The *Hectoroceras kochi* Zone (Ryazanian) in the North Sea Central Graben and remarks on the Late Cimmerian Unconformity

Tove Birkelund, Claus Koch Clausen, Henrik Nøhr Hansen and Lise Holm

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Ammonites, inoceramids and dinoflagellate cysts found in core material from the E-1 well in the Tail End Graben of the Danish part of the Central Graben are described. The core belongs to the upper, highly radioactive part of the Kimmeridge Clay Formation (unit J-4) and includes the ammonite *Hectoroceras kochi* indicating the basal Cretaceous, Lower Ryazanian *H. kochi* Zone. Dinoflagellates indicate the *Cannosphaeropsis thula* Subzone. Dinoflagellates from cuttings immediately below and above the boundary between the Kimmeridge Clay Formation and the overlying Valhall Formation indicate a Valanginian age for the boundary (*Spiniferites ramosus* Zone). No hiatus between the two formations is discernible in the dinoflagellates. The "Late Cimmerian unconformity" is discussed in the light of the new stratigraphic data from the well.

Tove Birkelund, Claus Koch Clausen, and Henrik Nøhr Hansen, Institute of Historical Geology and Palaeontology, Øster Voldgade 10, DK-1350 Copenhagen K., Lise Holm, Geological Survey of Denmark, Thoravej 31, DK-2400 Copenhagen NV.

One of the early wells in the southern part of the Danish North Sea, E-1, drilled in 1965 in the Central Graben (Fig. 1), yielded a fossiliferous core of laminated, organic-rich shale from the upper part of the Kimmeridge Clay Formation (core 8, 9783′ – 9792′). The core was summarily described by Rasmussen (1978) in a review of eight North Sea wells in the Danish sector. In that work the age of the core was suggested as being Late Jurassic on the basis of poorly preserved miospore and microplankton assemblages, from preliminary determinations by F. Bertelsen. However, in a figured well log (Fig. 12) in the same work it was referred to the lowermost part of the Cretaceous.

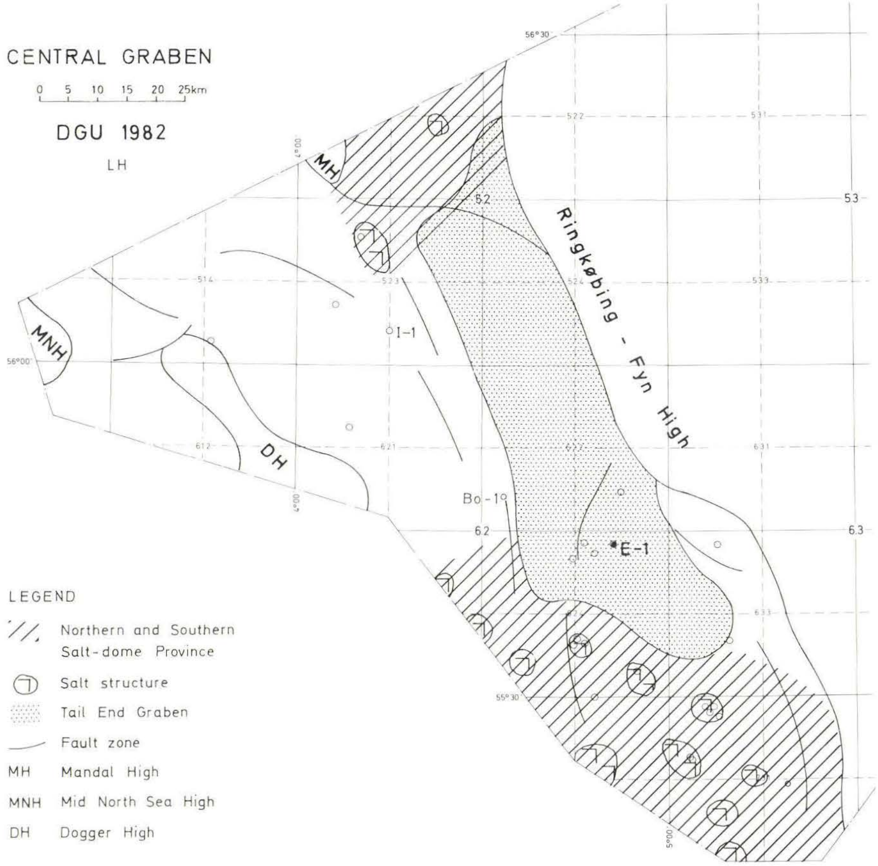


Fig. 1. Map showing structural units of the Danish part of the Central Graben (after Michelsen & Andersen 1983). Location of the E-1, Bo-1 and I-1 wells indicated.

In a recent survey of the geology of the Danish Central Graben (Michelsen 1982), Koch et al. referred the core to an informal J-4 unit, equivalent to the Kimmeridge Clay Formation described by Deegan & Scull (1977). The boundary with the overlying Valhall Formation (see Deegan & Scull 1977) was placed at 9727′, 56′ above the top of the core, and the entire J-4 unit was referred to the Kimmeridgian-Portlandian.

The discovery of ammonites in the core now makes it possible to determine the age precisely as the *Hectoroceras kochi* Zone of the Lower Ryazanian and this, in turn, provides a fine age calibration for the dinoflagellate assemblage of the core.

Dinoflagellate dating of cuttings from the uppermost part of the Kimmeridge Clay Formation above the core, and from the lowermost part of the overlying Valhall Formation indicate close to continuous sedimentation in this part of the Central Graben. The boundary between the Kimmeridge Clay Formation and Valhall Formation is discussed further below in relation to the "Late Cimmerian Unconformity".

Geological setting and lithology of the core

The E-1 well is situated in the southernmost part of the Tail End Graben (Andersen et al. 1982, Michelsen & Andersen 1983) (Fig. 1). The well was drilled on a structural closure at the level of the "Top Chalk Group" (the Tyra Field). The structure is an antiformal flexure caused by Late Cretaceous – Early Tertiary inversion tectonics.

The Tail End Graben is the area showing the greatest subsidence during the Jurassic in the Danish part of the Central Graben (Holm 1983), especially during the Late Jurassic. The total Jurassic sequence is 3000 m thick in the southern part, and the maximum thickness is more than 4000 m further northwards. The thickness of the J-4 unit is estimated to be at least 1600 m in the area around the E-1 well. After deposition of the J-4 unit, a period of relatively slow subsidence followed during which the Valhall Formation was deposited.

The J-4 unit is characterized by high gamma ray activity and a low sonic velocity, interspersed with many high velocity peaks representing dolomite stringers (Koch et al. 1982) (Fig. 2). The E-1 well penetrated one of the most complete developments of the upper part of the J-4 unit in the Danish part of the Central Graben. In the uppermost part, an interval of 25 m with very high radioactivity is found, corresponding to the Mandal Formation in the northern part of the Central Graben (Hamar et al. 1983). In the Danish part of the Central Graben this highly radioactive interval is known from only two other wells, Bo-1 and I-1 (Fig. 1). In the well Bo-1 this interval is 30 m thick and displays the highest gamma ray readings. In the I-1 well the highly radioactive interval attains the greatest thickness, more than 100 m, but this may be due to structural complexity.

The core described here belongs to this highly radioactive interval. It consists of a dark, finely laminated, organic-rich shale deposited under euxinic conditions. An x-radiograph of the rock shown in Fig. 3 reveals the microlaminated character of the rock, with a fine first- and second-order cyclicity.

The organic matter of the J-4 unit in the E-1 well is dominated by liptinite, mainly alginite, associated with varying amounts of vitrinite and inertinite. A remarkable increase in liptinite, mainly alginite, characterizes the top of the unit (Lindgreen et al. 1982).

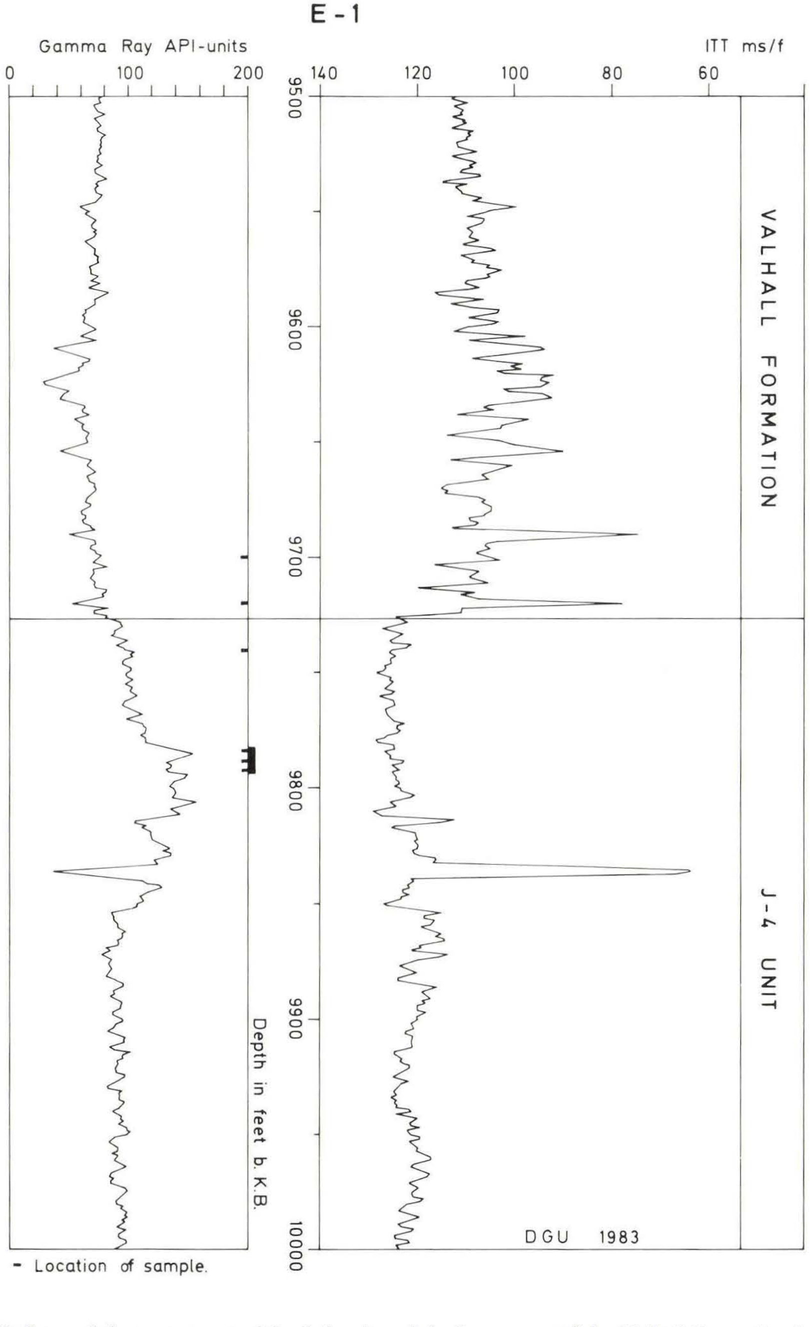


Fig. 2. Logs of the upper part of the J-4 unit and the lower part of the Valhall Formation in the E-1 well. Location of the investigated core and cutting samples indicated.

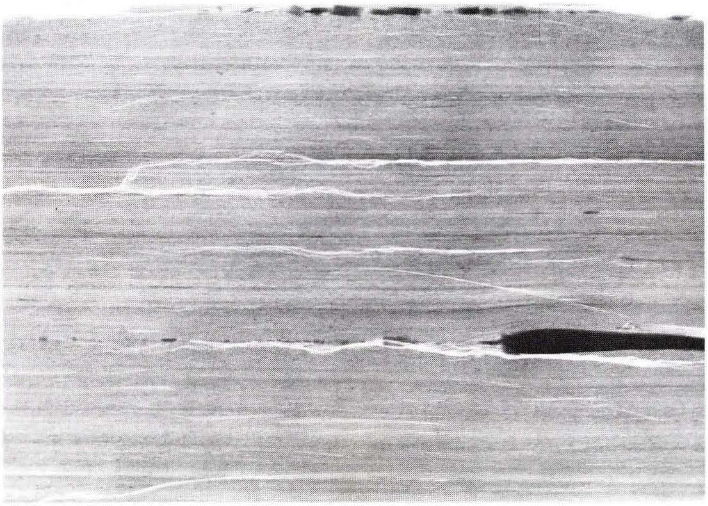


Fig. 3. X-radiograph of core 8 showing the micro-laminated character of the rock, × 1.

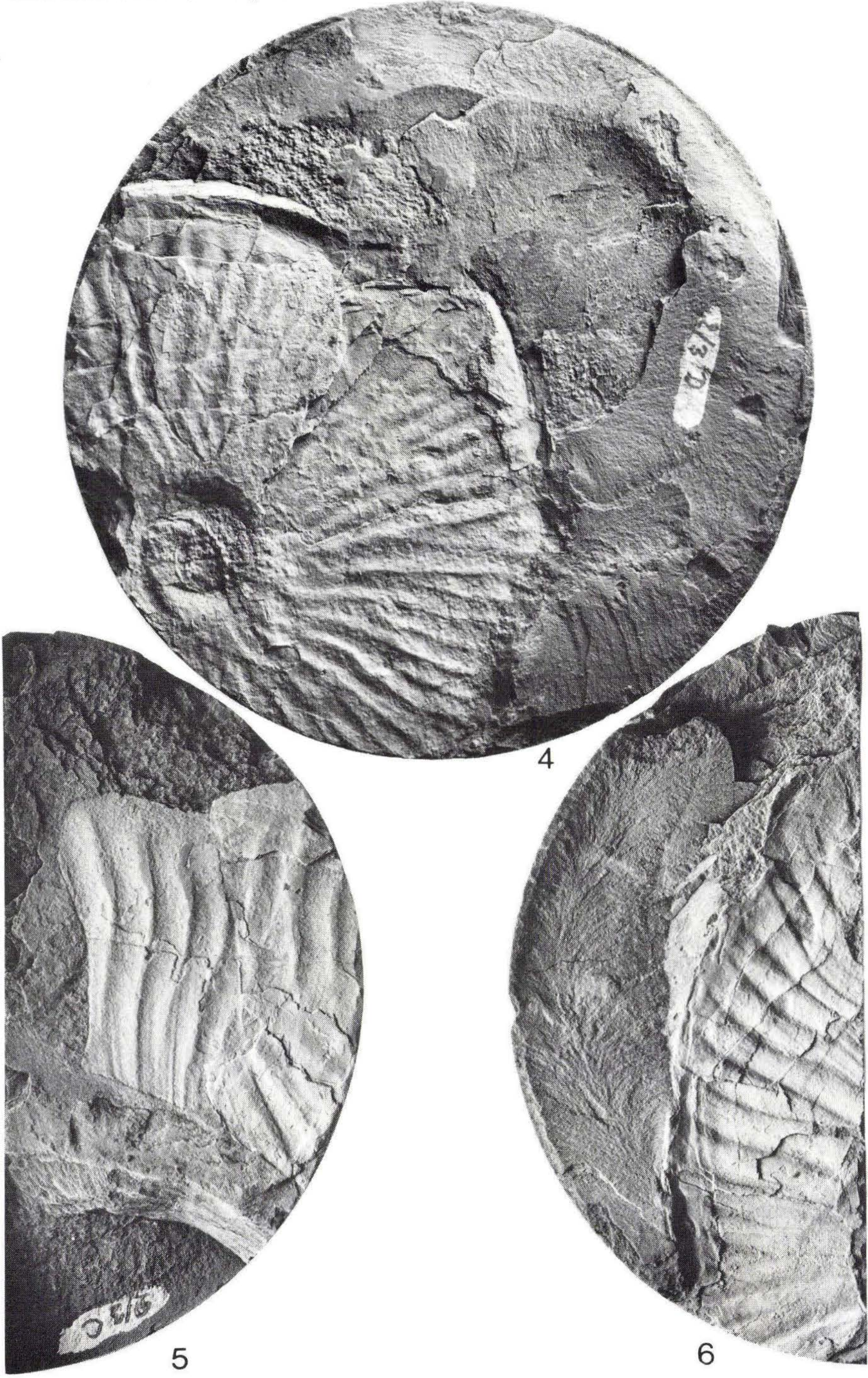
Ammonites (T. B.)

Three fragments of ammonites have been recovered from the core, one 120–130 cm below top, one 106–108 cm below top, and one 33–43 cm below top. The first is fairly complete, while the others are fragments, probably of body chambers. All of them belong to the Boreal genus *Hectoroceras.*

This genus was established by Spath (1947) who referred it to the family Craspeditidae. It is characterized by its narrow, high-walled umbilicus and compressed oxycone coiling with flat sides and a blunt venter. The ribbing is flexuous, with long primaries which branch above the middle of the flat whorl sides. The ribs tend to terminate close to the venter, leaving the venter smooth. The suture line is very simple, but with numerous auxilliaries.

Besides the type species, *Hectoroceras kochi* Spath, 1947, which is by far the best known, only a few other species have been referred to the genus: *H. larwoodi* Casey, 1973, and *H. tolijense* (Nikitin, 1884) by Klimova (1972).

The best preserved specimen from the core (Fig. 4) seems to be rather close to the type species, *H. kochi,* which is primarily known from Spath's description of rich collections from southern Jameson Land (Spath 1947, p. 21, pl. 1, figs 1–5; pl. 2, figs 1–4 (fig. 2 holotype); pl. 3, fig. 1; text fig. 5). Topotypes have also been figured in Surlyk et al. (1973, pl. 4, figs 1–2) and occurrences further north, in Wollaston Forland, have been figured by Surlyk (1978, pl. 5, fig. 5). Occurrences in the northern USSR have been described by e.g. Shulgina (1972, p. 173, pl. 3, fig. 2) and in England by Casey (1961,



Figs 4–6. Hectoroceras cf. *kochi* Spath, 1947 from core 8. 4: Crushed phragmocone, 120–130 cm below top MGUH 16077; 5: Fragment of body chamber, 106–108 cm below top, MGUH 16078; 6: Fragment of body chamber, 33–43 cm below top, MGUH 16079. All × 1.

1973, p. 244, pl. 7, figs 1–3). The specimens from these scattered localities all lie within the range of variation of the rich collections from the type area of the species in southern Jameson Land.

The most complete specimen from the core (Fig. 4) has less flexuous ribs than most figured specimens, but is in this respect very close to the holotype, which also has rather straight ribs. One of the large fragments (Fig. 6) closely matches large specimens from East Greenland, while the other fragment (Fig. 5) is less certain.

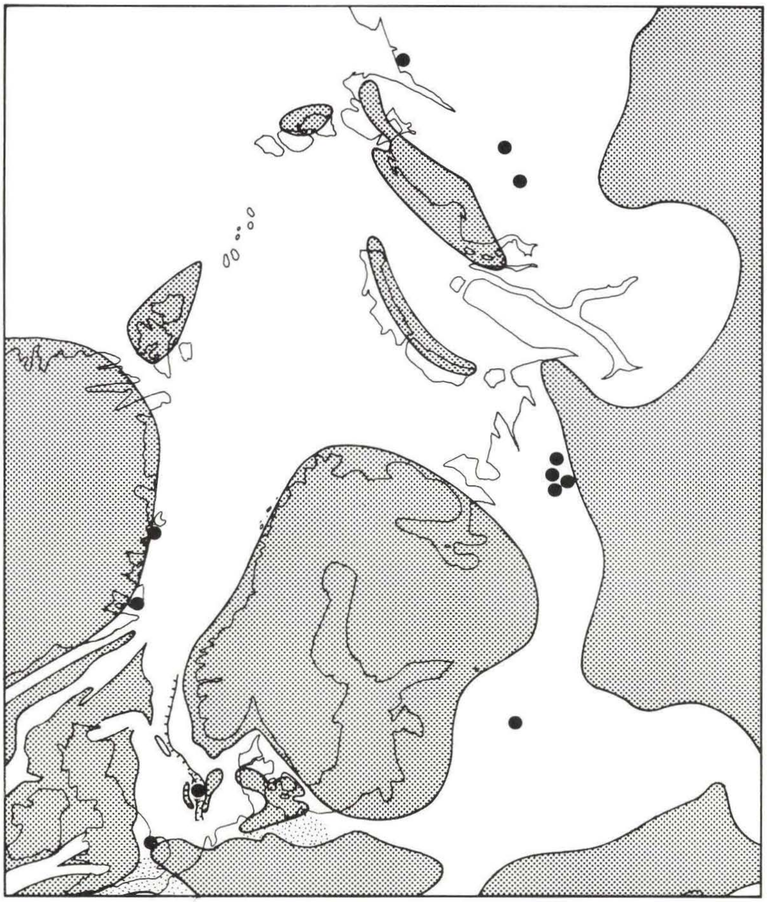


Fig. 7. Distribution of the genus *Hectoroceras* in the Lower Ryazanian. Palaeogeography mainly after Casey (1973) and Ziegler (1982). Projection after Smith & Briden (1977), slightly modified.

Stratigraphy

The wide distribution of *Hectoroceras* (Fig. 7) during a short interval in the Ryazanian makes it an excellent stratigraphic marker (Surlyk 1978; Callomon & Birkelund 1983, table 2).

It characterizes the upper part of the Lower Ryazanian, the *Hectoroceras kochi* Zone, in East Greenland, eastern England, N and NW Siberia and is also known from the Volga Basin. In East Greenland the *H. kochi* Zone is underlain by the *Praetollia maynci* Zone (Surlyk 1978), in England by the *Praetollia (Runctonia) runctoni* Zone (Casey 1973, Casey et al. 1977), and in Siberia by zones characterized by the genus *Chetaites,* in the upper part of which *P. maynci* also has been found (Shulgina 1972). The discovery of *Hectoroceras* in the Volga Basin in the lower part (but not the lowermost part) of the former *Riasanites riasanensis* Zone ties the stratigraphy of Siberia and the Russian Platform nicely together (see Casey et al. 1977, Mesezhnikov et al. 1979).

Inoceramid bivalves (C.K.C.)

Recrystallized bivalves occur scattered throughout the core, but only specimens from the upper part are suitable for closer description.

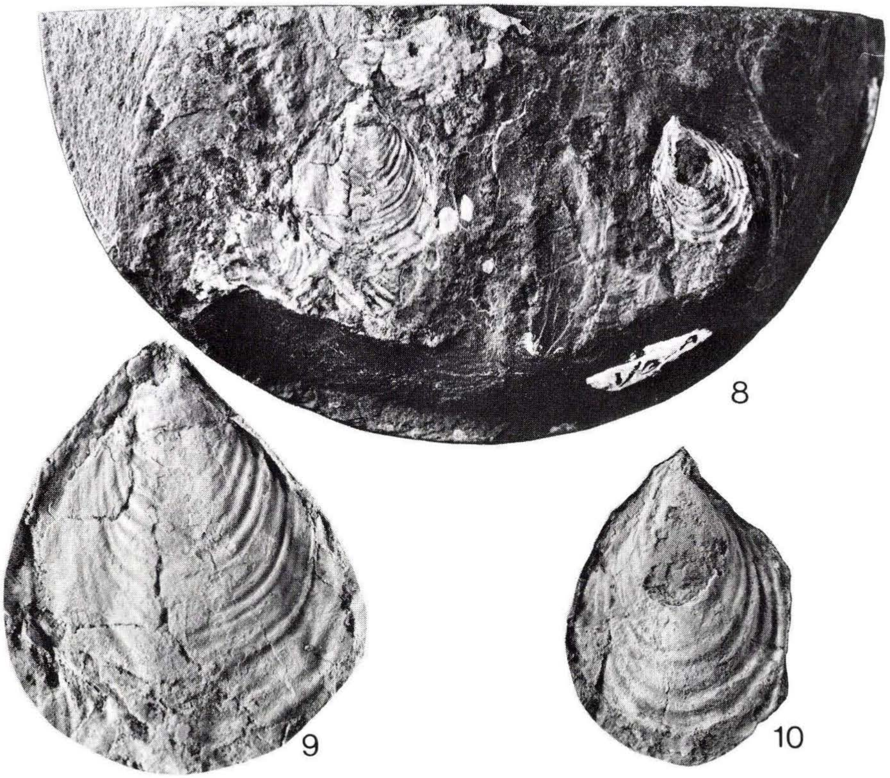
Two bivalved specimens and one fragment from a level 25–28 cm below the top of the core are tentatively referred to *Inoceramus vereshagini* Pochialaynen, 1969 (Figs. 8–10).

The specimens are equivalved or slightly inequivalved and have a prominent commarginal ribbing of well-defined ribs. The outline is ovate and the ratio between height and width 1.2. A small wing is developed. The beaks are subterminal with an angle of 70–80°. The umbones are gently prosogyrate, projecting only weakly above the hinge-line. The hinge-line is rather long and straight, with a uniform series of narrow ligament-pits (only six pits visible). The pits are separated by thin, raised interspaces. Muscle scars are not visible.

The specimens seem to be close to *I. vereshagini.* According to Zakharov & Turbina (1979) this species is highly variable in sculpture, changing with growth, as are the outline of the test and the value of the anterioligamental angle (50–70°).

Stratigraphy

I. vereshagini has been recorded by Zakharov & Turbina (1979) as ranging



Figs 8–10. Inoceramus aff. *vereshagini* Pochialaynen, 1969. 8: Bedding plane with the two bivalved specimens and one fragment, × 1. 9: Largest specimen, bivalved, showing right valve, MGUH 16080, c. × 3. 10: Small bivalved specimen showing right valve, MGUH 16081, c. × 3.

from the *Craspedites taimyrensis* Zone (Upper Volgian) to the *Chetaites sibiricus* Zone (lowermost Ryazanian) in the northern part of central Sibiria (the Katanga depression), and from the Valanginian in the north-east and far east (the northern Sikhote-Alin) of USSR.

Palaeoecology

In a discussion of some Late Jurassic inoceramid bivalves Crame (1982) suggested that the replacement of the genus *Retroceramus* by the genus *Inoceramus* in the Early Cretaceous reflected the adoption of an epibyssate mode of life.

The occurrence of *Inoceramus* in non-bioturbated, laminated rock would suggest, according to Kauffman's (1975) interpretation of the benthonic life habit of the bivalve, a small content of free oxygen in the bottom waters. Such oxic environment may have been of temporary duration in an otherwise generally anoxic sea floor, since there is no other evidence apart from *Inoceramus* of active benthos.

Dinoflagellate cysts (H. N. H.)

Three samples from the core were used in the palynological analysis: Sample 1 from core interval 9783′–9785′, 40–45 cm below the top of the core; sample 2 from core interval 9785′–9788′, 99–101 cm below the top of the core, and sample 3 from core interval 9788′–9792′, 165–175 cm below the top of the core.

Preparation of the samples: After a standard palynological preparation with HCl and HF it was barely possible to identify any palynomorphs. The dominating organic matter is amorphous, probably of marine algal origin as it exhibited UV induced fluorescence. Strong oxidation with HNO_3 for 17 minutes and 30 minutes treatment in an ultrasonic bath (80 000 HZ) were necessary to clean the palynomorphs from some of the amorphous organic matter.

Discussion of the dinocyst distribution and the age of the core

The dinocyst species identified in the three samples are listed in Fig. 11. As may be seen, the three samples contain almost the same species, dating the interval 9783′–9792′ as in the *Cannosphaeropsis thula* Subzone (Davey 1982) of the Lower Ryazanian (see Fig. 12). The stratigraphically most diagnostic species are:

Batioladinium radiculatum Davey 1982, *B. ponum* Davey 1982 (Fig. 22) and *Gonuaulacysta* sp. A Davey 1979 all appear at the base of the subzone.

Cannosphaeropsis thula Davey 1982 (Fig. 21) defines the top of the subzone by its last occurrence.

Further, the presence of *Gochteodinia villosa* (Vozzhennikova 1979) Norris 1975 indicates a Late Volgian – Late Ryazanian age.

It is also worth mentioning that the species *Stiphrosphaeridium dictyophorum* (Cookson & Eisenack 1958) Davey 1982 (Figs 13–14) occurs commonly in all three samples. According to Davey (1982) it is similarly common in the two ammonite zones of the Lower Ryazanian in eastern England: The *Praetollia runctoni* and *Hectoroceras kochi* Zones.

The age determination is further supported by the absence of the genus *Muderongia* Cookson & Eisenack 1958, which is only missing in the *Canno-*

Core			Cuttings			
9788'–92'	9785'–88'	9783'–85'	9740'	9720'	9700'	Selected dinoflagellate cysts
x	x	x				*Batioladinium pomum* Davey, 1982
x	x	x				*Batioladinium radiculatum* Davey, 1982
x	x	x				*Canningia compta* Davey, 1982
x	x	x				*Cannosphaeropsis thula* Davey, 1982
x	x	x				*Chlamydophorella membranoidea* Vozzhennikova, 1967
	x	x				*Cleistosphaeridium tribuliferum* (Sarjeant, 1966) Davey et al., 1969
x	x	x				*Dingodinium spinosum* (Duxbury, 1977) Davey, 1979
x		x				*Gochteodinia villosa* (Vozzhennikova, 1976) Norris, 1978
x	x	x				*Gonyaulacysta* sp. A Davey, 1979
x	x	x				*Pareodinia* spp.
x	x	x				*Stiphrosphaeridium dictyophorum* (Cookson & Eisenack, 1958) Davey, 1982
x	x	x	x	x	x	*Gonyaulacysta* spp.
x	x	x	x	x	x	*Hystrichodinium voigtii* (Alberti, 1961) Davey, 1974
x			x			*Isthmocystis distincta* Duxbury, 1979
x	x	x	x	x	x	*Scriniodinium pharo* (Duxbury, 1977) Davey, 1982
	x	x	x	x	x	*Sirmiodinium grossii* Alberti, 1961
	x	x	x	x	x	*Tanyosphaeridium* spp.
x		x	x	x	x	*Tubotuberella apatela* (Cookson & Eisenack, 1960) Ioannides et al., 1977
				x		*Canningia* aff. *compta* Davey, 1982
			x	x	x	*Dingodinium albertii* Sarjeant, 1966
			x	x	x	*Gochteodinia villosa multifurcata* Davey, 1982
			x	x	x	*Heslertonia heslertonensis* (Neale & Sarjeant, 1962) Sarjeant, 1966
				x	x	*Hystrichosphaeridium* cf. *recurvatum* (White, 1842) Davey & Williams, 1966
			x	x	x	*Kleithriasphaeridium* spp.
				x	x	*Lagenorhytis delicatula* (Duxbury, 1977) Duxbury, 1979
			x	x	x	*Muderongia simplex* Alberti, 1961
			x	x	x	*Phoberocysta neocomica* (Gocht, 1957) Millioud, 1969
			x	x	x	*Pseudoceratium pelliferum* Gocht, 1957
			x	x	x	*Scriniodinium campanulum* Gocht, 1959
			x	x	x	*Surculosphaeridium* sp. III Davey, 1982
			x	x	x	*Trichodinium ciliatum* (Gocht, 1959) Eisenack, 1964
				x		*Concavissimisporites verrucosus* (Delcourt & Sprumont, 1955) Dörhöfer & Norris, 1977

Fig. 11. List of selected dinoflagellate cysts from the investigated core and cuttings.

AGE		BOREAL AMMONITE ZONES	DINOCYST ZONATION (after Davey 1979)	
			SUBZONES	ZONES
Valanginian	late	"Astieria" fauna		*Spiniferites ramosus*
		tuberculata *		
		bidichotomoides *		
		triptychoides *		
		pitrei		
		Dichotomites spp.		
	early	*Polyptychites*		
		Paratollia		
Ryazanian	late	*albidum*		*Pseudoceratium pelliferum*
		stenomphalus	*Scriniodinium pharo*	*Gochteodinia villosa*
		icenii		
	early	*kochi*	*Cannosphaeropsis thula*	
		runctoni		
Portlandian	late	*lamplughi*	*Egmontodinium expiratum*	
		preplicomphalus		
		primitivus		
	early	*oppressus*		
		anguiformis		
		kerberus		*Dingodinium spinosum*
		okusensis		
		glaucolithus		*Avellodinium culmulum*
		albani		

* German Boreal Zones

Fig. 12. Correlation of the dinocyst zonation to the Boreal ammonite zonation for the Portlandian to Valanginian (after Davey 1982).

sphaeropsis thula Subzone, the *C. thula/Egmontodinium expiratum* Subzone and the *Dingodinium spinosum* Zone in the late Jurassic – early Cretaceous dinocyst sequence of the North Sea area (see Davey 1982, Fig. 3).

Egmontodinium expiratum Davey 1982, characterizing the lowermost part of the *Gochteodinia villosa* Zone, has not been found in any of the three samples. In England it has been reported from the *Praetollia runctoni* Zone but not from the *Hectoroceras kochi* Zone. This supports correlation of the core interval 9783′–9792′ with the top of the *C. thula* Subzone, in good agreement with the occurrence of *Hectoroceras kochi.*

Canningia compta Davey 1982 constitutes up to 60% of the dinocyst assemblages in sample 9788′–9792′. Some occur as single specimens (Figs

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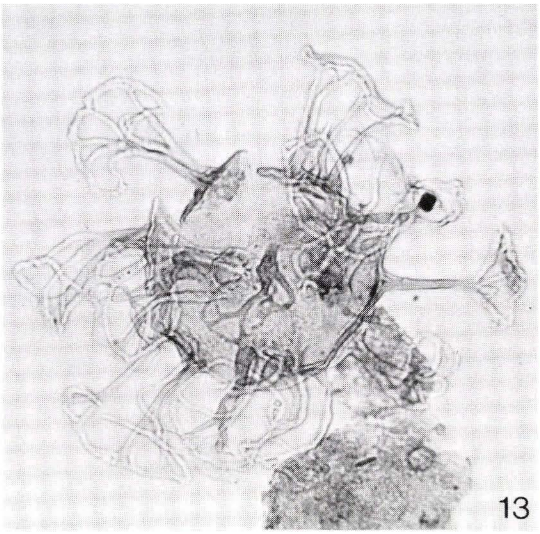
Figs 13–18. 13: *Stiphrosphaeridium dictyophorum,* sample 9788′–9792′, MGUH 16082, c. × 550. 14: *S. dictyophorum,* sample 9788′–9792′, MGUH 16083, c. × 550. 15: *Canningia compta,* sample 9788′–9792′, MGUH 16084, c. × 550. 16: *C. compta,* sample 9788′–9792′, MGUH 16085, c. × 550. 17: Coprolitic lump of *C. compta,* sample 9788′–9792′, MGUH 16086, c. × 150. 18: Coprolitic lump of *C. compta,* sample 9788′–9792′, MGUH 16087, c. × 300. Authors of these taxa are given in fig. 11.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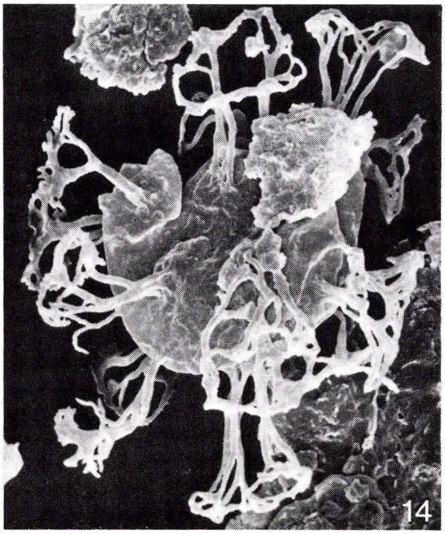
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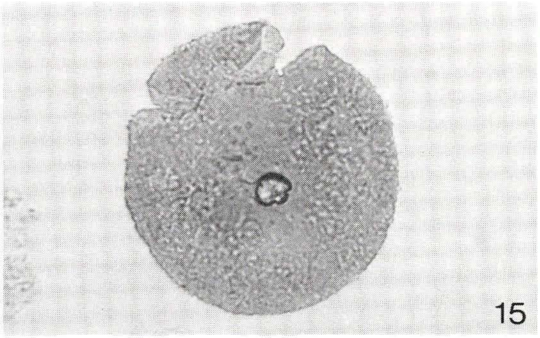
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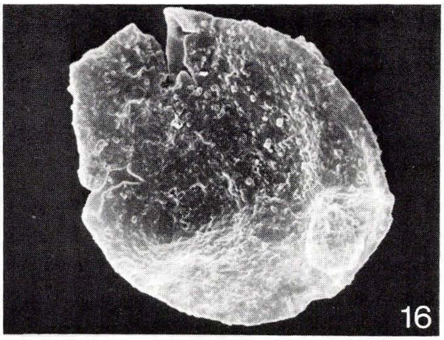
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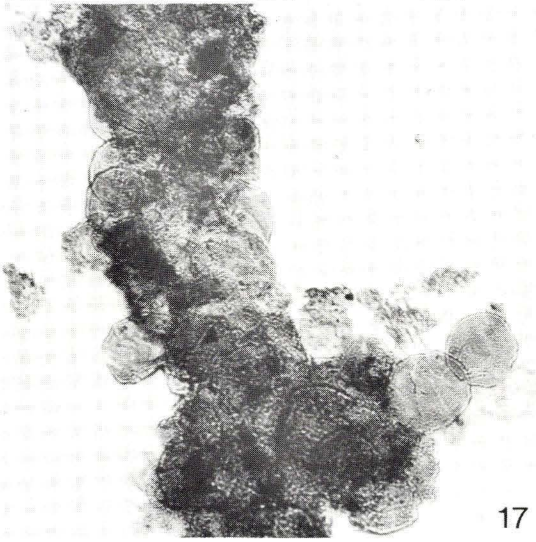
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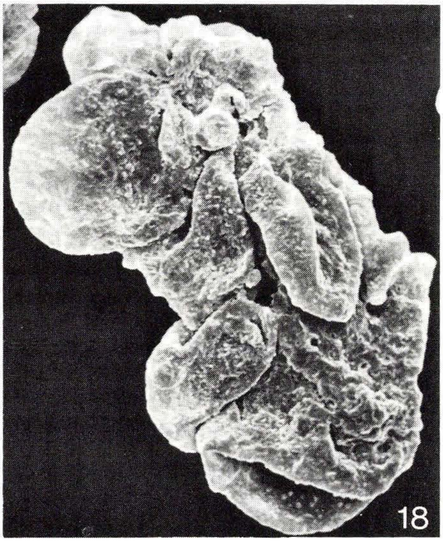
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15–16), but the most common occurrence of the species is in strings or lumps (Figs 17–18), the specimens being cemented together with amorphous organic matter. These lumps are not destroyed even after treatment with nitric acid and ultrasonics. On the basis of shape and coherence, these lumps are interpreted as coprolites, probably of pelagic organisms if the anoxic bottom conditions did not allow much benthonic life. The abundant occurrence in the core of this species is remarkable, as it is stressed by Davey (1982) that the species fluorished in the relatively shallow shelf seas of eastern England during the Volgian and the Ryazanian, but not in the same abundance over most of the North Sea Basin.

F. Bertelsen (1968) reported *Cleistosphaeridium tribuliferum* (Sarjeant, 1966) Davey et al. 1969 from core 8 and on that basis dated the core interval to an Oxfordian age. According to Davey (1982) *C. tribuliferum* continues into the *C. thula/E. expiratum* Subzone, but the present investigation extends its known occurrence to the *C. thula* Subzone.

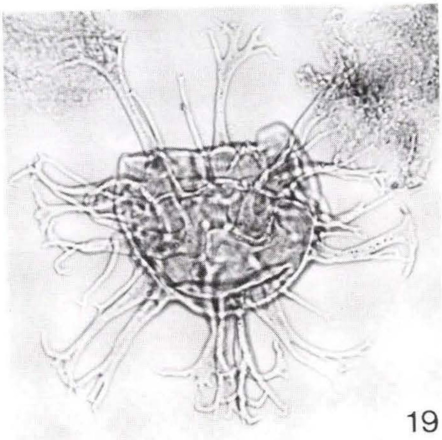
Dinocysts from cuttings around the J-4 unit/Valhall Formation boundary

According to Michelsen (1982) the boundary between the J-4 unit and the Valhall Formation in the E-1 well lies at 9727′, 56′ above the dated core. To get an idea of the age of that boundary cuttings from the levels 9740′, 9720′ and 9700′ were investigated.

The organic content of the samples reflects the character of the two formations. Thus, the sample from 9740′ contains a good deal of unstructured organic matter, while the samples from level 9700′ and 9720′ contain mainly structured organic matter, following the change from anoxic to oxic bottom conditions at the boundary between the formations. Nevertheless, some mixing of the material must be expected.

The identified species from the three samples are listed in Fig. 11. They contain the same assemblage of species, dating the interval 9700′–9740′ to the Valanginian *Spiniferites ramosus* Zone (Davey 1979) (see Fig. 12). The exact age within the Valanginian, however, is uncertain.

Figs 19–27. 19: *Surculosphaeridium* sp. III, sample 9720′, MGUH 16088. 20: *Hystrichosphaeridium* cf. *recurvatum*, sample 9740′, MGUH 16089. 21: *Cannosphaeropsis thula*, sample 9788′–9792′, MGUH 16090. 22: *Batioladinium pomum*, sample 9788′–9792′, MGUH 16091. 23: *Pseudoceratium pelliferum*, sample 9700′. MGUH 16092. 24: *Phoberocysta neocomica*, sample 9700′, MGUH 16093. 25: *Gochteodinia villosa multifurcata*, sample 9720′, MGUH 16094. 26: *Lagenorhytis delicatula*, sample 9700′, MGUH 16095. 27: *Concavissimisporites verrucosus*, sample 9720′, MGUH 16096. All c. × 550. Authors of these taxa are given in fig. 11.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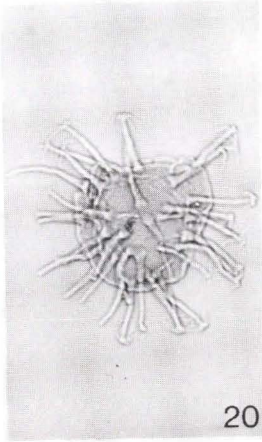
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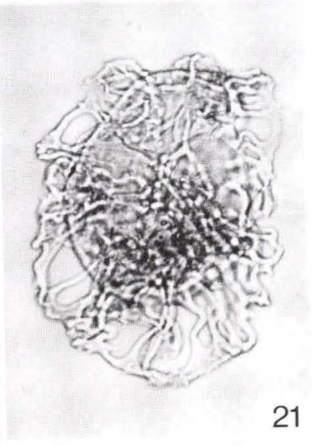
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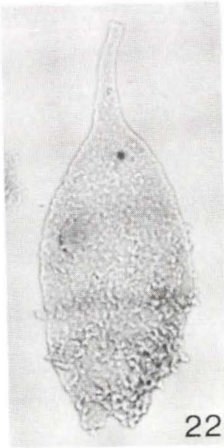
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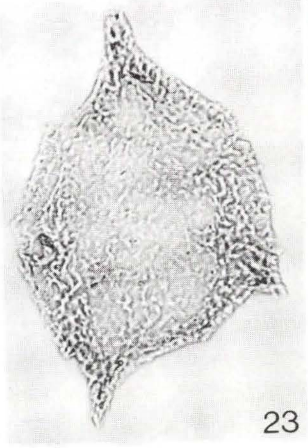
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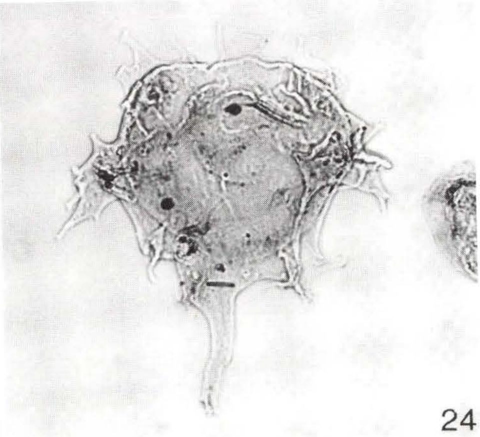
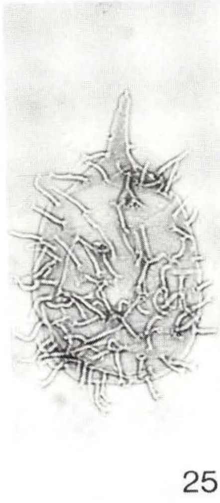

24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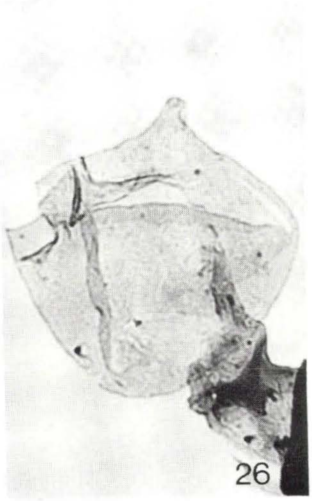
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Gochteodinia villosa multifurcata Davey 1982 (Fig. 25) appears near the Ryazanian-Valanginian boundary and extends throughout the Valanginian into the early Hauterivian (Davey 1982).

Phoberocysta neocomica (Gocht 1957) Millioud 1969 (Fig. 23) appears a little later in the Valanginian, at the base of the *S. ramosus* Zone s.str. in the Haldager 1 borehole (see Davey 1982, Fig. 3), and should thus exclude the lowermost Valanginian. On the other hand, the persistent occurrence of *Scrinidinium pharo* (Duxbury 1977) Davey 1982 in all three samples points to a very early Valanginian age. In addition, the occurrence of *Surculosphaeridium* sp. III Davey 1982 (Fig. 19), up to now found only in beds D3 and D4 of the Lower Valanginian at Speeton, may indicate an early Valanginian age. Well preserved specimens of that species have been found in the samples, confirming the description given by Davey (1982) on the basis of fragmented material.

Pollen and spores have not been examined in any detail, but the spore *Concavissimisporites verrucosus* (Delcourt & Sprumont 1955) Dörhöfer & Norris 1977 (Fig. 27) occurs in the cuttings from 9720′. It is reported from Hills 4 palynozone (Dörhöfer & Norris 1977) covering the Upper Ryazanian, Lower Valanginian and the lower part of Upper Valanginian in south England and north Germany. Generally, species characterizing the Hauterivian *Discorsia nanna* Zone (Davey 1979) are not present. Only *Hystrichosphaeridium* cf. *recurvatum* (White 1842) Davey & Williams 1966 (Fig. 20), described from the *D. nanna* Zone in the Haldager 1 bore-hole by Davey (1982), has been found in the cuttings from 9700′ and 9720′.

In conclusions, no hiatus is apparent in the J-4 unit – Valhall Formation boundary interval on the basis of the cuttings described here. The boundary between the formations lies in the Valanginian, probably in the early part.

Biostratigraphical conclusions

Ammonites and dinoflagellates date the core interval 9783′–9792′ to the Lower Ryazanian *Hectoroceras kochi* Zone and the *Cannosphaeropsis thula* dinocyst Subzone, while dinoflagellates from cuttings from the top of the J-4 unit and the base of the Valhall Formation (9700′–9740′) indicate a Valanginian age for that interval (*Spiniferites ramosus* Zone).

The early Cretaceous age of the highly radioactive upper part of the Kimmeridge Clay Formation (J-4 unit) of the Central Graben of the Danish sector is in good agreement with other parts of the Central- and Viking Grabens. Thus, Fyfe et al. (1980), Costa (1981), Rawson & Riley (1982), and Hamar et al. (1983) all agree that the organic mudstone facies of the

Upper Jurassic persists into the Ryazanian, and Hamar et al. (1983) has now established a separate formation for the hot shales of Ryazanian age from the northern part of the Central Graben: the Mandal Formation.

The age of the boundary between the Kimmeridge Clay Formation (Mandal Formation) and the Valhall Formation (viz. the change from anoxic to oxic conditions) was claimed to be Late Ryazanian by e.g. Fyfe et al. (1980), Riley & Tyson (in Fyfe et al. 1980), Rawson & Riley (1982), and Hesjedal & Hamar (1983). The present work seems to show that the boundary is early Valanginian in the E-1 well described here.

The Late Cimmerian Unconformity

Many authors have applied the term "Late Cimmerian" in a general sense to tectonism in the late Jurassic and early Cretaceous.

Ziegler (1978, 1982) used the term "the Late Cimmerian phase" in a restricted sense for a major rifting pulse which, according to him, affected the entire Arctic – North Atlantic rift system in Early Cretaceous time, and is believed to have coincided with a sharp eustatic drop in sea-level (Vail et al. 1977). The term has been applied in the North Sea especially to the socalled "Late Cimmerian regional unconformity" between the Kimmeridge Clay Formation (J-4 unit) and the Valhall Formation. In a number of papers in Michelsen (1982) this unconformity was considered to be characterized by a major hiatus in the Danish part of the Central Graben and to be of Late Jurassic age at least partly. The present work shows that the hiatus has been overestimated in at least some parts of the Central Graben and that the age of the unconformity (defined by the base of the Valhall Formation) is in fact Early Cretaceous and thus belongs to the Late Cimmerian phase in the strict sense of Ziegler.

Some authors have recently questioned whether there is a regional unconformity at the top of the Kimmeridge Clay formation at all (Riley & Tyson in Fyfe et al. 1980). Rawson & Riley (1982) claimed that although a major hiatus (or a condensed sequence) may occur at basin margins or above structural highs over most of the North Sea, the base of the Valhall Formation is conformable with underlying sediments, and Hesjedal & Hamar (1983) stress that no angular unconformity can be traced in the central part of the Graben north of the Danish sector. Likewise, in the E-1 well described here, no unconformity could be seen, but in the area around the E-1 well, a weak sesimic angular unconformity seems to mark the base of the Valhall Formation (K. Damtoft Poulsen, pers. comm. 1983).

In addition, both the Jurassic-Cretaceous boundary and the top of the

Lower Ryazanian (*Hectoroceras kochi* Zone) are characterized by erosional unconformities in eastern England, which may reflect slightly earlier local movements (Casey 1973, Rawson & Riley 1982).

The distinct seismic reflector at the base of the Valhall Formation represents a lithological boundary, which is considered isochronous by some authors (Riley & Tyson in Fyfe et al. 1980, Rawson & Riley 1982, Hesjedal & Hamar 1983), as it marks a change from mainly anoxic conditions (deposition under a stratified water column) to well oxygenated bottom conditions. However, the boundary is not necessarily strictly isochronous. The Valanginian (and not Ryazanian) age of the boundary in the E-1 well may very well be explained by the persistence of anoxic conditions in some of the deeper parts of the basin, but more exact biostratigraphic datings are needed to map the boundary in detail.

In conclusion, it seems as if the Late Cimmerian phase in the strict sense (early Early Cretaceous) was reduced to relatively minor movements in Ryazanian and ?Early Valanginian time in the North Sea basin, while oscillations in sea-level caused characteristic lithological changes around the Ryazanian – Valanginian boundary.

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Dansk sammendrag

En borekerne fra E-1 boringen i Tail End Graben indeholder ammoniter, inoceramer og dinoflagellatcyster, der daterer kernen til Nedre Ryazanien. Kernen tilhører den særlig radioaktive øvre del af den såkaldte J-4 unit (svarende til Deegan & Sculls Kimmeridge Clay Formation) og er beliggende ca. 50′ under grænsen mellem J-4 enheden og Valhall Formationen. Grænsen mellem de to enheder kan på grundlag af dimoflagellatcyster fra cuttings dateres til Nedre Valanginien og der kan ikke påvises nogen lakune mellem de to formationer på grundlag af disse. Den såkaldte "Late Cimmerian Unconformity" diskuteres i lyset af denne boring, og det konkluderes, at Nordsøen kun var svagt påvirket af tektonisk uro i tidlig tidlig kridt.

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