Geological age: The Unit ranges from Late Oxfordian to Portlandian in age.

Depositional environment: The fine-grained sediment, the flora/fauna, and the high organic content suggest that the J-4 Unit was deposited in a marine environment with high organic productivity and restricted bottom circulation, probably deeper shelf.

Distribution and thickness: Seismic mapping of the internal reflectors in the Jurassic sequence has not yet been carried out. A two way time to the Top Jurassic has been mapped, but no depth conversion has been made. This means that the regional depths and thicknesses mentioned below are only very approximate.

The J-4 Unit is present in most of the area (fig. 22). Only on salt structures and on structural highs is it likely to be absent. In the southern part of the Danish Central Graben, the thickness is several hundred metres and the Unit lies within the depth interval 2 1/2 to 5 kilometres, depending on its location in relation to the salt structures. The Unit is thinnest and situated highest on the structures, while in the rim-synclines it is thickest and deepest situated.

In the Tail End Graben the J-4 Unit reaches its greatest thickness. In the G-1 well, situated in the transition zone between the southern part of Central Graben and the Tail End Graben, the thickness is 1204 m .The thickness is expected to increase northwards in the Tail End Graben. Locally it might exceed two thousand metres. The depth to the top of the Unit is 3 kilometres in the southern part of the Tail End Graben, and the top dips to 4 kilometres towards the north.

In the areas north and south of the Dogger High, the depth to the Top Jurassic is generally from 3 to 4 kilometres and it can exceed 5 kilometres locally. The thickness of the J-4 Unit in these areas is not yet known.

Source rock potential: Investigations of the M-8 and I-1 sections have shown that the J-4 Unit must be regarded as the most important source rock for oil generation. It is potentially good in M-8, and rich to extremely rich in I-1. It is immature in M-8, but probably mature in the adjacent basinal areas of this structure. It is mature in I-1.

Reservoir potential: Generally poor, but hydrocarbon shows have been reported from the lime- and dolostone stringer, which thus might have reservoir characteristics.

Sealing potential: Good, due to the thick and homogeneous claystone sequence.

3.5 Early Cretaceous

By Jens Morten Hansen & Arne Buch

The Early Cretaceous sea primarily covered the same basinal regions as the Late Jurassic sea but, late in the Early Cretaceous the sea also covered Late Jurassic land masses. During Early Cretaceous time the topography of the North Sea region became gradually buried. The following major transgression comprises the transition Early/Late Cretaceous. At the Jurassic/Cretaceous transition, the Late Cimmerian unconformity is a significant feature (fig. 24), known from large parts of the North Sea region. The subsequent transgression and sedimentation of marine clay (the Valhall Formation), and marine sand (the LC-1 Unit), started late in Late Jurassic. Therefore, the formations described in the present chapter also comprise sediments of Late Jurassic age. Thicknesses of the Lower Cretaceous sediments are given in fig. 15.

LC-1 Unit *(informal name)*

The LC-1 Unit has been established in order to treat the Early Cretaceous - Late Jurassic sandstones in the V-1 well. These sandstones cannot be considered to be a part of any other formation known from the Central Graben, but they are probably equivalent to the Devil's Hole Formation (see Deegan & Scull 1977).

Type section: The Danish V-1 well, 8947-9462' b.KB.

Reference section: None at present.

Thickness: The Unit interfingers with other formations and comprises only sandstones, siltstones, carbonate-cemented siltstones (?marls), and marls. The total thickness of these sandstones, siltstones, and marly beds (excluding clay beds) is 61.5 m in V-1.

Lithology: Sand- and siltstones, silty sandstones, sandy siltstone, and sandy marl. It is grey to dark grey with thin subordinate grey to dark grey shales and clays. Calcareous and pyritic.

Log characteristics: The Unit is characterized by low gamma ray readings and very irregular sonic velocities.

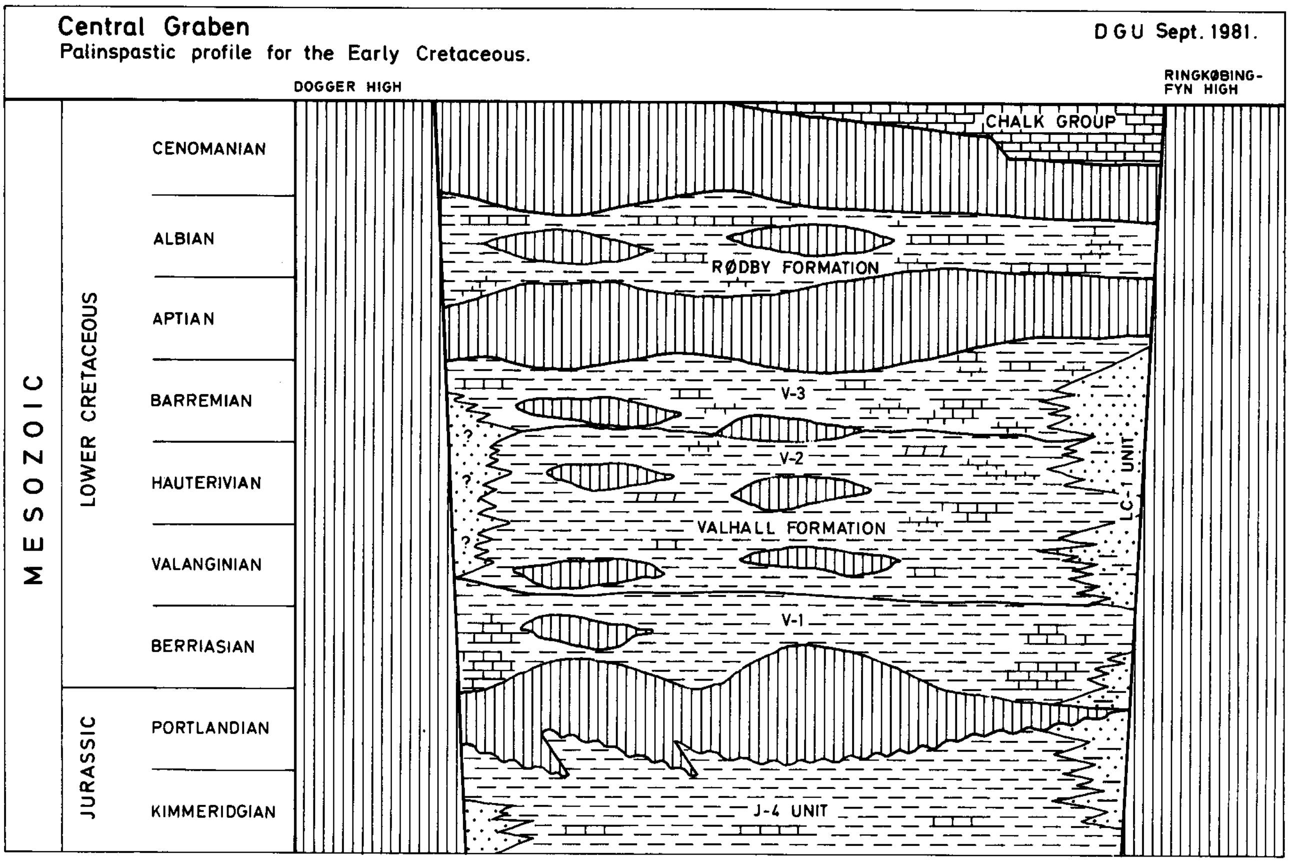

Fig. 24: Palinspastic profile of Early Cretaceous deposits. For legend, see fig. 3.

Boundaries: In the type section the boundaries are marked by a clear break in the gamma ray readings from high values in the Valhall Formation to lower values in the LC-1 Unit.

In the type well the LC-1 Unit is believed to interfinger with the J-4 Unit from 9114' to 9462' b.KB, where the lowermost sandstone beds occur.

Distribution: The LC-1 Unit is known only from the V-1 well, which is situated comparatively close to the southwestern margin of the East North Sea Block of the Ringkøbing-Fyn High. Consequently the distribution is speculative. However, the depositional environment of the Unit indicates, that it has been deposited along the southwestern margin of the Ringkøbing-Fyn High (fig. 24). There is no evidence for similar deposits along the northern and southern margins of the High, although such deposits might be present. The LC-1 Unit is analogous to the W-1 Unit east of the Dogger High (see chapter 3.4) as well as to the Devil's Hole Formation (Deegan & Scull 1977) in the British sector of the central North Sea.

Depositional environment: Palaeontological data indicate a deep-water, marine environment. The content of microfossils indicates that, to some extent, these have been reworked from older strata. A study of the dipmeter log indicates that the sandstones are neither cross-bedded nor channelled, but apparently form sand sheets which are parallel to the interbedded thin clay layers. This information indicates that the sand was transported by, and deposited from density currents, and not by water currents. Furthermore, the thickest sand sequence (8972-9114') shows a still steeper dip downhole. At the top of the sand sequence, the dip is about 10°, while at the bottom it is about 20°, which could indicate a 10° syn-sedimentary rotation of the fault block on which the Unit was deposited. The plunge of the dip is towards NE, i.e. towards the southwestern margin of the Ringkøbing-Fyn High.

These observations indicate that the LC-1 Unit was deposited from density currents originating from uplifted parts of the Ringkøbing-Fyn High during periods of rotational faulting within the Central Graben area.

Geological age: Biostratigraphical studies on foraminifera as well as on dinoflagellates indicate a Kimmeridgian to mainly Hauterivian/Barremian age for the sandstones.

Source rock potential: Poor.

Reservoir potential: No cores have been cut and no tests have been performed in the Unit. The neutron porosity varies between 3 and 35% and averages 20-25% in the upper thick sandstone.

Valhall Formation Deegan & Scull 1977

The Formation was established by Deegan & Scull (1977), who stated that the Formation is widely distributed in the central North Sea and is thin or absent only on structural highs. It may be equivalent to the Speeton Clay Formation in the southern North Sea and to the Vedsted Formation in the Norwegian-Danish Basin (Larsen 1966). The Devil's Hole Formation (British sector of the central North Sea) and the LC-1 Unit are time equivalent to the Formation. These, however, are fault-scarp controlled sandstone bodies.

Type section: Norwegian 2/11-1 well (southernmost part of the Norwegian sector) 2910-3540 m b.KB; thickness is 630 m.

Reference sections: The Formation is most completely developed in the following reference wells:

G-1 (7410- 8088' b.KB, thickness 207 m),
E-1 (8297- 9727' b.KB, thickness 436 m), and
I-1 (9508-11018' b.KB, thickness 459 m).

Thickness: The thicknesses listed above for the reference wells appear to be 'normal', i.e. from areas where Early Cretaceous halokinesis has not severely affected the accumulation of sediments.

As reflected by the seismic mapping, the 'Early Cretaceous Formations' (also including a minor series of the Upper Jurassic) exhibit a complex structural development which, particularily in the western and middle part of the Danish Central Graben, appears to have been controlled by syn-sedimentary growth of salt domes, faulting, and possibly also by shale flow in underlying sediments. Hence, the maximum thicknesses of the Early Cretaceous formations (mainly the Valhall Formation) are obtained in rim-synclines to salt domes and in the downwarped side of the Tail End Graben. The seismic thickness may locally exceed 700 m and possibly reach 1200 m (fig. 15). However, the Formation has not been drilled in any of these areas.

Lithology: In the type well the Formation is a soft, grey, calcareous mudstone, which grades into a marl. The colour may be light grey to reddish-grey. In other Norwegian wells, mudstones dominate. In the Danish sector, grey and dark grey mudstones and shales predominate, but abundant limestones, marls, and siltstone beds may occur. Generally speaking, siltstones are most abundant in the lower part, while calcareous beds are most abundant in the upper part. In addition to the grey mudstones, greenish and reddish mudstones, shales, and calcareous beds may occur mainly in the upper part.

Log characteristics: On the basis of logs, the Formation can be divided into three members: Valhall-1, 2, and 3. The lower member (Valhall-1) has a comparatively low gamma ray reading and correspondingly a comparatively high sonic velocity. The middle member (Valhall-2) has the highest gamma ray and the lowest sonic velocity of the Formation and it also exhibits the most regular log pattern of the Formation.

The upper member (Valhall-3) shows a more irregular pattern than the lower and middle members. These log characteristics may indicate an alternation between shales and siltstones in Valhall-1, a comparatively clean mudstone in Valhall-2, and a mixture of mudstone, shales, siltstones and marls in Valhall-3.

Boundaries: The boundaries to the underlying J-4 Unit as well as to the overlying Rødby Formation are generally difficult to distinguish on the basis of log motifs alone. However, depending on the magnitude of the hiatus between the J-4 Unit and the Valhall Formation (corresponding to the Late Cimmerian unconformity), the log breaks may be more or less easily distinguished.

In general the lower boundary is marked by a higher, sometimes much higher gamma ray reading, and higher sonic velocity in the J-4 Unit than in the Valhall Formation indicating a higher organic content and a harder rock type in the J-4 Unit.

The upper boundary between the Valhall and the Rødby Formations is also complicated by hiati. However, the gamma ray as well as the sonic velocity of the Rødby Formation are generally more irregular than those of the Valhall Formation.

Distribution: The Formation is widely distributed in the central North Sea, and it is also the most prominent part of the Lower Cretaceous in the Danish Central Graben (fig. 24). However, the Formation is generally thin or absent on structural highs, including salt domes, the Ringkøbing-Fyn High, and the Dogger High. In the northern part of the Danish Central Graben, the formation may also be thin or absent from areas with shale flow. However, on the basis of the available data it is not possible to conclude whether the Formation is present in W-1 and Q-1 - or not.

Geological age: In general the biostratigraphical datings indicate that both the upper and the lower boundaries of the Valhall Formation are diachronous (fig. 24).

Along the margin of the Ringkøbing-Fyn High, the Formation appears to be most completely developed and the Portlandian, Berriasian, Valanginian, Hauterivian, Barremian, and Lower Aptian stages appear to be represented. In the central part of the southern area, as well as in the northern part of the Danish sector (I-1), the Valhall Formation is more restricted in time, since the Portlandian, parts of the Berriasian and Barremian, as well as the Aptian are missing.

On the basis of the available data, it is impossible to conclude whether some of these hiati within the Early Cretaceous are of regional significance, or whether they are exclusively the result of syn-sedimentary halokinesis and faulting activity.

Depositional environment: Foraminiferal evidence suggests an open marine, neritic environment. Micropalaeontological, as well as palynological, evidence indicates predominantly aerobic bottom conditions, although thin strata with high preservation of sapropel may indicate occasional anaerobic conditions, at least in the sea bottom sediments.

Compared to the Late Jurassic formations the Valhall Formation is generally lighter in colour, indicating a larger terrigenous influx in relation to primary, marine production of organic material.

Several wells indicate that especially the Valhall-2 member is composed of numerous fining-upwards sequences with a thickness of the magnitude of 10-20'. This, together with the fact that the Valhall Formation contains a relatively large amount of terrigenous organic material, and microfossils reworked from older strata, may indicate that some parts of the Formation were formed by submarine fan accumulation, while other parts were formed by normal marine mud accumulation.

Source rock potential: The study of the organic matter of the Formation in a few wells indicates that it has no significant potential. In one well (V-1) the spore-coloration indicates that the organic matter is mature, which is unlikely to be the case in most of the other wells.

Reservoir potential: Generally poor. Intraformational porous zones belong to the LC-1 Unit or analogous yet undescribed formations.

Sealing potential: Good, due to the relatively thick and homogeneous mudstone series.

Rødby Formation Larsen 1966

The Rødby Formation was established by Larsen (1966) and named after the Rødby-1 well in south-eastern Denmark.

Type section: Danish Rødby-1 well, 459-469 m b.GL.

Reference sections: In the Danish Central Graben the Formation appears to be most completely developed in the following wells:

I-1 (9355-9508' b.KB, thickness 47 m) and
E-1 (8162-8297' b.KB, thickness 41 m).

Thickness: The Formation is generally thin, less than 50 m, typically 10-20 m, although local thickenings may occur as for instance in the I-1 and E-1 wells.

Lithology: The lithology of the Formation varies considerably from well to well, but the main characteristic feature is the occurrence of red to reddish-pink, yellowish brown, and occasionally also greenish marls, limestones or calcareous mudstones interbedded with grey clays and shales. In the I-1 well, greenish shales predominate in the lower 44 m of the Formation, while the upper 3 m consist of reddish limestone.

Log characteristics: The gamma ray readings are generally higher than in the overlying Chalk Group and lower than in the underlying Valhall Formation. The sonic velocity response varies greatly, although the sonic velocity generally is lower than in the Chalk Group and higher than in the Valhall Formation. These highly varying log responses reflect the heterogeneous nature of the Formation.

Boundaries: The upper boundary is usually marked by a slight break in the gamma ray and by the occurrence of reddish marls and shales below light grey limestones and marls.

The lower boundary is generally difficult to pinpoint on the basis of wireline logs alone, but it is defined by the occurrence of marls and limestones, or mudstones with reddish coloration above the boundary.

Distribution: The Formation is present in the Danish O-1, A-2, G-1, M-1, M-8, E-1, E-3, and I-1 wells. It is widely distributed in the central North Sea outside structural highs, in the southern part of the Danish-Norwegian Basin, and south of the Ringkøbing-Fyn High.

Geological age: On the basis of foraminiferal faunas, the Formation is invariably dated Albian and occasionally also referred to parts of the Aptian (? Late Aptian).

Depositional environment: Marine shelf.

Source rock potential: Poor. The content of organic material is too low to give any source rock potential.

Reservoir potential: Unknown.

Sealing potential: Fair, but this cannot yet be evaluated further.

3.6 Late Cretaceous and Danian limestone

By Kirsten Lieberkind, Inger Bang, Naja Mikkelsen & Erik Nygaard

At the termination of the Early Cretaceous period, the sea transgressed large earlier land areas. The transgression, the reduced relief of the continents, the generally diminished tectonic activity, the climatic change, and the enormous production of calcareous nannoplankton in the oceans profoundly changed the gross facies pattern in the North Sea region. The clastic sedimentation was replaced during Late Cre-

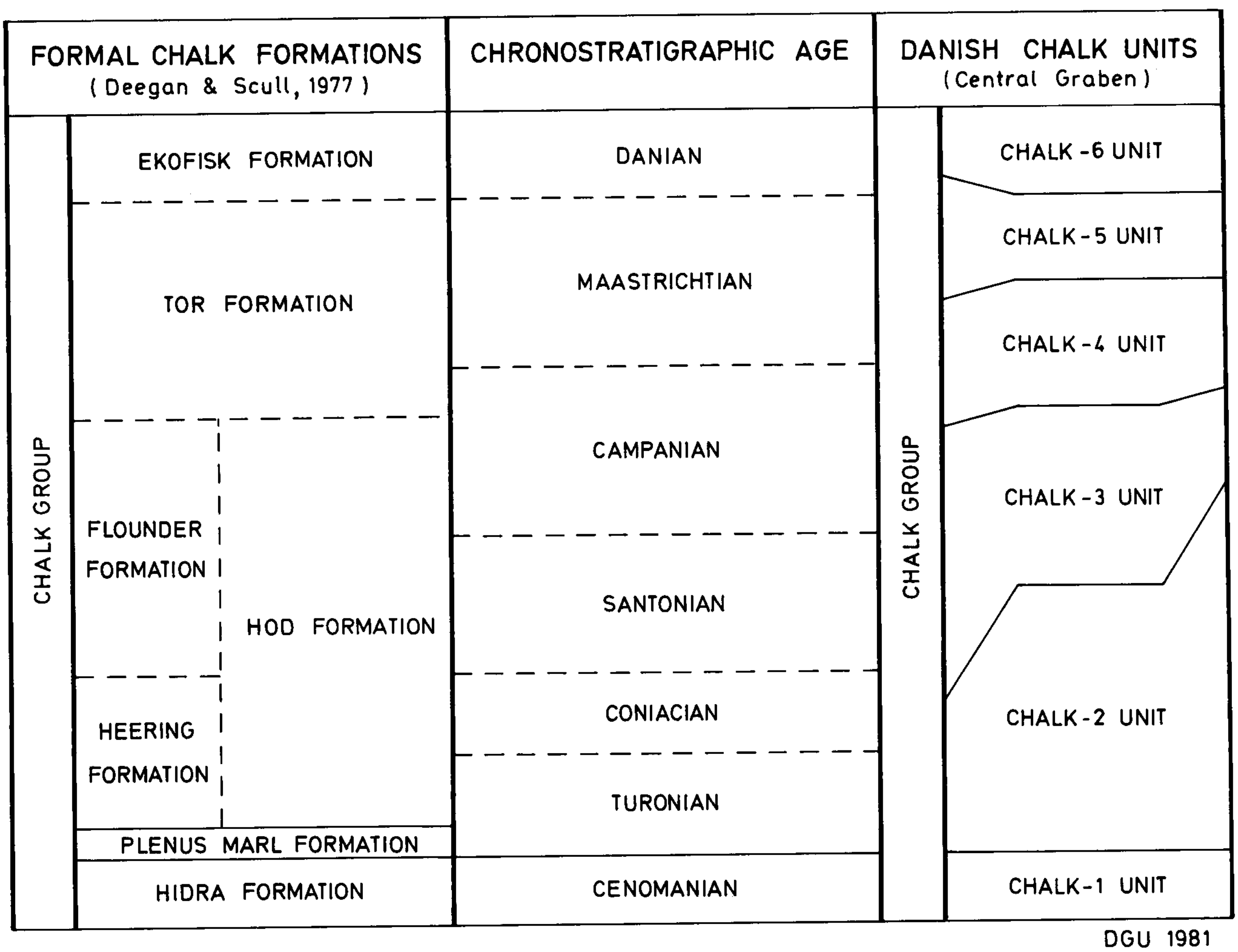

Fig. 25: A correlation between Chalk Units in the Danish Central Graben, the chronostratigraphic time table, and the formal Chalk Formations established by Deegan & Scull (1977) for the Northern and Central North Sea area.