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Ammonites and dinoflagellate cysts in the Upper Oxfordian and Kimmeridgian of the northeastern Norwegian Sea (Nordland VII offshore area): biostratigraphical and biogeographical significance

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With 5 figures

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Abstract: Ammonites and dinoflagellate cysts recovered from Upper Oxfordian and Kimmeridgian deposits in a core 6814/04-U-01 from offshore northern Nordland, Norway, allow a detailed biostratigraphic subdivision of the studied sequence. The numerous ammonites of the families Cardioceratidae and Aulacostephanidae found in the Kimmeridgian strata show both Boreal and Subboreal affinities and allow a correlation with the standard Boreal and Subboreal biostratigraphic zonations. The Kimmeridgian ammonite fauna from offshore northern Nordland shows an intermediate character between the Subboreal fauna of Northwest Europe and the Boreal fauna of the southern Barents Shelf and Svalbard. The dinoflagellate cyst assemblages are typically of low diversity and are related to the Upper Jurassic Boreal/Arctic *Paragonyaulacysta borealis* assemblage. They apparently seem to show the same type of provincialism within the "Kimmeridge Clay Sea" as the ammonites.

Zusammenfassung: Ammoniten und Dinoflagellatenzysten aus Ablagerungen des Oberen Oxford und des Kimmeridge in dem vor der Küste des nördlichen Teils der Provinz Nordland (Explorationsgebiet Nordland VII), Norwegen, genommenen Bohrkern 6814/04-U-01 erlauben eine detaillierte Unterteilung der untersuchten Schichtenfolge. Die zahlreichen Ammoniten der Familien Cardioceratidae und

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Aulacostephanidae, die in den Kimmeridge-Schichten gefunden wurden, zeigen Ähnlichkeiten sowohl mit borealen als auch subborealen Formen und erlauben eine Korrelation mit den biostratigraphischen Standard-Zonierungen für das Boreal und Subboreal. Die Ammonitenfaunen des Kimmeridge aus dem Schelfbereich des nördlichen Nordlands haben einen intermediären Charakter zwischen der subborealen Fauna Nordwesteuropas und der borealen Fauna des südlichen Barents-Schelfs und Svalbards. Die Dinoflagellatenzysten-Vergesellschaftungen haben typischerweise eine geringe Diversität und zeigen Beziehungen zur oberjurassischen boreal/arktischen *Paragonyaulacysta borealis* Vergesellschaftung. Sie scheinen den gleichen Typ von Provenzialismus innerhalb der "Kimmeridge-Clay-See" zu zeigen wie die Ammoniten.

Introduction

Although there has been a rapid increase in the number of detailed paleontological studies of the Upper Jurassic of the Boreal and Subboreal provinces during the past 2-3 decades, there still exists a number of major gaps in our knowledge. The ammonite records, mainly from the British Isles, East and North Greenland, Svalbard and the Barents Shelf, have given fair indications of the faunas inhabiting the "Kimmeridgian Clay Sea" (MILLER 1990), but there are still major "black spot areas" with nearly no data. These areas will most likely hold some of the missing key information on the biostratigraphic relationship and potential correlation of the today established Boreal and Subboreal biostratigraphic zonations. The present study area in the northeastern Norwegian Sea, just off the coast of northern Nordland in Northern Norway, represents such a key area (Fig. 1). In Late Oxfordian and Kimmeridgian times this area was located between the now well documented ammonite Subboreal Province in Britain and the North Sea area and the Boreal Province of the present Barents Shelf (including Svalbard)/Arctic Ocean. The main objective of the present paper has consequently been to document the ammonite succession recovered from Upper Oxfordian and Kimmeridigian strata from this "virgin area", and to provide new information that will give improved correlation between the previously established Subboreal and Boreal ammonite zonations.

In addition to the ammonite succession we have also studied the marine microfloras in core 6814/04-U-01. As a result of petroleum exploration in offshore England, Denmark and Norway, dinoflagellate cysts are now established as a key tool for biostratigraphic subdivision and correlation of exploration wells in the North Sea, Norwegian Sea and Barents Sea. A well documented correlation between the Upper Jurassic ammonite zones and the

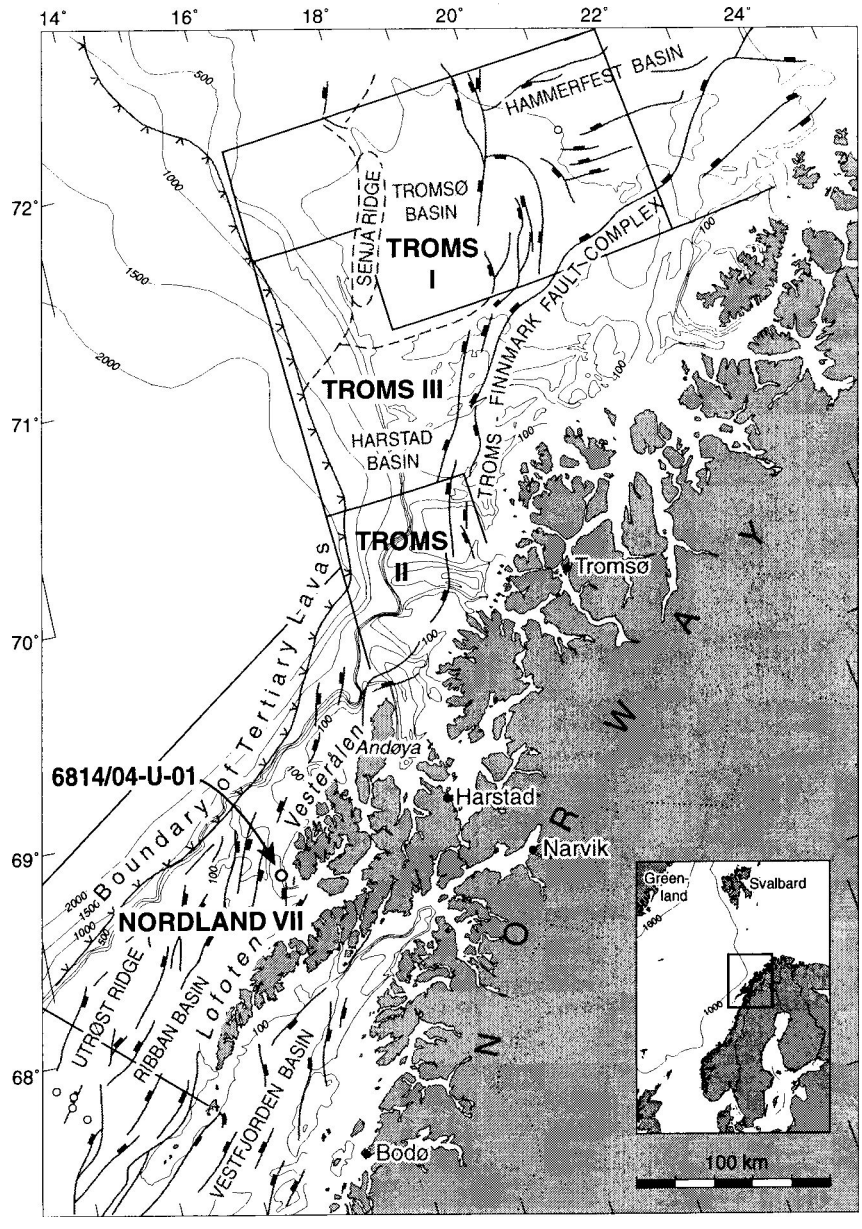


Fig. 1. Location map for Borehole 6814/04-U-01 off northern Nordland, Norway (offshore Nordland VII area, northeastern Norwegian Sea).

dinoflagellate cyst biostratigraphy allows a more secure age-determination of the strata drilled by exploration wells. Previous studies have shown that the Upper Jurassic dinoflagellate cyst assemblages from the Barents Shelf and Svalbard (WIERZBOWSKI & ÅRHUS 1990, SMELROR et al. 1998) differ significantly from those found in the Subboreal areas, and that the dinoflagellate cyst zonations defined for Britain and the North Sea (RIDING & THOMAS 1992) cannot be applied directly to the contemporaneous succession in the Boreal Province. In this respect, the present paper focused on providing new information from an "under-explored" geographic area, and a discussion of the observed differences in the characters of the Upper Oxfordian-Kimmeridgian Boreal and Subboreal dinoflagellate cyst assemblages.

Lithology and lithostratigraphy of the Upper Oxfordian - Kimmeridgian strata of core 6814/04-U-01

Borehole 6814/04-U-01 was drilled in the northernmost part of the Ribban Basin, just south of the coast of Vesterålen (Fig. 1), where Cretaceous and Jurassic strata subcrop on the seafloor. The borehole was drilled to 191.25 m below the seafloor, and by continues coring more than 180 m of Kimmeridgian to Upper Bathonian sediments were recovered (SMELROR et al. 2001). A lithological log of the upper part of core 6814/04-U-01 is shown in Fig. 2. The Upper Oxfordian and Kimmeridgian in this core are assigned to the Hekkingen Formation. As described by SMELROR et al. (2001) the studied core section can be subdivided lithostratigraphically into two members, a lower Rauåte Member and an overlying Alge Member. The Rauåte Member represents a proximal facies development of the Hekkingen Formation and the studied core-interval in 6814/04-U-01 is designated as the type section of this member.

In core 6814/04-U-01 the basal boundary of the Hekkingen Formation is sharp and marked by an unconformity where Upper Oxfordian dark grey siltstones of the Rauåte Member overlie ?Middle Callovian sandstones of the Måsnykan Formation (Fig. 2). The Rauåte Member is 19.4 m thick in this type section, and consists of dark grey, calcareous and micaceous muddy siltstone, which becomes increasingly muddy upwards. The upper boundary of the Rauåte Member is marked by a change to dark grey, finely laminated, pyritic and slightly calcareous, claystones of the Alge Member. On the gamma log this boundary is marked by a change to higher gamma readings. In 6814/04-U-01, only 9.8 m of the Alge Member were recovered, but a composite thickness of 50 m, is reported for the latter member in the Troms III area to the north (SMELROR et al. 2001).

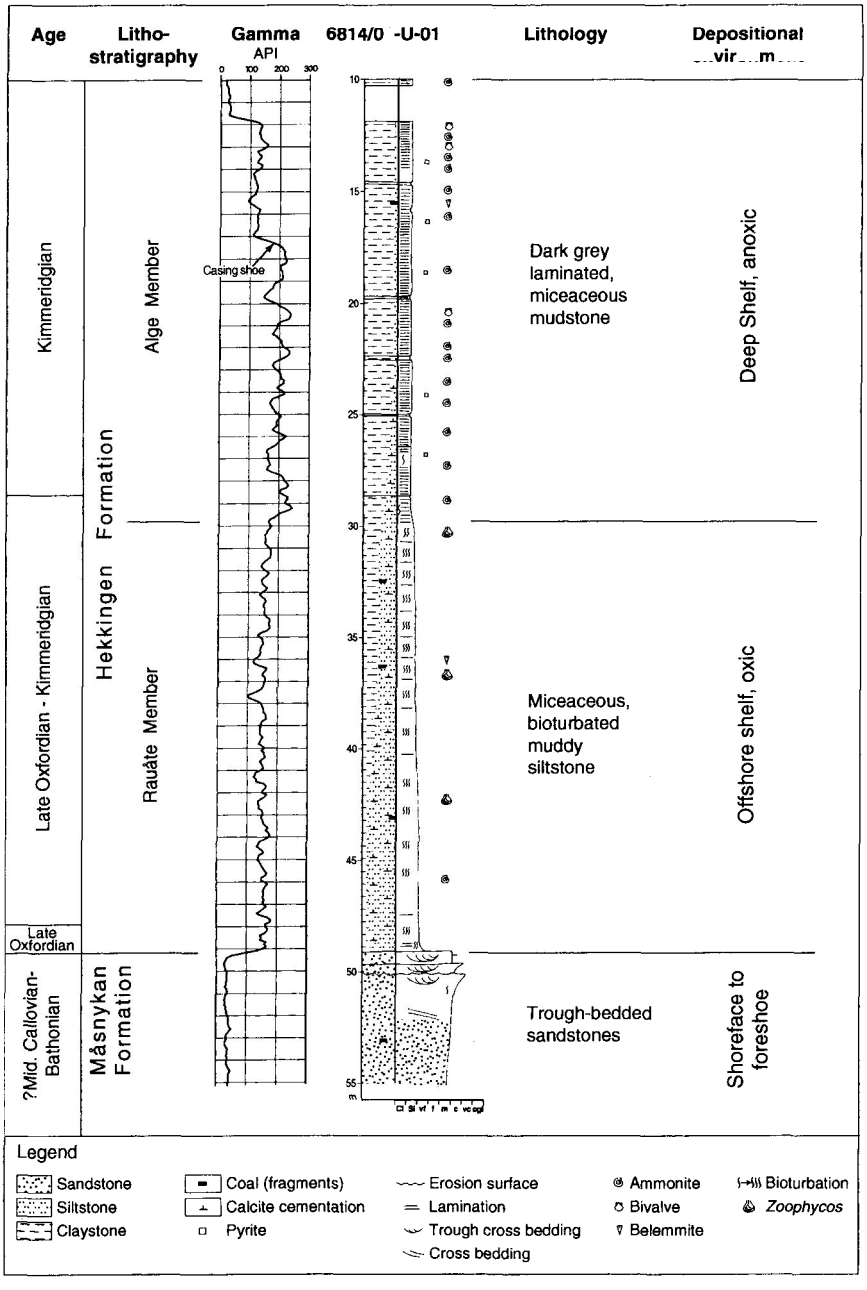


Fig. 2. Lithological log and stratigraphic interpretation of core 6814/04-U-01.

The Rauåte Member is interpreted as a deposit of well oxygenated shelf environment, below wave base. The overlying Alge Member is typically more organic-rich and its depositional environment as being anoxic to dysoxic. SMELROR et al. (2001) explained the deposition of the Alge Member in the Nordland VII and Troms III areas by applying the "expanding puddle" model of WIGNALL & HALLAM (1991), modified to account for relatively high sedimentation rates and for a possible wedge of brackish water during periods of deposition.

Late Oxfordian and Kimmeridgian ammonites in the core

The Upper Oxfordian and Kimmeridgian deposits of core 6814/04-U-01 yielded numerous ammonites which are heavily flatted, badly crushed and often only fragmentary (Fig. 3). Most of them were, however, identifiable, at least at generic level. Most of the identified ammonites (45 specimens) are of the genus *Amoeboceras* (family Cardioceratidae). Less common are representatives of the family Aulacostephanidae (13 specimens). The distribution of recognised taxa (genera, subgenera, species) in the core is shown in Fig. 4. Only brief descriptions, and some comments dealing with the better preserved specimens are presented here.

Genus *Amoeboceras*

Detailed identification of the specimens was often possible and resulted in the recognition of a fairly complete succession of the ammonite genus *Amoeboceras*. The systematic positions of all species recognised here (i.e. the latest Oxfordian - Kimmeridgian species) have been discussed in papers by MESEZHENIKOV & ROMM (1973), SYKES & CALLOMON (1979), CALLOMON (1985), BIRKELUND & CALLOMON (1985), MESEZHNIKOV et al. 1989), WIERZBOWSKI (1989), and WIERZBOWSKI & SMELROR (1993).

The oldest specimen in the Hekkingen Formation was recovered at 47.88 m i.e. within the Rauåte Member). It is small, attaining 23 mm in diameter. The inner whorls, up to about 10-12 mm, are smooth. The ribs on the outer whorl are fairly strong consisting of somewhat flexuous primaries, and short curved secondaries. They are accentuated at the umbilicus, at the furcation point located high on the whorl side, and at the ventrolateral margin. This specimen (Fig. 3a) shows several features of the *A. serratum* group (cf. SYKES & CALLOMON 1979), such as smooth inner whorls and character of the ribbing, und it may be referred to as *Amoeboceras* cf. *serratum* (SOWERBY).

Three poorly preserved specimens found between 28.60 m and 28.25 m i.e. within the Alge Member) are from 18 mm to 25 mm in diameter, and show a backward curve of the ribs close to the furcation point located high on the whorl side. These are typical features of the *Amoeboceras* (*Plasmatites*) *bauhini* group cf. SYKES & CALLOMON 1979, BIRKELUND & CALLOMON 1985). Two of the specimens, from 28.60 m, and 28.50 m are densely ribbed on their outer whorl (Fig. 3b) and may be referred to as *Amoeboceras* (*Plasmatites*) cf. *lineatum* (QUENSTEDT). A single specimen (Fig. 3c) from 28.25 m shows more widely spaced ribbing consisting of markedly prorsiradiate primaries divided from rursiradiate secondaries by a smooth spiral band; it is identified as *Amoeboceras* (*Plasmatites*) *bauhini* (OPPEL).

A single specimen found at 27.95 m represents half of an outer whorl, about 20 mm in height. The ribbing is coarse, consisting of fairly long primaries separated from short ventrolateral nodes. The latter are spaced independently of the primary ribs. These morphologic features suggest affinity of the specimen with early members of the subgenus *Amoebites*, such as *Amoeboceras* (*Amoebites*) *bayi* BIRKELUND & CALLOMON, or *A.* (*A.*) *subkitchini* SPATH but, due to its fragmentary nature, unequivocal identification is difficult.

About 10 specimens of various sizes found in the core between 24.70 m and 22.55 m are assigned to the species *Amoeboceras* (*Amoebites*) *subkitchini* SPATH - *A.* (*A.*) cf. *subkitchini* SPATH. Larger specimens, attaining about 70 mm in diameter when complete (Figs. 3e, f), but mostly preserved as fragments (Fig. 3d), show strong ribbing on the outer whorl with long primaries and well developed ventrolateral nodes. The nodes are separated from the primary ribs, and at larger diameters spaced independently of them. A few smaller specimens, about 20 mm in diameter, are found at 23.56 m in the core. They show fine, simple and bifurcate ribs being similar to specimens recognised as immature specimens, and/or microconchs of *A. subkitchini* (see BIRKELUND & CALLOMON 1985, WIERZBOWSKI 1989).

Two fairly small specimens (Figs. 3g, h) found at 17.04 m and 15.07 m show rather loosely spaced ribs on the inner whorls (about 34 primary ribs at 20 mm diameter in most complete specimen). The ribbing becomes coarse on the outer whorl with heavy nodes already developed at about 25-30 mm diameter. The small size of the specimens, their coarse ribbing, and narrow umbilicus (equalling about 31-34 % of the diameter) are typical of *Amoeboceras* (*Amoebites*) *kitchini* (SALFELD). The identification of these specimens, is additionally supported by the occurrence (at 15.35 m) of small specimens showing fairly numerous secondary ribs which is a typical feature of the last *Amoebites*, including *A. kitchini* and related forms (BIRKELUND & CALLOMON 1985, WIERZBOWSKI & SMELROR 1993).

A single, poorly preserved specimen, about 35 mm in diameter, from 13.93 m shows rests of fairly strong, sparse primary ribs, and ventrolateral nodes, at the end of the outer whorl. The specimen may be tentatively referred to the *Amoeboceras* (*Amoebites*) *kitchini* group.

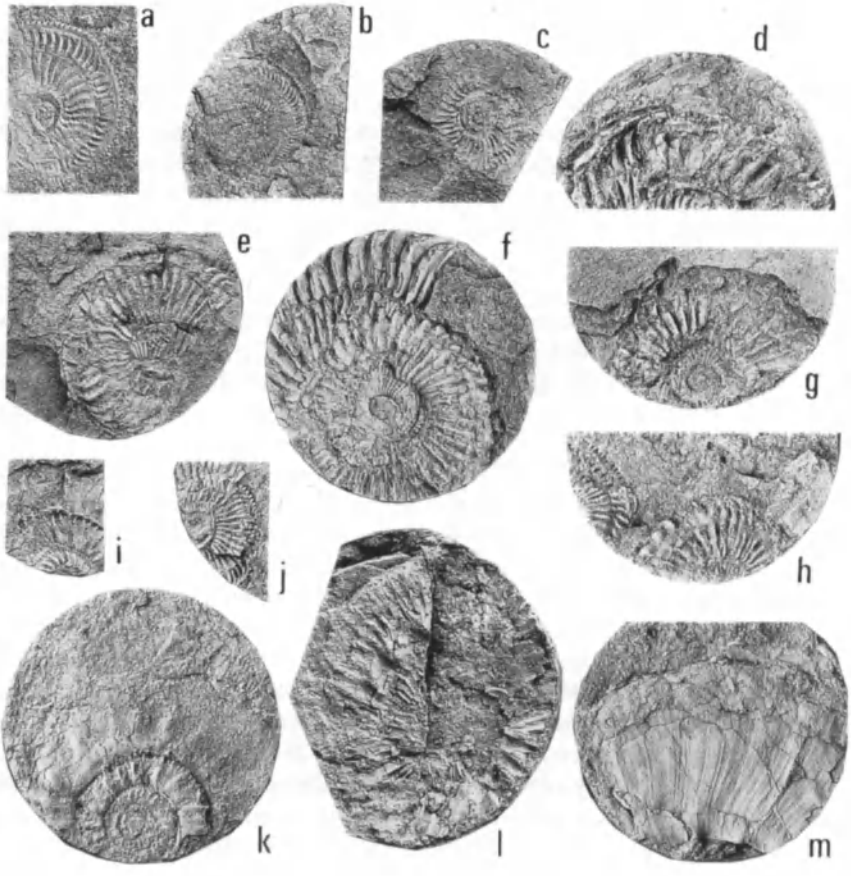
Several small, attaining only a few centimetres in diameter, poorly preserved specimens were found at 12.32 m and 12.20 m in the core. All of them show very weakly ornamented inner whorls up to about 8 - 10 mm in diameter, and more strongly ornamented outer whorls. The ornamentation of the outer whorls consists of prorsiradiate ribs markedly projected towards the venter. The ribs are single and biplicate with weakly developed elongated ventrolateral tubercles (Fig, 3j). The specimens may be attributed to the subgenus *Euprionoceras*, possibly to the species *Amoeboceras* (*Eyprionoceras*) *norvegicum* WIERZBOWSKI, as shown by their weakly ornamented inner whorls (WIERZBOWSKI & SMELROR 1993).

Family Aulacostephanidae

Due to their large size, the ammonites of the family Aulacostephanidae are more difficult for unequivocal identification in the core than the generally smaller-sized ammonites of the genus *Amoeboceras*. Nevertheless, the identification of the aulacostephanids at the genus level, and in a few cases at species level, is possible. The systematic position of the recognised ammonites of the family Aulacostephanidae has been discussed by BIRKELUND, THUSU & VIGRAN (1978), BIRKELUND et al. (1983), and BIRKELUND & CALLOMON (1985).

The oldest, but poorly preserved specimens in the core from 28.50 m and 27.77 m in the Alge Member possibly belong to the genus *Pictonia*. Younger specimens showing bullate primary ribs are found at 23.56 m, 20.72 m,

Fig. 3. Ammonites from core 6814/04-U-01
(all specimens of approximately 90 % of natural size).
a. *Amoeboceras* cf. *serratum* (SOWERBY), 47.88 m.
b. *Amoeboceras* (*Plasmatites*) cf. *lineatum* (QUENSTEDT), 28.60 m.
c. *Amoeboceras* (*Plasmatites*) *bauhini* (OPPEL), 28.25 m.
d. *Amoeboceras* (*Amoebites*) cf. *subkitchini* SPATH, 24.70 m.
e. *Amoeboceras* (*Amoebites*) *subkitchini* SPATH, 24.35 m.
f. *Amoeboceras* (*Amoebites*) *subkitchini* SPATH, 24.37 m.



g. *Amoeboceras* (*Amoebites*) *kitchini* (SALFELD), 17.04 m.
h. *Amoeboceras* (*Amoebites*) *kitchini* (SALFELD), 15.07 m.
i. *Rasenia* sp., 23.56 m.
j. *Amoeboceras* (*Euprionoceras*) cf. *norvegicum* WIERZBOWSKI, 12.20 m.
k. *Aulacostephanoides* cf. *mutabilis* (SOWERBY), 15.04 m.
l. *Aulacostephanus eudoxus* (D'ORBIGNY), 10.26 m.
m. *Rasenioides* sp. close to *R. discoides* HANTZPERGUE,
or *Aulacostephanoides* sp. close to *A. linealis* (QUENSTEDT), 15.35 m.

18.77 m, and 16.30 m. These may be classified as *Rasenia* spp.. Due to their fragmentary preservation, no unequivocal assignment of these specimens to particular *Rasenia* species is possible, but the specimen from 23.56 m (Fig. 3i) shows more evolute coiling and raseniid ribbing appearing at a small diameter, and thus seems similar to *Rasenia evoluta* SPATH (see BIRKELUND, THUSU & VIGRAN 1978, BIRKELUND & CALLOMON 1985).

A single specimen from 15.35 m (Fig. 3 m) represents part of an outer whorl of a large, involute form. The ornamentation is very fine consisting of densely spaced thin, feeble ribs which become wider and more distinct at the venter. The character of the venter is unknown. The specimen is either a fragment of a late macroconch representative of the genus *Rasenioides* (see HANTZPERGUE 1989), such as *Rasenioides discoidus* HANTZPERGUE, or a fragment of an early fine-ribbed macroconch of the genus *Aulacostephanoides* (see ZIEGLER 1962), such as *Aulacosphinctoides linealis* (QUENSTEDT).

A younger specimen (Fig. 3k) coming from 15.04 m shows heavily ornamented inner whorls with short, swollen, and distant primary ribs (about 10 per half a whorl at about 40 mm diameter). On the outer whorl, at about 75 mm diameter, the primary ribs disappear; at the same diameter, the preserved outer part of the whorl reveals, numerous densely spaced secondary ribs. The coiling is between involute and evolute. These features indicate affinities with more-heavy ribbed forms of the genus *Aulacostephanoides* (see ZIEGLER 1962, BIRKELUND et al. 1983), and the specimen is identified as *Aulacostephanoides* cf. *mutabilis* (SOWERBY).

The youngest specimen in the core is from 10.26 m and is heavily crushed. Nevertheless, it is fairly complete, and has ribbing preserved (Fig. 3l). Its maximum diameter is about 60 mm. A smooth fragment of shell preserved at this diameter may be part of the final aperture. Although no detailed measurements are possible, the coiling of the outer whorl is markedly evolute. The ribbing consists of very strong, somewhat elongated primaries (about 18-20 on the last whorl), and strong, coarse secondaries. There are about three of secondary ribs to one primary rib. The specimen is identified as *Aulacostephanus eudoxus* (D'ORBIGNY).

Ammonite biostratigraphy, correlations and biogeograhy

The Hekkingen Formation of core 6814/04-U-01 yielded only rare ammonites in the Upper Oxfordian Rauåte Member, but numerous ammonites in the Kimmeridgian Alge Member. The latter record makes the Kimmeridgian succession from the core the most completely known succession of this age in the north-eastern and eastern Norwegian Sea. The few isolated ammonite occurrences previously reported from the Upper Oxfordian and Kimme-

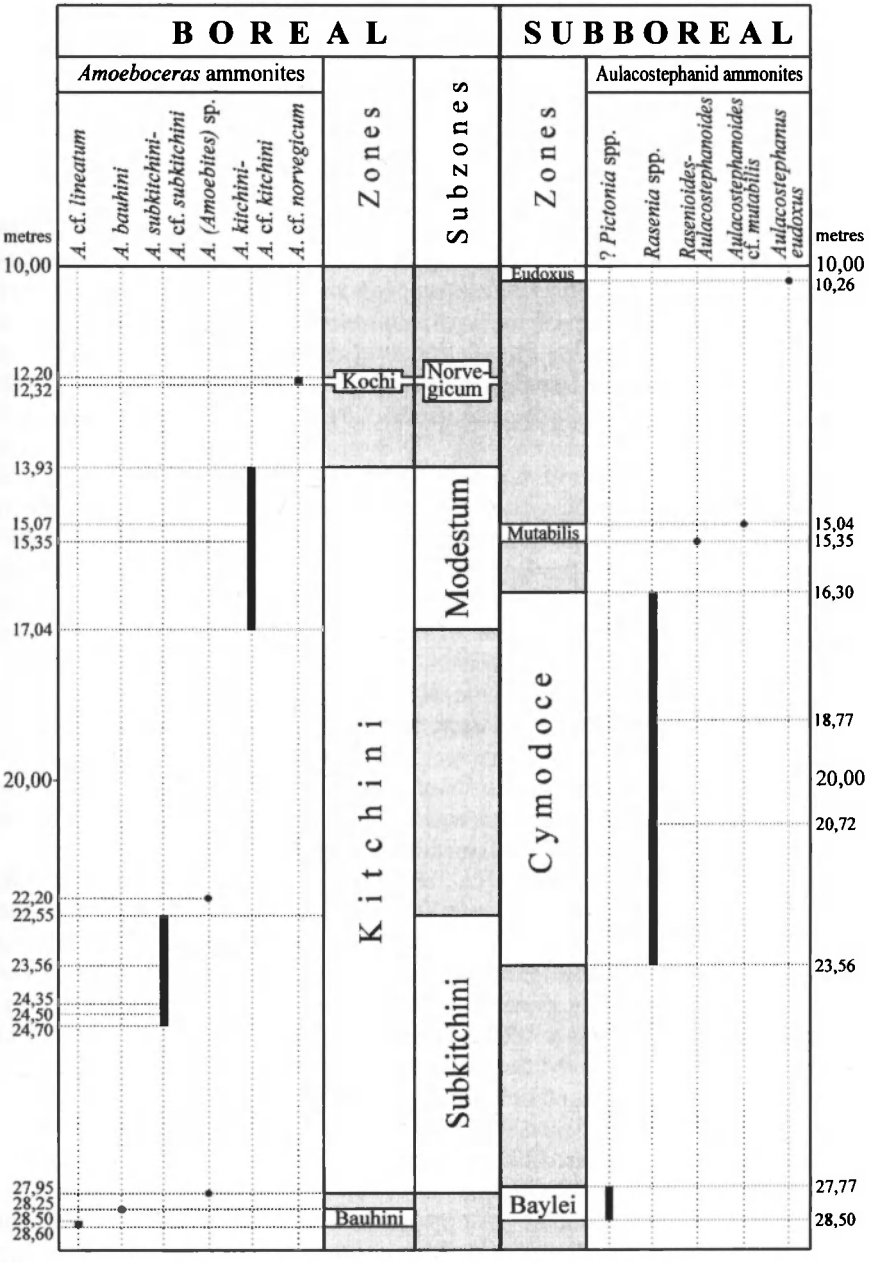


Fig. 4. Distribution of ammonites in the Kimmeridgian in the upper part of core 6814/04-U-01 and their stratigraphical interpretation in terms of the Boreal and the Subboreal zonations.

ridgian of the Norwegian Sea area were too scanty to establish a full ammonite succession for this stratigraphic interval. These earlier data include some core specimens (ÅRHUS, BIRKELUND & SMELROR 1989, SHULGINA & BURDYKINA 1992) as well as outcrop material from Andøya, northern Nordland (BIRKELUND, THUSU & VIGRAN 1978). They are discussed below in relation to the ammonite faunas recorded from 6814/04-U-01 (see Fig. 4).

The ammonite faunas in the Hekkingen Formation of core 6814/04-U-01 belong to the families Cardioceratidae and Aulacostephanidae. The ammonites of the family Cardioceratidae (represented by the genus *Amoeboceras*) predominate constituting 77.6 % of all specimens. This is the group of ammonites on which the Boreal zonation of the Upper Oxfordian and Kimmeridgian has been based (SYKES & CALLOMON 1979, WIERZBOWSKI & SMELROR 1993). On the other hand, the historically important Subboreal ammonite zonal scheme for the Upper Oxfordian and Kimmeridgian is based on successive members of the family Aulacostephanidae (see BIRKELUND et al. 1983, and earlier papers cited therein). Thus, particular attention should be paid to the fact that the Kimmeridgian ammonites in 6814/04-U-01 enable the recognition of both the Boreal and Subboreal ammonite zonations and allow close correlation between the two zonations. This is because of the special biogeographical position of the present north-eastern Norwegian Sea 6814/04-U-01 core site during the Late Oxfordian and Kimmeridgian. Similar to central East Greenland (cf. BIRKELUND & CALLOMON 1985), the offshore northern Nordland area occupied at that time an intermediate position between north-west Europe (e.g. England) which was the home-area of the Subboreal ammonite faunas, and the western Barents Sea (e.g. Spitsbergen) which by that time belonged to the narrowly defined Boreal Province characterised by the occurrence of Boreal ammonites.

The ammonite *Amoeboceras* cf. *serratum* (SOWERBY) found at 47.88 m, the oldest in core 6814/04-U-01, is indicative of the Serratum Zone of the Boreal Upper Oxfordian cf. SYKES & CALLOMON 1979). The overlying deposits are barren of ammonites up to 28.60 m, where the first *Plasmatites* diagnostic of the Bauhini Zone of the lowermost Kimmeridgian appears (cf. WIERZBOWSKI & SMELROR 1993). The Bauhini Zone extends up to 28.25 m and it is characterized by the occurrence of *Amoeboceras* (*Plasmatites*) *bauhini* (OPPEL) and *A.* (*P.*) cf. *lineatum* (QUENSTEDT). Hence, the barren interval in the core between 47.88 m and 28.60 m belongs mostly to the Upper Oxfordian, and possibly includes the Regulare Zone and the Rosenkrantzi Zone (cf. SYKES & CALLOMON 1979).

The Rosenkrantzi Zone of the uppermost Oxfordian, and the subsequent Bauhini Zone of the lowermost Kimmeridgian, were recognised in an approximately 3.7 m thick interval of a shallow core drilled on the Trøndelag

Platform in the eastern part of the Norwegian Sea. The former zone is characterised by the occurrence of "*Amoeboceras* sp. cf. or aff. *rosenkrantzi* SPATH", the latter by "*Amoeboceras* sp. cf. or aff. *bauhini* (OPPEL)" as indicated by ÅRHUS, BIRKELUND & SMELROR (1989, fig. 3d-i). The Upper Oxfordian ammonites of the genus *Amoeboceras* referred to as "*Amoeboceras* ex gr. *alternans* BUCH" and "? *Prionodoceras* sp. indet" were also reported from the shallow cores 7018/05-U-01 and 7018/05-U-02 drilled in the Troms III area somewhat northwest of borehole 6814/04-U-01 (SHULGINA & BURDYKINA 1992). Unfortunately, the specimens from the Troms III cores have not been figured and this precludes any closer comparison and more detailed stratigraphic interpretation.

The presence of the Kitchini Zone is firmly proved in the studied core 6814/04-U-01. The base of this zone is placed at 27.95 m, where the first representative of the subgenus *Amoebites*, referred to as *Amoeboceras* (*Amoebites*) ex gr. *bayi-subkitchini*, has been found. The top of this zone is identified by the last appearance of *A.* (*Amoebites*) ex gr. *kitchini* at 13.93 m (Fig. 4).

The Kitchini Zone is characterised by the occurrence of typical *Amoebites* species (see WIERZBOWSKI & SMELROR 1993), from *Amoeboceras* (*Amoebites*) *bayi* BIRKELUND & CALLOMON and *A.* (*A.*) *subkitchini* SPATH in the lower part of the zone, to an assemblage of closely allied species grouped around weakly noded *Amoeboceras* (*Amoebites*) *modestum* MESEZHNIKOV & ROMM, and more heavily noded *A.* (*A.*) *kitchini* (SALFELD) - in the upper part of the zone. This differentiation of the ammonite faunas within the Kitchini Zone enabled WIERZBOWSKI & SMELROR (1993) to subdivide the zone informally into two ammonites horizons: the subkitchini horizon below, and the modestum horizon above. The two ammonite faunas in the Kitchini Zone of core 6814/04-U-01 occur at the same stratigraphic level as those previously described from the Barents Sea, East Greenland and Siberia (cf. BIRKELUND & CALLOMON 1985, WIERZBOWSKI & SMELROR 1993), and suggests that the two previously distinguished horizons should be elevated to subzones: the Subkitchini Subzone and the Modestum Subzone (Fig. 4). The Subkitchini Zone, as characterised by the occurrence of *Amoeboceras* ex gr. *bayi-subkitchini* and *A. subkitchini* - *A.* cf. *subkitchini*, extends from 27.95 m to 22.55 m in core 6814/04-U-01. The Modestum Subzone, as characterised by the occurrence of *A. kitchini* - *A.* ex gr. *kitchini*, extends from 17.04 m to 13.93 m in core 6814/04-U-01.

The presence of the Kitchini Zone in the offshore Troms III area (core 7018/05-U-01) may be inferred from the occurrence of the cited, but not figured, specimen "*Amoeboceras* ex gr. *kitchini*" (see SHULGINA & BURDYKINA 1992).

The youngest *Amoeboceras* fauna in core 6814/04-U-01 occurs between 12.32 m and 12.20 m and comprises *A.* (*Euprionoceras*) cf. *norvegicum* WIERZBOWSKI. This indicates the lower part of the Kochi Zone. This part of the zone, which is characterised by the occurrence of the oldest representatives of the subgenus *Euprionoceras* with weakly ornamentod inner whorls, was originally denoted as the norvegicum horizon (WIERZBOWSKI & SMELROR 1993). It is now distinguished as the Norvegicum Subzone (Fig. 4).

The faunas of the family Aulacostephanidae from core 6814/04-U-01 make it possible to recognise most of the Kimmeridgian zones of the Subboreal zonation (Fig. 4). The oldest fauna with ?*Pictonia* spp., occurring between 28.50 m and 27.77 m, possibly indicates the Baylei Zone. A still younger fauna consisting of *Rasenia* spp. found between 23.56 m and 16.30 m, is indicative of the Cymodoce Zone, although no detailed subdivision of this zone into horizons (cf. BIRKELUND, THUSU & VIGRAN 1978, BIRKELUND et al. 1983) is possible here. The ammonite referred to as late *Rasenioides* or early *Aulacostephanoides* from 15.35 m, is possibly related to *R. discoidus* HANTZPERGUE or *A. linealis* (QUENSTEDT). This indicates the lowermost part of the Mutabilis Zone, whereas the specimen from 15.04 m interpreted as *Aulacostephanoides* cf. *mutabilis* (SOWERBY) is diagnostic for a somewhat younger part of this zone (cf. BIRKELUND et al. 1983). The ammonite *Aulacostephanus eudoxus* (D'ORBIGNY) found at 10.26 m is indicative of the Eudoxus Zone (cf. ZIEGLER 1962).

The correlation between the Kimmeridgian Boreal and Subboreal zonations based on the ammonite succession in core 6814/04-U-01 (Fig. 4) generally confirms the previously presented correlation based on central East Greenland (BIRKELUND & CALLOMON 1985), and the southern Barents Sea and Spitsbergen (WIERZBOWSKI 1989, WIERZBOWSKI & SMELROR 1993). The Boreal Bauhini Zone corresponds to the lower part of the Subboreal Baylei Zone. The Boreal Kitchini Zone corresponds to the upper part of the Baylei Zone, the whole of the Cymodoce Zone, and at least some part of the Mutabilis Zone of the Subboreal zonation. The boundary between the Subkitchini Subzone and the Modestum Subzone of the Boreal Kitchini Zone lies within the upper part of the Subboreal Cymodoce Zone. This is confirmed by some older data from the Norwegian Sea area as shown by the occurrence of numerous specimens of *Rasenia evoluta* SALFELD together with *Amoeboceras* (*Amoebites*) of the *A. kitchini* group in the Andøya section in the Vesterålen Islands (BIRKELUND, THUSU & VIGRAN 1978), and the occurrences of *"Amoeboceras* ex gr. *kitchini* (SALFELD) and *Rasenia*? sp. juv." in borehole 7018/05-U-01 (SHULGINA & BURDYKINA 1992) offshore Troms.

Age	Depth m / Dinoflagellates	*Stephanelytron redcliffense*	*Escharisphaeridia psilata*	*Gonyaulacysta jurassica*	*Rhynchodiniopsis cladophora*	*Sentusidinium* spp.	*Sirmiodinium grossii*	*Cribrodinium granuligerum*	*Ellipsoidictyum/Valensiella* spp.	*Atopodinium haromense*	*Escharisphaeridia* spp.	*Paragonyaulacysta borealis*	*Pareodinia ceratophora*	*Cribroperidinium globatum*	*Scriniodinium* spp.	*Systematophora areolata*	*Scriniodinium* spp.	*Cribroperidinium longicorne*	*Leptodinium mirioudi*	Lithostratigraphic unit	
Kimmeridgian	10.52		x	x	x	x	x							x						Alge Mb.	Hekkingen Formation
	13.26		x		x	x	x														
	14.55			x			x					x				x	x				
	16.60		x			x	x							x	x						
	19.80		x	x	x	x	x			x	x	x									
	23.37			x								x	x					x	x		
	25.44		x	x	x		x		x			x	x								
	27.34										x			x		x					
Late Oxfordian	32.25			x	x	x	x		x	x					x					Rauåte Mb.	
	35.21		x		x	x					x										
	41.11		x					x			x			x	x						
	43.70		x		x	x			x	x		x	x	x							
	46.75		x	x		x			x	x	x	x									
	48.88	x	x	x		x	x	x	x	x	x										
	49.00	x	x	x	x	x	x														

Fig. 5. Distribution of dinoflagellate cysts in the upper part of core 6814/04-U-01.

The younger Kochi Zone of the Boreal zonation has a somewhat less precisely defined position within the Subboreal ammonite succession and is usually placed close to the Mutabilis and Eudoxus zonal boundary (BIRKELUND & CALLOMON 1985, WIERZBOWSKI & SMELROR 1993). The occurrence of ammonites indicative of the lower part of the Kochi Zone, i.e. the Norvegicum Subzone, sandwiched between ammonites diagnostic of the Mutabilis Zone, and those of the Eudoxus Zone in core 6814/04-U-01, makes the correlation clearer.

Dinoflagellate cyst biostratigraphy and biogeography

The dinoflagellate cyst assemblages recovered from the Hekkingen Formation in core 6814/04-U-01 (Fig. 5) show low abundance and are typically of low diversity. The low abundance of marine microplankton in the samples may partly be due to masking caused by the high (to very high) proportions

of amorphous organic matter in the palynological preparations, an effect commonly noted for the dark, organic rich, "Kimmeridgian Clay Sea" deposits (TYSON 1993). The low species diversity, however, appears to be typical of the high latitude/Arctic Oxfordian-Berriasian dinoflagellate cyst assemblages. Such low diversity assemblages were originally described as the *Pareodinia borealis* (now *Paragonyaulacysta borealis*) assemblage from Arctic Canada by BRIDEAUX & FISHER (1976). Comparable assemblages have later been documented from North Greenland (HÅKANSSON et al. 1981), Svalbard (BJAERKE 1980), the Barents Shelf (WIERZBOWSKI & ÅRHUS 1990, SMELROR et al. 1998), and Arctic Russia (ILYINA 1988).

Most of the species used to define the dinoflagellate cyst biozonal limits of the British Upper Jurassic (RIDING & THOMAS 1992) are missing or very rare on the Barents Shelf (including Svalbard) and on the north-western margin of the Norwegian Sea. This hampers the application of the zonations defined in the British and North Sea Subboreal Province to the present study area. Upper Jurassic dinoflagellate cyst assemblages described from East Greenland (PIASECKI 1980) and the Norwegian Sea area off Mid-Norway (VAN DER ZWAN 1990) appear to be intermediate between those from the Subboreal North Sea area (including Britain) and those found in the restricted Boreal areas (i.e. the *Paragonyaulacysta borealis* assemblage).

At present, there is no formal dinoflagellate cyst zonation established for the Upper Jurassic of the Barents Shelf or Norwegian Sea areas. This is partly due to the low species diversity in the deposits, and partly to the fact that most of the recovered species are long-ranging and not particularly useful for detailed biostratigraphic subdivision of the sedimentary sequences. Endemic Boreal species are few and are, as pointed out by WIERZBOWSKI & ÅRHUS (1990), scarce in most areas, or long-ranging.

The dinoflagellate cyst assemblages from the Upper Oxfordian-Kimmeridgian strata of core 6814/04-U-01 are also characterised by long-ranging species. There are, however, some restricted species occurrences which appear to be of some value for regional biostratigraphic correlations as discussed below.

The youngest occurrence of *Stephanelytron redcliffense* is noted at 48.80 m, i.e. just below (or within) beds correlated with the Serratum Zone in the core. In core 7227/08-U-03 from the Nordkapp Basin, WIERZBOWSKI & ÅRHUS (1990) also found the last occurrence datum of this species just below (or within) the Serratum Zone. In the Janusfjellet section on Spitsbergen this species has not been recorded above the Middle Oxfordian (ÅRHUS, unpublished data). In contrast this species is known to range up into the Lower Kimmeridgian in the Subboreal Province (RIDING & THOMAS 1992).

In the British Jurassic, RIDING & THOMAS (1992) found that the youngest occurrence of *Cteidodinium ornatum* coincides with the Oxfordian-

Kimmeridgian boundary. In core 6814/04-U-01 this species is only recorded from the ?Middle Callovian part of the underlying Måsnykan Formation. RIDING & THOMAS (1992) also found that the youngest occurrence of *Nannoceratopsis pellucida* coincides with the Baylei Zone in Subboreal British Jurassic. In the present 6814/04-U-01 core, *N. pellucida* is found up to 27.34 m. The ammonite recovery suggests a correlation with the Baylei Zone for the core interval between 28.25 m and 27.95 m, and thus supports the dinoflagellate cyst age determination at this level. In borehole 7227/08-U-03, WIERZBOWSKI & ÅRHUS (1990) also found the last occurrence of *Nannoceratopsis pellucida* to coincide with the Subboreal Baylei Zone.

The single occurrence of *Cribroperidinium longicorne* at 23.37 m may also be of some biostratigraphic value. This occurrence is close to the base of the Subboreal Cymodoce Zone as recognised in core 6814/04-U-01. This is in agreement with the oldest occurrence in the Cymodoce Zone recognised in the British Jurassic by RIDING & THOMAS (1992). In the Janusfjellet section on Central Spitsbergen, this species has it oldest occurrence in beds containing *Amoeboceras subkitchini* (M.S. pers. obs.). This first appearance datum in the Janusfjellet section coincides with the present record from core 6814/04-U-01.

The youngest occurrence of *Rhynchodiniopsis cladophora* is observed at 10.52 m, in beds correlated with the Eudoxus Zone. This is in agreement with the youngest occurrence of this species reported in core 7227/08-U-03 in the Nordkapp Basin (WIERZBOWSKI & ÅRHUS 1990).

The presence of *Gonyaulacysta jurassica* up to 10.52 m further supports an age not younger than Kimmeridgian for the youngest part of core 6814/04-U-01. In the Janusfjellet section, *G. jurassica* is not found above beds correlated with the Amoeboceras elegans Zone (ÅRHUS unpublished data), while in borehole 7227/08-U-03 this species is known to range into beds correlated to the Subboreal Autissiodorensis Zone (WIERZBOWSKI & ÅRHUS 1990). In the British Jurassic this species does not range above the overlying Pectinatites elegans Zone (RIDING & THOMAS 1992).

The most striking feature of the Upper Oxfordian-Kimmeridgian dinoflagellate cyst assemblages from core 6814/04-U-01 off northern Nordland is the rare occurrence of chorate dinoflagellate cysts compared with what is found in contemporaneous deposits of the Subboreal and Tethyan provinces. In core 6814/04-U-01, chorate cysts are represented by a few specimens of *Systematophora areolata*. In contrast, species of the genus *Systematophora*, together with other chorate forms of the genera *Adnatosphaeridium, Oligosphaeridium, Perisseiasphaeridium* and *Taeniophora* are often common in Britain and the North Sea area (NØHR-HANSEN 1986, RIDING & THOMAS 1988, POULSEN 1996). Representatives of these chorate taxa are also present

off Mid Norway (VAN DER ZWAN 1990) and in East Greenland (PIASECKI 1980), but are generally less frequent. In this respect, the dinoflagellate cyst assemblages from these latter areas seem to be intermediate between the Subboreal British and North Sea assemblages, and the *Paragonyaulacysta borealis* assemblage typically restricted to the Boreal/Arctic Province. The Upper Oxfordian and Kimmeridgian dinoflagellate cyst assemblages apparently show clear trends of provincialism within the "Kimmeridgian Clay Sea", and this provincialism generally seems to mirror the marine faunal provinces recognised by the ammonites. The rare chorate cysts in offshore Nordland VII area indicate a closer connection to the Boreal Province than to the Subboreal Province in the south.

References

ÅRHUS, N., BIRKELUND, T. & SMELROR, M. (1989): Biostratigraphy of some Callovian and Oxfordian cores off Vega, Helgeland, Norway. – Norsk Geol. Tidssk., **69**: 39-56.

BIRKELUND, T. & CALLOMON, J. H. (1985): The Kimmeridgian ammonite faunas of Milne Land, central East Greenland. – Grønlands Geol. Unders., Bull., **153**: 1-56.

BIRKELUND, T., CALLOMON, J. H., CLAUSEN, C. K., NØHR-HANSEN, H. & SALINAS, I. (1983): The Lower Kimmeridge Clay at Westbury, Wiltshire, England. – Proc. Geol. Assoc., **94** (4): 289-309.

BIRKELUND, T., THUSU, B. & VIGRAN, J. (1978): Jurassic-Cretaceous biostratigraphy of Norway with comments on the British Rasenia cymodoce Zone. – Palaeontology, **21** (1): 31-63.

BJAERKE, T. (1980): Mesozoic palynology of Svalbard V. Dinoflagellate cysts from the Agarhdfjellet Member (Middle and Upper Jurassic) in Spitsbergen. – Norsk Polarinst. Skr., **172**: 145-167.

BRIDEAUX, W. W. & FISHER, M. J. (1976): Upper Jurassic - Lower Cretaceous dinoflagellate assemblages from Arctic Canada. - Geol. Surv. Canada, Bull., **259**, 53 pp.

CALLOMON, J. H. (1985): The evolution of the Jurassic ammonite family Cardioceratidae. – Spec. Pap. Paleont., **33**: 49-90.

HANTZPERGUE, P. (1989): Les ammonites kimméridgiennes du haut-fond d'Europe occidentale: biochronologie, systématique, évolution, paléobiogeographie. – Cah. Paléont.; Centre Nat. Rech. Sci.: 428 pp.

HÅKANSSON, E. T., BIRKELUND, T., PIASECKI, S. & ZAKHAROV, V. (1981): Jurassic - Cretaceous boundary strata of the extreme Arctic (Peary Land, North Greenland). - Geol. Soc. Denmark, Bull., **30**: 11-42.

ILYINA, V. I. (1988): Microphytoplankton of the Jurassic-Cretaceous boundary deposits of Urduk-Chaya Cape (Paksa Peninsula). – In: KHLONOVA, A. F. (Ed.): Palynology in the USSR, 103-107. Novosibirsk: Nauka. [In Russian].

MESEZHNIKOV, M. S. & ROMM, G. M. (1973): K sistematike podroda *Amoebites* (Ammonoidea, Cardioceratidae). – Paleont. Zh., **3**: 35-46.

MESEZHNIKOV, M. S., KALACHEVA, E. D. & ROTKYTE, L. M. (1989): Zonal subdivision of the Middle and Upper Oxfordian of the Russian Platform; Description of Ammonoids. – In: MESEHNIKOVA, M. S. (Ed.): The Middle and Upper Oxfordian of the Russian Platform, p. 30-44 and 69-108. Leningrad: Nauka. [In Russian].

MILLER, R. G. (1990): A paleogeographic approach to the Kimmeridge Clay Formation. – In: HUC, A. Y. (Ed.): Deposition of organic facies, 13-26. AAPG Studies in Geology, **30**, Tulsa, U.S.A.

NØHR-HANSEN, H. (1986): Dinocyst stratigraphy of the Lower Kimmeridge Clay, Westbury, England. – Geol. Soc. Denmark, Bull., **35**: 31-51.

PIASECKI, S. (1980): Middle to Late Jurassic dinoflagellate cyst stratigraphy from Milne Land and Jameson Land (East Greenland) correlated with ammonite stratigraphy. – Unpubl. thesis, Univ. Copenhagen, 170 p.

POULSEN, N. E. (1996): Dinoflagellate cysts from marine Jurassic deposits of Denmark and Poland. – Amer. Assoc. Stratigr. Palynol. Contrib. Ser., **31**, 227 pp.

RIDING, J. B. & THOMAS, J. E. (1988): Dinoflagellate cyst stratigraphy of the Kimmeridge Clay (Upper Jurassic) from the Dorset Coast, southern England. – Palynology, **12**: 65-88.

RIDING, J. B. & THOMAS, J. E. (1992): Dinoflagellate cysts of the Jurassic System. In POWELL, A. J. Ed.: A Stratigraphic Index of Dinoflagellate Cysts, 7-98. Brit. Micropalaeont. Soc. Publ. Ser., Chapmann & Hall, London.

SHULGINA, N. I. & BURDYKINA, M. D. (1992): Biostratgraficheskye skemy jury i nizhnevo mela shelfov Barentseva, Norvezhskovo i Severnovo morey. In: GRAMBERG, I. S. & SHULGINA, N. I. (Eds.): Geologicheskaya istorya Arktiki v mezozoye i kenozoye 106-114. St. Petersburg: VNIIOkeanologiya.

SMELROR, M., MØRK, A., MONTEIL, E., RUTLEDGE, D. & LEEREVELD, H. (1998): The Klippfisk Formation - a new lithostratigraphic unit of Lower Cretaceous platform carbonates on the Western Barents Shelf. – Polar Res., **17** (2): 181-202.

SMELROR, M., MØRK, A., MØRK, M. B. E., WEISS, H. M. & LØSETH, H. (2001): Middle Jurassic – Lower Cretaceous transgressive-regressive sequences and facies distribution off Northern Nordland and Troms, Norway. – In: MARTINSEN, O. J. & DREYER, T. (Eds.): Sedimentary environments offshore Norway - Palaeozoic to Recent, 211-232, NPF Spec. Publ., Elsevier, Amsterdam.

SYKES, R. M. & CALLOMON, J. H. (1979): The *Amoeboceras* zonation of the Boreal Upper Oxfordian. – Palaeontology, **22** (4): 839-903.

TYSON, R. V. (1993): Palynofacies analysis. In: JENKINS, D. G. (Ed.): Applied Micropaleontology, 153-191. Kluwer Academic Publishers, The Netherlands.

VAN DER ZWAN, C. J. (1990): Palynostratigraphy and Palynofacies Reconstructions of the Upper Jurassic to Lowermost Cretaceous of the Draugen Field, Offshore Mid Norway. – Rev. Palaeobot. Palynol., **62**: 157-186.

WIERZBOWSKI, A. (1989): Ammonites and stratigraphy of the Kimmeridgian at Wimanfjellet, Sassenfjorden, Spitsbergen. – Acta Palaeont. Polon., **34** (4): 355-378.

WIERZBOWSKI, A. & ÅRHUS, N. (1990): Ammonite and dinoflagellate cyst succesion of an Upper Oxfordian-Kimmeridgian black shale core from the Nordkapp Basin, southern Barents Sea. – Newsl. Strat., **22** (1): 7-19.

WIERZBOWSKI, A. & SMELROR, M. (1993): Ammonite succesion in the Kimmeridgian of southwestern Barents Sea, and the *Amoeboceras* zonation of the Boreal Kimmeridgian. – Acta Geol. Polon., **43** (3-4). 229-249.

WIGNALL, P. B. & HALLAM, A. (1991): Biofacies, stratigraphic distribution and depositional models of British onshore Jurassic black shales. – In: TYSON, R. V. & PEARSON, T. H. (Eds.): Modern and Ancient Continental Shelf Anoxia, 291-309. Geol. Soc. Spec. Publ., **58**; London.

ZIEGLER, B. (1962): Ammoniten-Gattung *Aulacostephanus* im Oberjura (Taxionomie, Stratigraphie, Biologie). – Palaeontographica, **119 A**: 1-172.

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