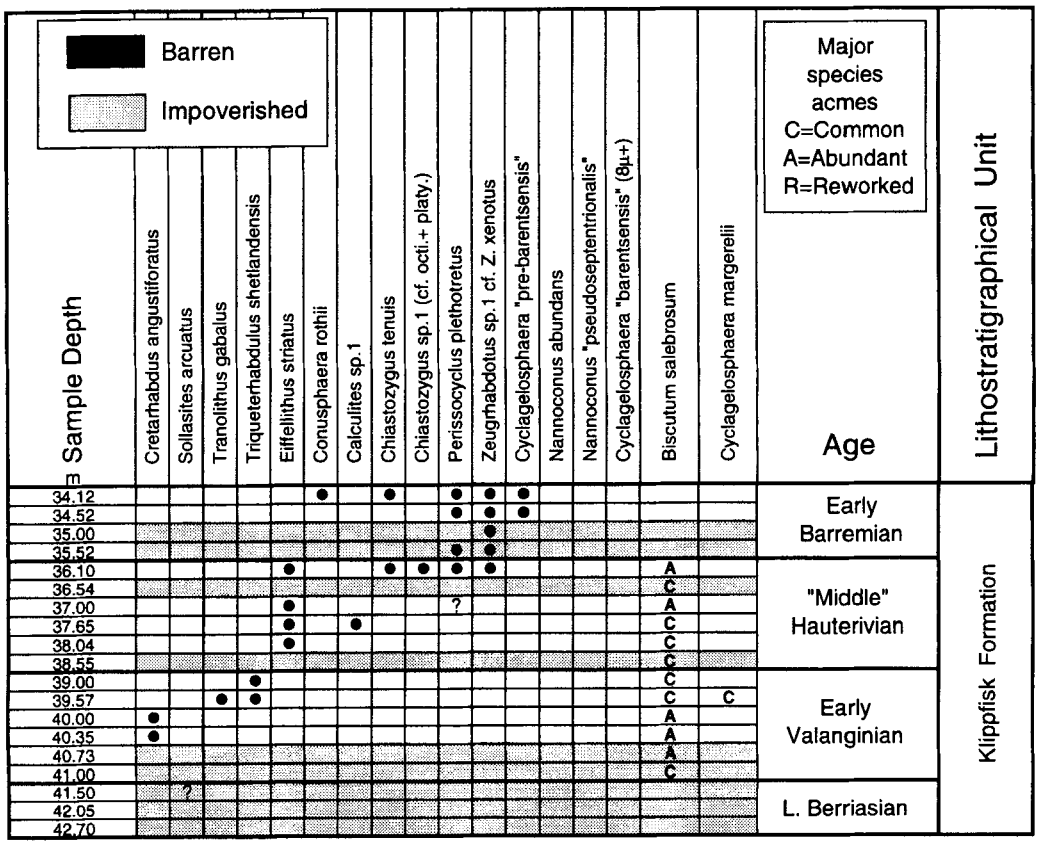


Fig. 7. Distribution chart of nannofossils in core 7430/10-U-01.

so condensed that species such as *Eprolithus antiquus* may be restricted to an interval between samples.

33.00–36.00 m – ?Barremian (?variabilis Zone). – An abrupt lithological change at 36.00 m (from nodular limestone to marl) is reflected by a dramatic turnover in the nannoflora. *Biscutum salebrosum*, which dominates assemblages below 36.00 m, disappears at this boundary, as does *Eiffellithus striatus*. There are few age diagnostic nannofossils in the overlying marls, but the absence of *Tegulalithus septentrionalis* indicates an age no older than gottschei Zone (Late Hauterivian). The abrupt extinction of *Biscutum salebrosum* suggests that there may be a considerable break at 36.00 m; it seems likely that sedimentation may not have resumed until the Early Barremian, which would fit with well corroborated microfaunal and palynological data, but a latest Hauterivian age cannot be ruled out on nannofossil evidence alone. *Conusphaera rothii*, at 34.12 m, indicates that these marls are no younger than Early Barremian. *Perissocyclus plethotretus* is conspicuous throughout this interval, as it is in the early Barremian of Speeton (where it seems to die out in the late Barremian). The absence of *Nannoconus abundans* from this interval suggests that it may be earliest Barremian (variabilis Zone) in age.

11.20–33.00 m – 'middle'–Late Barremian. – *Biscutum salebrosum*, *Eiffellithus striatus*, and *Triqueterhabdullus shetlandensis* are reworked at 32.67 – this assemblage indicates reworking down to the Valanginian, and may record a minor sequence boundary. The overlying silts are very poorly nannofossiliferous. The first age-significant nannofossil, *Nannoconus 'pseudoseptentrionalis'*, occurs at 24.30 m and indicates a Late

Barremian age (this species appears at the base of the elegans Zone at Speeton). Sporadic occurrences of *Nannoconus abundans* in the silts above confirm a Barremian age. *Cyclagelosphaera 'barentsensis'* is a conspicuous element of the less-heavily etched samples above 22.90 m; this species has been recorded rarely in the elegans Zone at Speeton.

Palynostratigraphy

A distribution chart of dinoflagellate cysts is presented in Fig. 8. Selected palynomorphs from 7430/10-U-01 are shown in Fig. 9, and examples of palynofacies from the individual formations are shown in Fig. 10.

67.60–58.01 m – latest Kimmeridgian sensu gallico (eudoxus-autissiodorensis Zone). – Assemblage with *Paragonyaulacysta capillosa* and *Paragonyaulacysta? borealis*, including in the most upper part, *Cribroperidinium* aff. *longicorne*, *Gonyaulacysta jurassica*, *Tetrachacysta spinosigibberosa* and *Tubotuberella apatela*. *P. capillosa* and *P.? borealis* were described from the Late Kimmeridgian-Early Ryazanian in Arctic Canada (Brideaux & Fischer 1976) (Fig. 9). Piasecki (1980) found *P. capillosa* in the upper part of the eudoxus and in the autissiodorensis Zones of East Greenland in good agreement with the ammonite evidence from this hole.

56.73–53.65 m – Early Volgian. – Some *Senoniasphaera jurassica* specimens have been found in these two samples, as well as a single specimen of *Egmontodinium polyplacophorum* at 56.73 m. Piasecki (1980) reported *S. jurassica* from the Lower Volgian scitulus Zone and younger strata in East Greenland, and *E. polyplacophorum* also seems to appear consistent only in the earliest Volgian or equivalent beds (in the elegans Zone according to Riding & Thomas 1992). *Tubotuberella apatela* has been found in nine of ten examined samples between 58.00 m and 44.50 m and *Sirmiodinium grossii* also occurs consistently from 58.00 m upwards. *Trichodinium* sp., sometimes referred to as *Acanthaulax* sp. or, by Piasecki (1980) as *Trichodinium* aff. *ciliatum*, appears at 56.73 m and is found in the five samples up to 43.30 m. In East Greenland the first representatives of this taxon are in the Lower Volgian scitilus Zone, but it appears possibly somewhat earlier in Spitsbergen. The species has a short range in East Greenland and disappears in the Lower Volgian wheatleyensis Zone. Also at Janusfjellet, Spitsbergen, it does not range above the lower part of the Volgian and seems to conflict with the stratigraphic occurrence of this taxon in the present core (Århus unpubl. information). *Gonyaulacysta jurassica* occurs scatteredly in the interval. Single specimens have been observed at 58.01, 53.01, 49.01, 44.50 and 43.30 m. Riding & Thomas (1992) reported *G. jurassica* to disappear at the top of the elegans Zone in England, and this correlates with the earliest Volgian. A single specimen of *Trichodinium* sp. found at 43.30 m is assumed reworked.

53.01–42.65 m – ?Late Volgian-Late Berriasian. – Some samples from this interval contain *Trichodinium* sp. and *G. jurassica* (see interval 56.73–55.01 m above). According to the range reported by Riding and Thomas (1992) for *G. jurassica*, one should expect these species to be reworked in the present interval. The first specimens of *Valensiella ovulum*, *Pandadinium saturnalis* and *Stiphrosphaeridium arbustum* (51.01 and 44.50 m), as well as *Systematophora palmula* and *Gochteodinia villosa* found at 42.65 m suggest that the Late Berriasian has been reached (Davey 1982; Riding & Thomas 1992). Reworked Oxfordian dinoflagellate cysts occur at 44.50, 43.85 and 43.30 m, in this glauconitic interval. Numerous thin-walled spheres assigned to *Leiosphaeridia*? sp. are common at 47.87 m and abundant at 47.50 m.

42.01–40.51 m – latest Berriasian-earliest Valanginian. – This interval is barren of palynomorphs.

40.30–39.05 m – Valanginian-Hauterivian. – The lower boundary is based on foraminifera and the upper boundary is based on palynomorphs, in agreement with the microfaunal record.

38.00–26.75 m – Early Barremian. – Eight samples between 38.00 m and 34.52 m are barren or poor in dinoflagellate cysts. A single well-preserved specimen of *Pseudoceratium anaphrissum* has been recorded at 38.00 m. The species is also present at 36.05 m and 33.57 m and more consistently in the claystone from 33.74 m to the top of the core. In British Isles, according to Costa & Davey (1992), this species occurs from the Early Barremian of the early Late Barremian (rarocinctum to lower rudefissicostatum zones).

Mutterlose & Harding (1987) and Harding (1990) reported this species only from the lower Barremian in northern Germany and England. In northeast Greenland, this species is also appears in the Early Barremian (Nøhr-Hansen 1993). Richer and more diverse assemblages appear from 33.74 m with the *Cribroperidinium edwardsii/muderongense* group, the *Oligosphaeridium complex/O.?asterigerum* group, *Gardodinium trabeculosum*, and *Batioladinium longicornutum* (from 33.29 m) as the most commonly and consistently occurring taxa. *Pseudoceratium nudum*, *Muderongia* cf. *asymmetrica* sensu Århus et al. 1990, *Protoellipsodinium spinosum* and *Surculosphaeridium? phoenix* also appear 33.74 m. *Nelchinopsis kostromiensis* occurs in fairly high numbers at 29.01 m and supports the evidence that this species ranges above the Hauterivian (Heilmann-Clausen 1987).

25.11–11.94 m – early Late Barremian (rudefissicostatum Zone). – Based on the first appearances of *Trichodinium speetonense* (25.10 m), *Cauca parva*, *Cribroperidinium? cornutum* and *Fromea quadrugata* (23.00 m) a Late Barremian age is assigned at this interval.

In British Isles, Costa & Davey (1992) and Duxbury (1980) reported the FAD of these species as early Late Barremian. Due to the presence up to the top of the core of *Aprobolocysta neistosa*, *Batioladinium longicornutum*, *Gonyaulacysta fastigiata* and *Muderongia* cf. *asymmetrica* sensu Århus et al. 1990, a Late Barremian (bidentatum Zone) age is excluded. It is also of interest to note the overlap, in the Barents sea, of *N. kostromiensis* and *P. anaphrissum* during the Barremian, as already reported from East Greenland (Nøhr-Hansen 1993).

Discussion

The nannofossil dating of the 41.50–39.00 m interval (latest Berriasian-earliest Valanginian) is in general agreement with the foraminifera-based dating in Århus (1991), although we have ruled out the possibility of there being any Hauterivian below 39.00 m (where Århus has one metre of undifferentiated Valanginian-Hauterivian). Similarly, the dating of the marls and siltstones above 36.00 m (Barremian) agrees with Århus' palynological dates. However, there is a major discrepancy over the age of the nodular limestone horizon. Århus (1991) and the present dinoflagellate stratigraphy dates this as Early Barremian, but the nannofossil data shows this bed to be Hauterivian in age. The palynological dating of this horizon is based on a single well-preserved dinoflagellate cyst in an otherwise barren sample from 38.00 m, and on the rare occurrence of a foraminifer at 37.75 m. We think the dinocyst was a contaminant, and possibly also the foraminifera.

The species which was recorded as *Dodekapodorhabdus noelae* (in Århus 1991) is here assigned to *Perissocyclys plethotretus*; the form Århus records as *Corollithion achylosum* may have been an overgrown *Chiastozygus tenuis*. The former species does not appear until the Aptian according to our data.

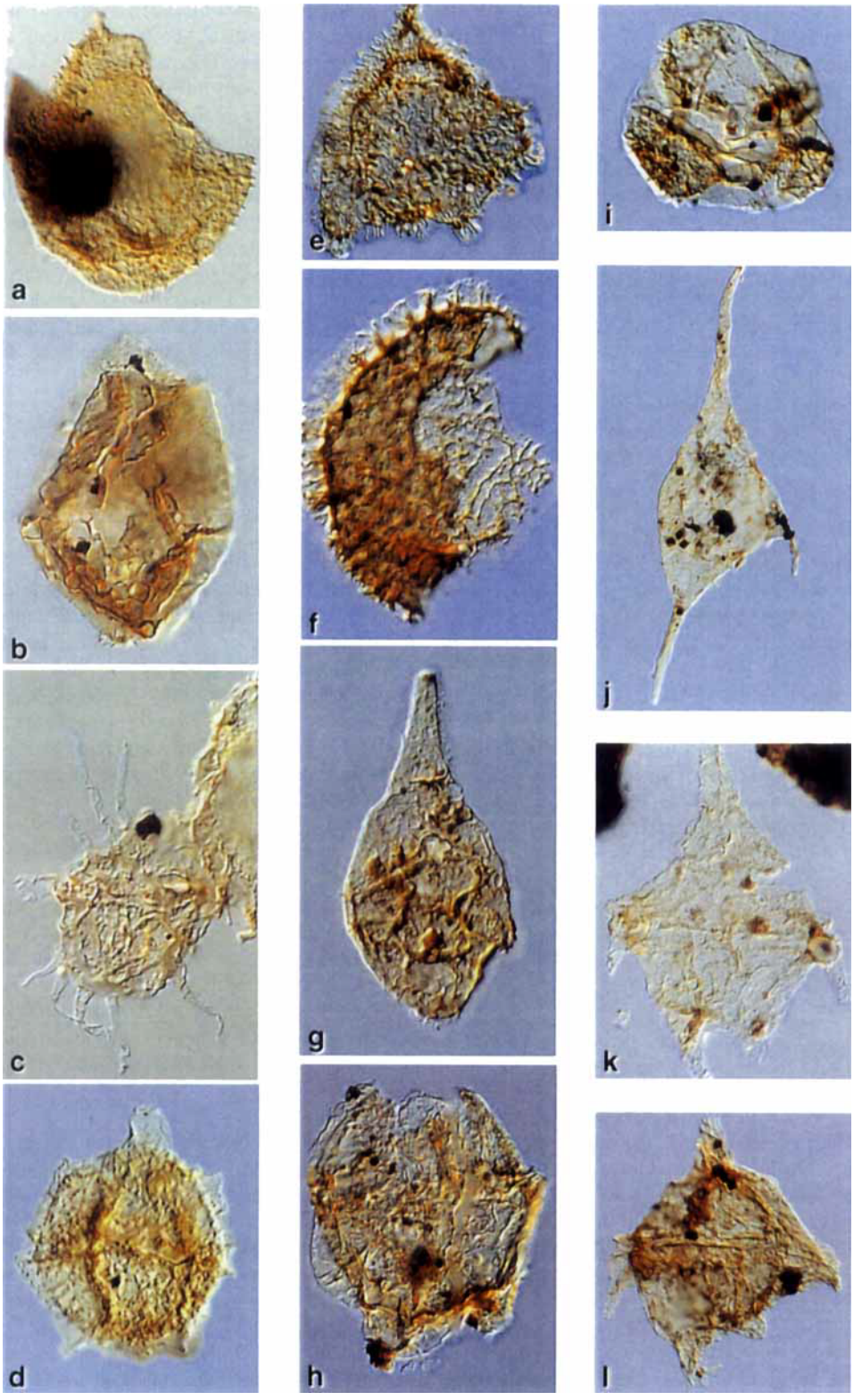
Core 7425/09-U-01

Nannofossil biostratigraphy

A total of 50 samples were analysed, at intervals of 30–50 cm. Nannofossil preservation is poor to moderate throughout the entire core. The carbonate-rich units yield moderately to heavily overgrown nannoflora, while assemblages from the siltstones are strongly etched. Nevertheless, few samples were entirely barren and most yielded age diagnostic assemblages. A distribution chart of the nannofossils is shown in Fig. 11.

64.00–65.60 m – latest Berriasian (late albidum Zone). – The presence of *Sollasites arcuatus* up to 64.28 m is indicative of a latest Berriasian age. Other characteristic elements of this interval include *Kokia borealis*, common/abundant *Biscutum salebrosum* and common *Sollasites* spp. (especially *Sollasites lowei*). *Cretarhabdus angustiforatus*, which occurs in the basal sample (65.60 m), first appears in the late Berriasian (Jakubowski 1987).

57.00–64.00 m – basal Valanginian (lower Paratollia spp. 'Zone'). – The disappearance of *Sollasites arcuatus* and reduction in abundance of *Sollasites* spp. at 64.00 m marks the Berriasian-Valanginian boundary. Characteristic Valanginian elements in the overlying interval include *Kokia curvata*, *Triqueterhabdulus shetlandensis*, and common/abundant *Biscutum salebrosum*. *Triqueterhabdulus shetlandensis* first appears several metres above the base of this interval. The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absence of *Micrantholithus speetonensis*, which appears in the upper part of the *Paratollia* spp. 'Zone' at Speeton, suggests that the whole of this interval falls within the lower part of this Zone. It is possible that *Micrantholithus speetonensis* may have been precluded from high latitudes by environmental limitations, but whatever the case, this interval is certainly Early Valanginian in age.

55.20–57.00 m – 'middle' Hauterivian (topmost regale to early gottschei Zone. – *Triqueterhabdulus shetlandensis* last occurs at 57.22 m, and *Eiffellithus striatus* first appears in the sample at 56.92 m. The latter species first appears in the late Valanginian of Germany (Mutterlose 1991), but *Eprolithus antiquus* in the same sample (56.92 m) denotes a late regale Zone age ('middle' Hauterivian). The presence of common *Cyclagelosphaera margerelii* in the same sample supports this age. The first occurrences of *Chiastozygus* spp. and *Zeugrhabdotus* sp. 1 at 55.68 m indicate an inversum Zone age. The last occurrences of *Eiffellithus striatus* and common/abundant *Biscutum salebrosum* at 55.20 m, and the first appearance of *Tegulalithus septentrionalis* in the same sample, indicate a speetonensis or gottschei Zone age. The continued presence of *Tegulalithus septentrionalis* at 55.20 m suggests an early gottschei Zone age; its last occurrence at this level corresponds with the top of the nodular limestone horizon.

50.10–55.20 m – Early Barremian (variabilis Zone). – The presence of very small eiffellithids rims from 54.50 m upwards suggests an early Barremian age (these dissolution-modified coccoliths are very similar to *Eiffellithus* sp. 2, which is restricted to the variabilis-rarocinctum Zones at Speeton). The presence of *Conusphaera* sp. aff. *rothii* up to 50.43 m also indicates an Early Barremian age (*Conusphaera rothii* disappears in the fissicostatum Zone). The absence of *Nannoconus abundans*, which first appears at the base of rarocinctum Zone, limits the age of this interval to the variabilis Zone. The low abundance of *Cyclagelosphaera margerelii* throughout this interval supports this age assignation. This species is common in the rarocinctum-fissicostatum Zones at Speeton, but depleted in the variabilis Zone.

Discussion

An Early Barremian age for the marls and siltstone above 55.00 m agrees with the interpretation of Århus (1991), based on palynological data. Likewise, the Late Berriasian date proposed here for the onset of carbonate deposition fits with the macrofossil and foraminiferal data. However, the new dating of the remainder of the core based on nannofossils gives a more precise age compared with the dates given in Århus (1991). Århus (1991) dated the lower part of the nodular

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Fig. 9. Palynomorphs from core 7430/10-U-01. All photographs in Nomarski interference contrast.

(a) *Trichodinium speetonense*. Kolje Formation. Depth 25.10 m. Slide ox1. EF: V34/1-2. Composite photomicrograph of 2 focus levels (×500).

(b) *Fromea quadrugata*. Kolje Formation. Depth 23.00 m. Slide ox1. EF: V30/1. Composite photomicrograph of 3 focus levels (×650).

(c) *Cauca parva*. Kolje Formation. Depth 23.00 m. Slide ox1. EF: V27. Composite photomicrograph of 5 focus levels (×600).

(d) *Nelchinopsis kostromiensis*. Kolje Formation. Depth 23.00 m. Slide ox1. EF: U33/1. Composite photomicrograph of 4 focus levels (×760).

(e) *Pseudoceratium anaphrissum*. Klippfisk Formation. Depth 38.00 m. Slide ox1. EF: Y24/1-3. Composite photomicrograph of 5 focus levels (×370).

(f) *Pandadinium saturnalis*. Klippfisk Formation. Depth 42.65 m. Slide ox1. EF: U21/1-2 (×570).

(g) *Paragonyaulacysta capillosa*. Hekkingen Formation. Depth 67.55 m. Slide ox3. EF: N18/4. Composite photomicrograph of 3 focus levels (×560).

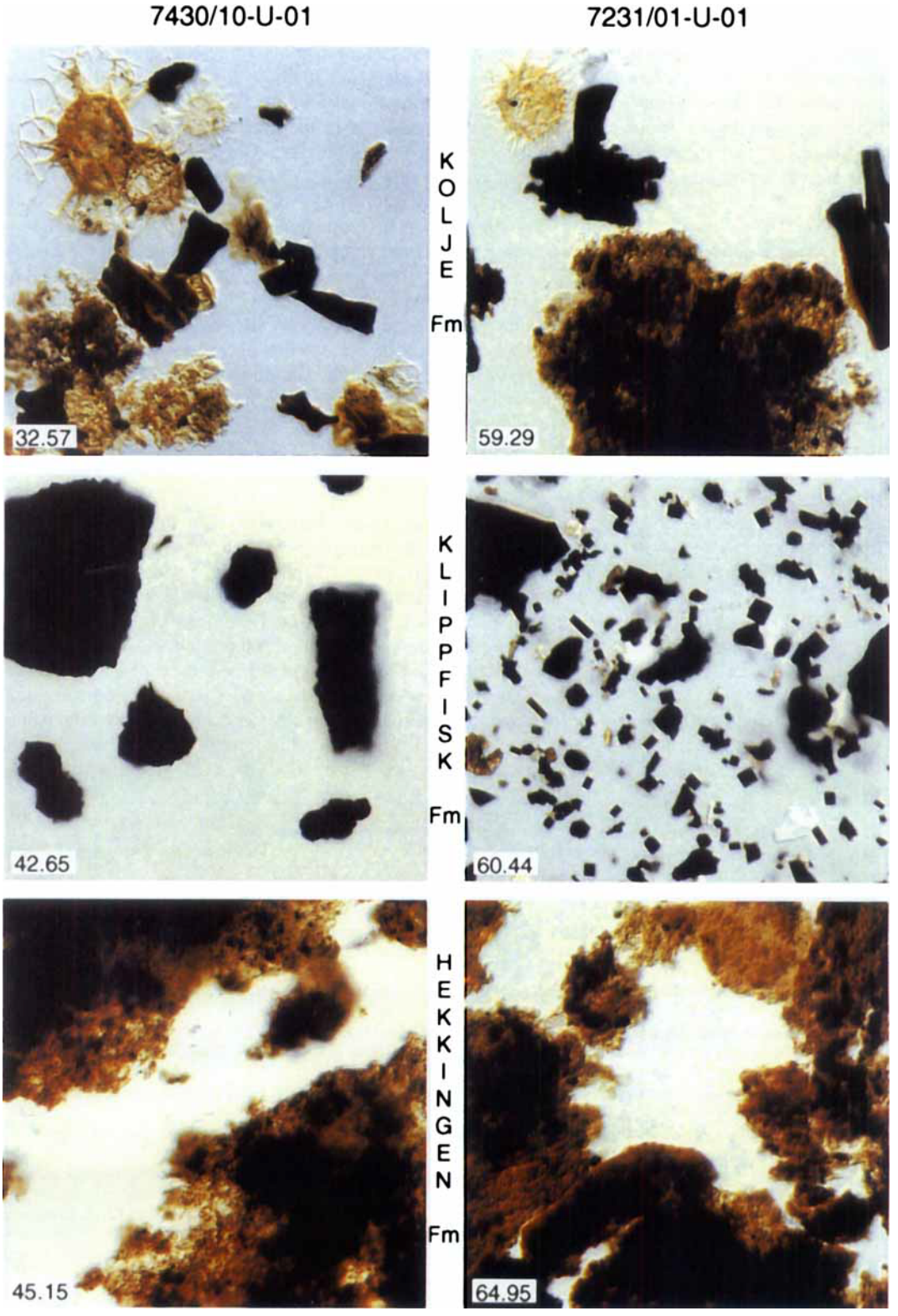
(h) *Senoniasphaera jurassica*. Hekkingen Formation. Depth 55.00 m. Slide ox3. EF: J39/2. Composite photomicrograph of 5 focus levels (×520).

(i) *Tetrachacysta spinosigibberosa*. Klippfisk Formation. Depth 33.74 m. Slide ox4. EF: N23/4. Composite photomicrograph of 3 focus levels (×570).

(j) *Pseudoceratium nudum*. Klippfisk Formation. Depth 33.74 m. Slide ox4. EF: J31. Composite photomicrograph of 6 focus levels (×450).

(k) *Muderongia* cf. *asymmetrica* sensu Århus et al. 1990. Klippfisk Formation. Depth 33.74 m. Slide ox4. EF: X37/2. Composite photograph of 7 focus levels (×440).

(l) *Muderongia asymmetrica*. Klippfisk Formation. Depth 33.74 m. Slide ox4. EF: M29/3 Composite photomicrograph of 4 focus levels (×380).


7430/10-U-01
7231/01-U-01
KOLJE Fm
KLIPPFISK Fm
HEKKINGEN Fm
32.57
59.29
42.65
60.44
45.15
64.95

limestone horizon as undifferentiated Valanginian-Hauterivian, with everything below this belonging to the Berriasian. Nannofloral evidence shows that there are, in fact, well differentiated Valanginian and Hauterivian units. This is confirmed by the new palynological analyses, suggesting an Early–'middle' Hauterivian age between 57.37 m–58.37 m. Sedimentation seems to have been continuous throughout the Late Berriasian-Early Valanginian. A major sequence boundary at 57.00 m is responsible for the absence of sediments of 'middle'–Late Valanginian and basal Hauterivian age. Most of the Hauterivian is represented, in extremely condensed form by 2 metres of nodular limestone. There may be a minor sequence boundary at 55.00 m, with the uppermost Hauterivian missing, or this time interval may be represented in very condensed from (between sample intervals). The change from carbonate to siliciclastic deposition, marked by a thin coarse-grained sandstone at about 53.5 m, probably marks a minor sequence boundary.

Tordenskjoldberget section, Kongsøya, Kong Karls Land

The Tordenskjoldberget section on Western Kongsøya (section D.833, fig. 13 in Smith et al. 1976) was sampled in 1976 by Mark B. Edwards. Calcareous nannoplankton from these samples have been described by Verdenius (1978), while Løfaldli (1978) reported on the foraminifera faunas. Later Doyle and Kelly (1988) described the belemnites from the Tordenskjoldberget section. They also gave an overview of the previous paleontological investigations of the Tordenskjoldberget Member sensu Smith et al. (1976). They pointed out that while calcareous nannofossils, bivalves and belemnites suggest a Valanginian-Hauterivian age for the member, palynomorphs indicate a Valanginian-Barremian age. We suggest that the difference in age determinations is due to the fact that calcareous nannoplankton, belemnites and bivalves have only been found in the calcareous lower part of the Tordenskjoldberget Member sensu Smith et al. (1976), i.e. the unit corresponding to the revised Tordenskjoldberget Member of the Klippfisk Formation as defined herein. Palynomorphs have been obtained from the shaly upper part of the Tordenskjoldberget Member sensu Smith et al. (1976), i.e. the Kolje Formation as described herein.

Palynostratigraphy

Twelve samples from the Tordenskjoldberget section were analysed for marine palynomorphs (Fig. 12). All samples yielded fairly well-preserved and moderately rich and diverse dinoflagellate assemblages. Only one sample represents the present Tordenskjoldberget Member, while the rest of the samples are from the Kolje Formation (Fig. 12).

Tordenskjoldberget Member. – The presence of *Valensiella magna*, *Dapsilidinium chems*, *Lithodinia pertusa*, *Nelchinopsis kostromiensis* and *Muderongia tetracantha* in sample S-12/24 suggest a latest Hauterivian age. According to Costa and Davey (1992), *N. kostromiensis* has its last occurrence in the latest Hauterivian Marginatus ammonite zone, but data from Heilmann-Clausen (1987) and the present core 7430/10-U-01 suggest that this species also ranges into the Early Barremian. *D. chems* and *L. pertusa* are typical Late Hauterivian markers, and the absence of typical Early Barremian forms, which first appears in the overlying samples, is taken as evidence for a Late Hauterivian age for sample S-12/24.

Kolje Formation. – The presence of *Pseudoceratium anaphrissum* and *Cerbia tabulata*, together with *Muderongia crucis* and *Rhynchodiniopsis fimbriata*, suggests a late Early Barremian age for sample S-12/34. According to Costa and Davey (1992), *P. anaphrissum* and *C. tabulata* only have

Fig. 10. Examples of palynofacies from the individual formations of core 7430/10-U-01, Bjarmeland Platform (left column) and core 7231/01-U-01, Nordkapp Basin (on the right column). Depth in metres. All photographs in Nomarski interference contrast (×460). Upper photographs: Kolje Formation, palynofacies characterised by abundant dinoflagellate cysts, some black wood fragments and amorphous organic matter. Middle photographs: Klippfisk Formation, palynofacies characterised by abundant black wood fragments. Lower photographs: Hekkingen Formation, palynofacies dominated by abundant amorphous organic matter.

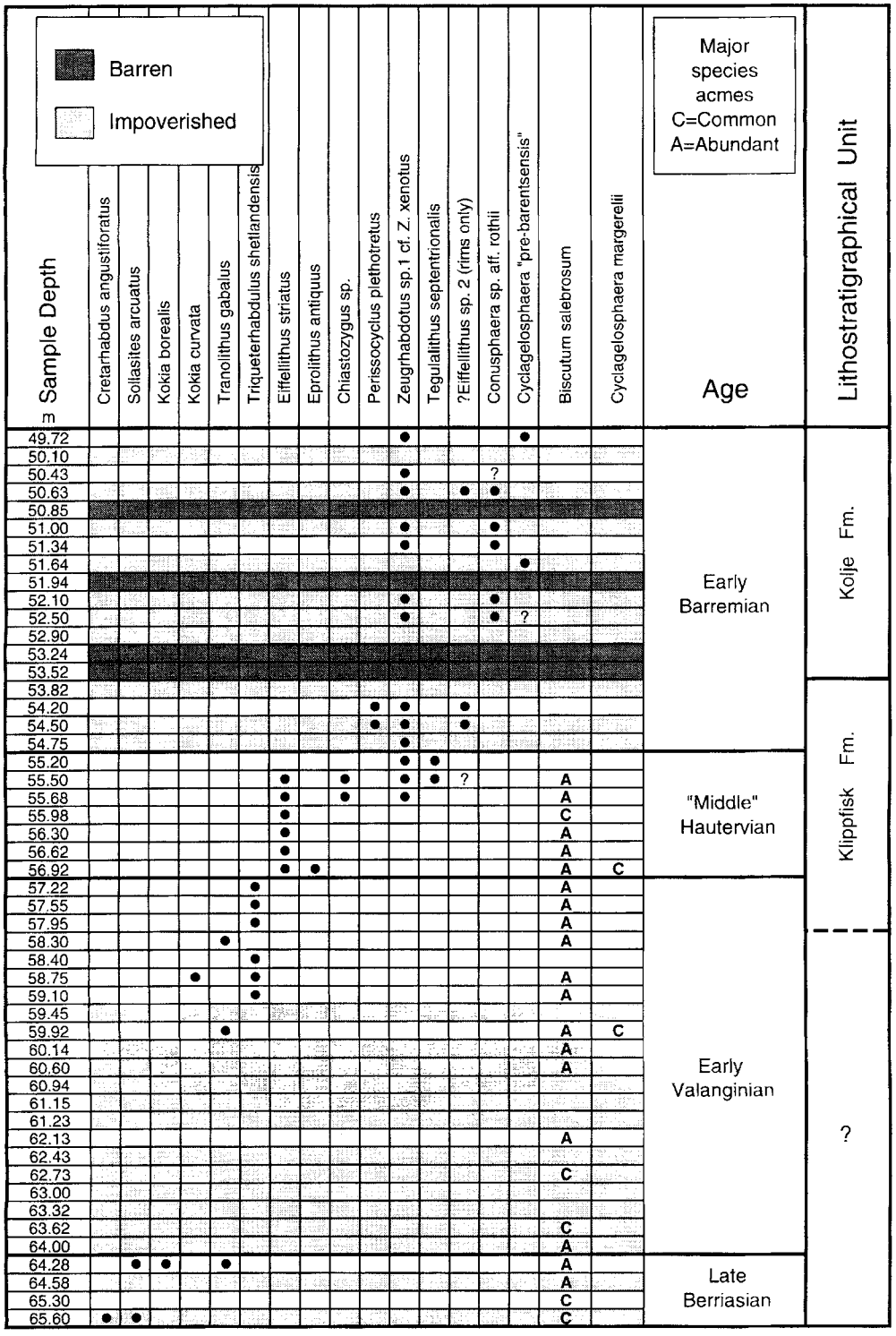


Fig. 11. Distribution chart of nannofossils in core 7425/09-U-01.

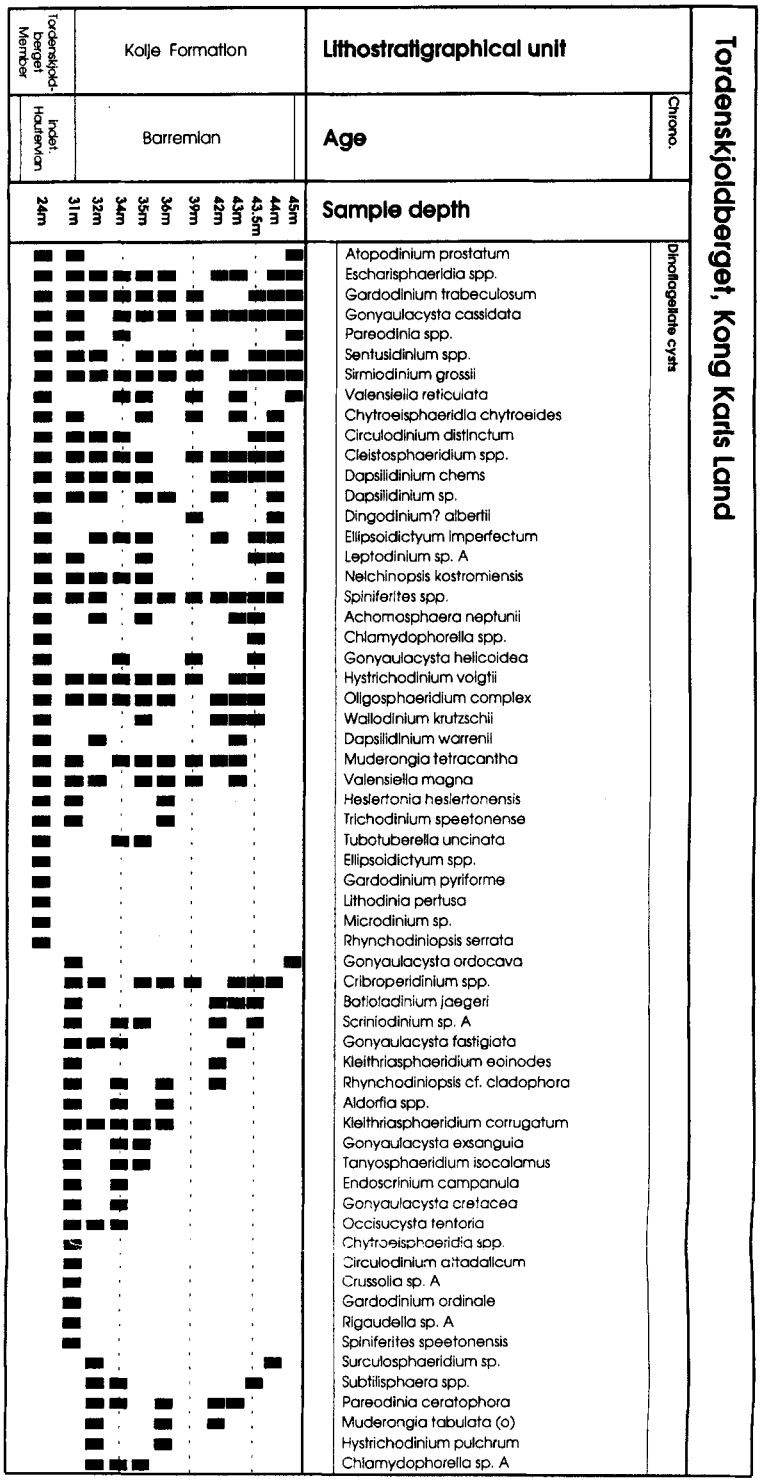


Fig. 12. Continued on next page.

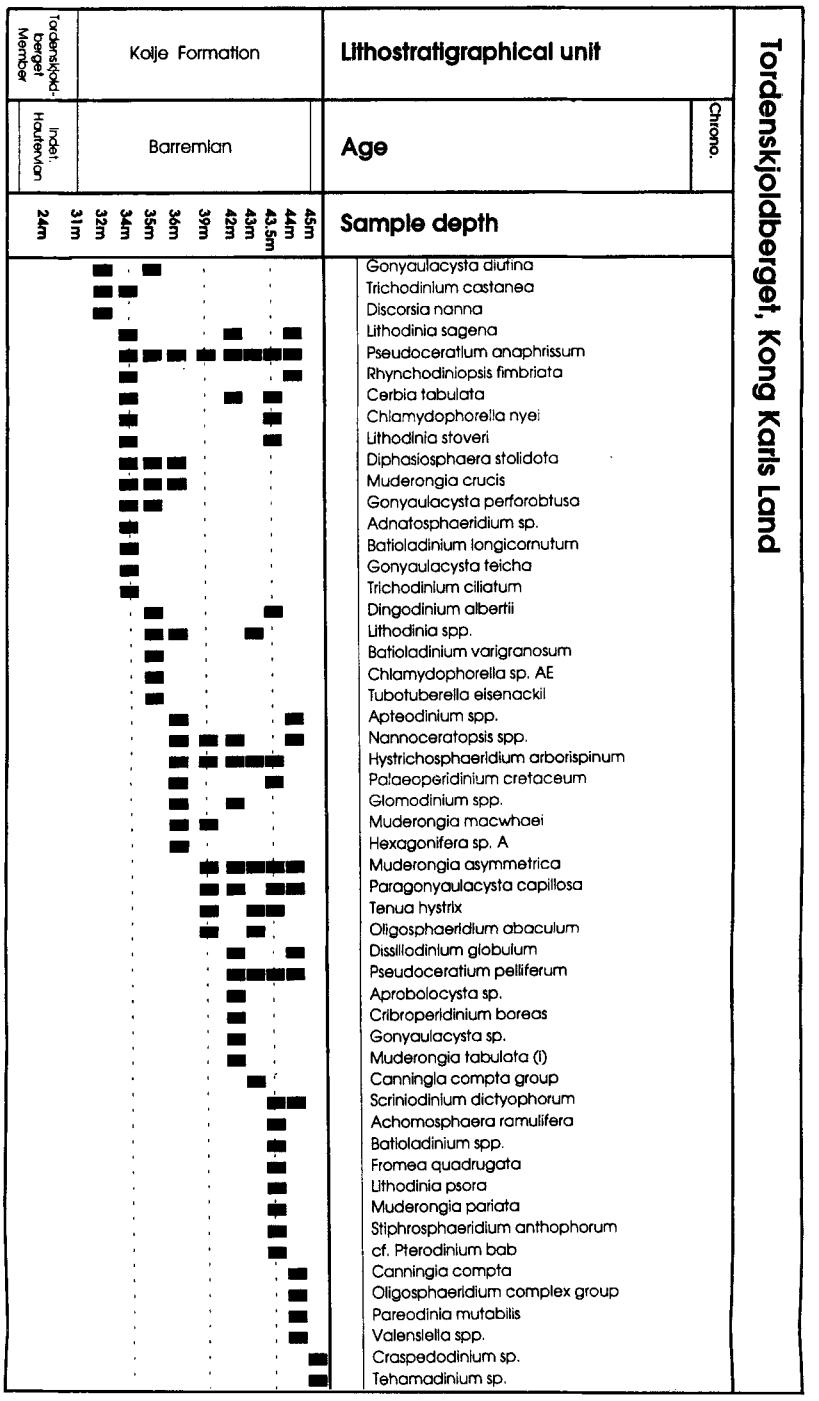


Fig. 12. Distribution chart of dinoflagellate cysts from the Tordenskjoldberget section, Kongsøya, Kong Karls Land.

overlapping ranges in a short interval in mid rudefissicostatum ammonite zone. The incoming of *Palaeoperidinium cretaceum* in sample S-12/36 supports an age not older than the mid rudefissicostatum zone at this level. The presence of *Fromea quadrugata* and *Muderongia pariata* in sample S-12/43.5 is taken as evidence for a Late Barremian (or possibly earliest Aptian) age also for the uppermost part of the Kolje Formation.

Discussion

The present palynological data suggest a Late Hauterivian age for the youngest deposits of the present Tordenskjoldberget Member (Klippfisk Formation) and support the previous age determinations based on bivalves, belemnites (Doyle & Kelly 1988) and nannoplankton (Verdenius 1978). The dinoflagellate cyst assemblages recovered from the overlying shales herein assigned to the Kolje Formation provide good evidence for a Barremian age. There are no firm biostratigraphic evidences for a major unconformity at the boundary between the Klippfisk Formation and the Kolje Formation on Kong Karls Land. Elsewhere on the Barents Shelf (including the locations of the coreholes 7425/09-U-01 and 7430/10-U-01), youngest Hauterivian deposits (gottschei-marginatus ammonite zones) seem to be missing, suggesting a withdrawal of the sea from these highs during the latest Hauterivian and/or earliest Barremian. Non-condensed carbonate deposition resumed in the earliest Barremian; shortly afterwards there was a major facies change from marls of the Klippfisk Formation to siltstone deposition of the overlying Kolje Formation. This facies change, which is marked by coarse sand in core 7425/09-U-01, represents an Early Barremian regional sequence boundary.

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