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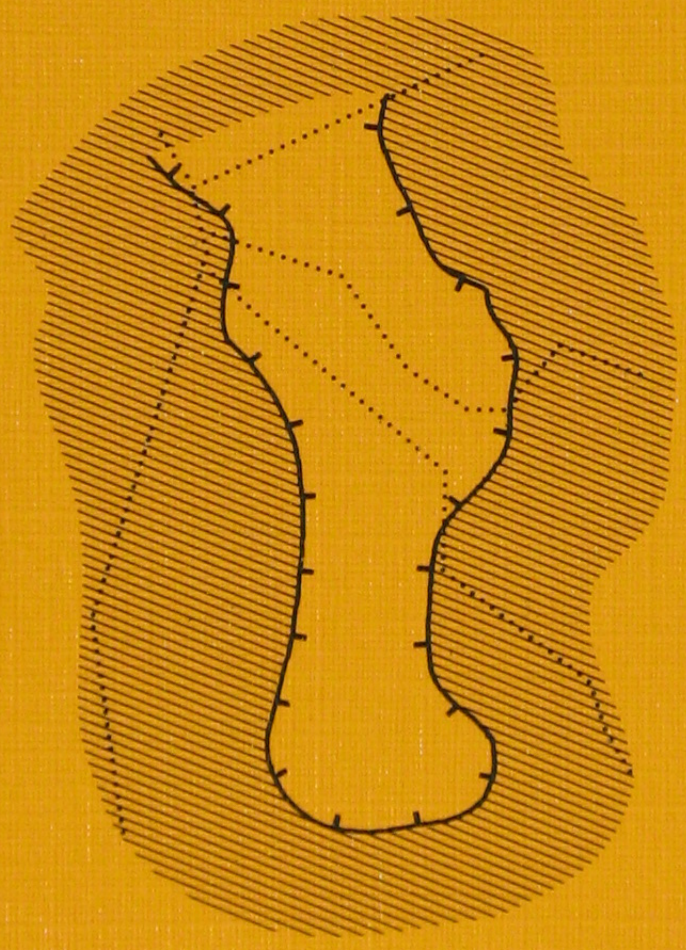
The Jurassic in the Southern Central Trough

EDITORS:
OLAF MICHELSEN & NILS FRANDSEN



Danmarks Geologiske Undersøgelse · København 1991

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Keywords:
Stratigraphy, biostratigraphy, structural geology, lithostratigraphy, petroleum geology, Jurassic, Central Graben, North Sea Basin.

Vignette:
Schematic outline of the southern Central Trough in the North Sea.

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Contents

Preface

In June 1989, DANSK OLIE- OG GAS-PRODUKTION A/S (DOPAS) sponsored a well attended symposium on the Jurassic in the Southern Central Trough held at the DOPAS premises in Hørsholm, Denmark.

The background for the symposium was a desire among geologists working in the Dutch, German and Danish sectors of the North Sea to establish a forum to discuss problems of lithostratigraphic correlation across the sector boundaries and eventually arrive at a common nomenclature.

A number of lectures were held at the symposium and an informal working group was established to deal with the details of lithostratigraphic correlation. The present publication, sponsored partly by DOPAS and partly by the Geological Survey of Denmark (DGU), contains extended abstracts of the lectures.

Hørsholm, Dec. 1990
Nils Frandsen

UPPER JURASSIC DINOCYST STRATIGRAPHY IN THE DANISH CENTRAL TROUGH

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Abstract

The English dinocyst zonations established by Woollam and Riding (1983) and Riding and Thomas (1988), and the Danish – English zonations of Davey (1979, 1982), are unified for the Danish North Sea area and the subzones of the *Endoscrinium luridum* Zone are redefined.

Two standard sections for the Upper Jurassic are described and correlations to five other wells in the Danish North Sea area are demonstrated.

Zonations

Many Jurassic dinoflagellate cyst zonations for NW Europe have been published during the last twenty years. Several are figured by Woollam and Riding (1983, fig. 9a, b). Additional data published simultaneously with or subsequent to the latter work include Davey (1982), Riley and Fenton (1982), Nøhr-Hansen (1986), Riding and Thomas (1988), Prauss (1989), Courtinat (1989).

An Upper Jurassic zonation (figs 1 and 2) is presented here for the Danish Central Trough. It is based on the work of Davey (1979; 1982), Woollam and Riding (1983), Nøhr-Hansen (1986), and Riding and Thomas (1988). Data on the stratigraphical distributions of dinoflagellate cysts from Riding (1987) and Cox *et al.* (1987) have also been incorporated. Some of the zones and subzones are discussed, and two subzones are revised. If correlation establishes the identity of two units, the first published name is preferred in the interest of simplicity (Hedberg, 1976 p. 20).

The standard ammonite zones are here treated as chronostratigraphic units (see Callomon, 1984; Wimbledon and Cope, 1978). The ammonite zones are referred to by the species name alone, e.g. Giganteses Zone.

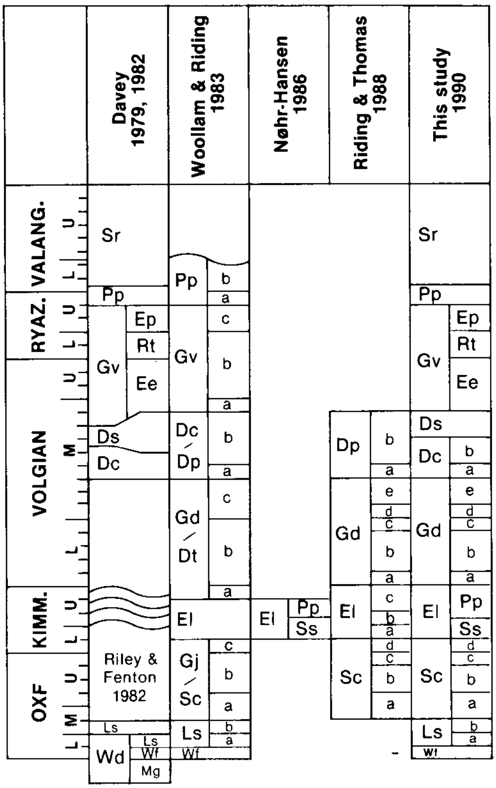

Fig. 1. Diagrammatic comparison of the proposed zonation scheme with others, published 1979–1988.

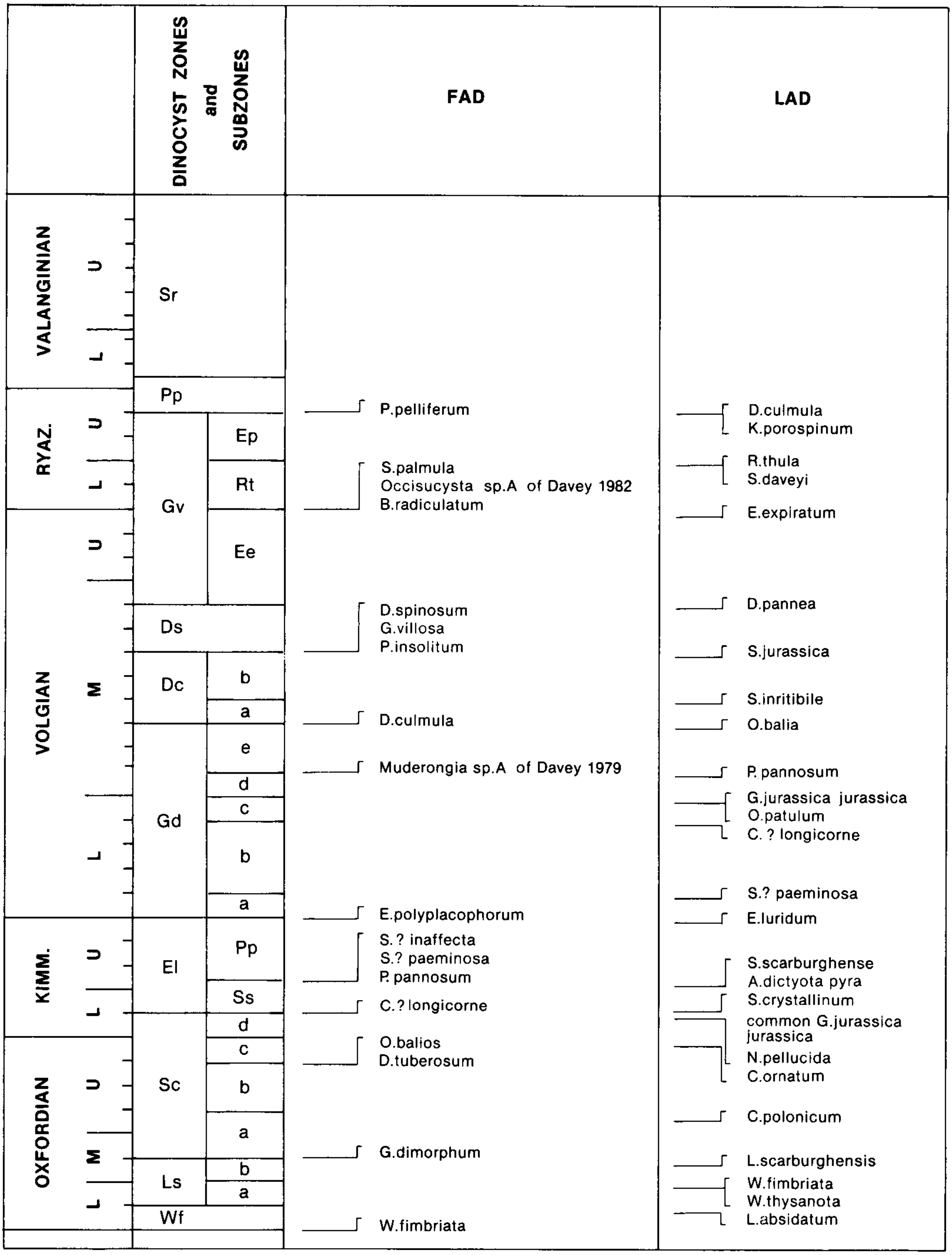

Fig. 2. Zonation scheme with first appearance datums (FAD) and last appearance datums (LAD).

Zone Dc and Zone Ds

The *Dichadogonyaulax culmula* Zone and the *Dingodinium spinosum* Zone were erected by Davey (1979). These two zones are based on the Portland Sand and the

Portland Stone of the Dorset coastal sections (Davey, 1979). Wimbledon and Cope (1978) revised the ammonite Zones corresponding to the *D. culmula* and *D. spinosum* Zones.

Davey (1979) correlated his *D. culmula* Zone with the Albani and Gorei Zones (Middle Volgian). The *D. culmula* Zone corresponds to the Portland Sand on Davey's (1979) Dorset section. Davey (1982) subsequently correlated the *D. culmula* Zone with the Albani to mid Okusensis Zone.

The *D. spinosum* Zone was correlated with the Giganteus Zone (Davey, 1979) which is equivalent to the Portland Stone on Davey's (1979) Dorset section. The *D. spinosum* Zone was correlated with the mid Okusensis to Kerberus Zone by Davey (1982).

The Dorset section of Davey (1979, fig. 2) refers to the Purbeck section of Arkell (1933 p. 495) and Wimbledon and Cope (1978) (Fig. 3). The Portland Sand of this section was assigned to the Albani and Glaucolithus Zones (Fig. 3) by Wimbledon and Cope (1978). For this reason, the *D. culmula* Zone is correlated with these two ammonite zones. The Portland Stone of the Purbeck section is equivalent to the Okusensis, Kerberus and Anguiformis Zones (Fig. 3) (Wimbledon and Cope, 1978) and the *D. spinosum* Zone is correlated to these zones. Hence, Davey's (1979) correlations between his dinoflagellate zones and the ammonite stratigraphy are believed to be correct.

The proposed *Dichadogonyaulax pannea* Zone (Dp) of Riding and Thomas (1988) correlates with the Dc and Ds Zones of Davey (1979). The latter zones have publication priority and are preferred to the more recently defined Dp Zone. However, the Subzone a and the Subzone b proposed by Woollam and Riding (1983), can be considered as subzones of the Dc Zone.

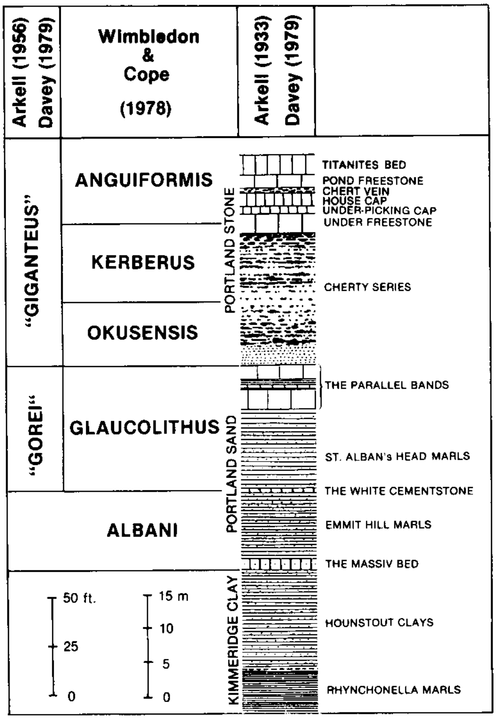

Fig. 3. Ammonite zonation of the Purbeck section, Dorset coast. After Arkell (1933, 1956), Wimbledon & Cope (1978) and Davey (1979).

The Subzone b of the Gd Zone

The *Glossodinium dimorphum* (Gd) Zone, Subzone b (Lower Volgian), was defined by Riding and Thomas (1988) as the interval from the top of their Subzone a to the last appearance of *Cribroperidinium longicorne*. The age of the top of this subzone is the top of the Hudlestoni Zone (Riding and Thomas, 1988). However, Raynaud (1978) reported the last appearance of *C. longicorne* as within the Pallasioides Zone; *C. longicorne* is, however, never found above the Hudlestoni Zone within England (Riding, oral commun., 1990). Therefore, based on the present knowledge,the top of the proposed subzone of Riding and Thomas (1988) should be maintained at the range top of *C. longicorne*.

The Subzones of the El Zone

Nøhr-Hansen (1986) proposed the *Stephanelytron scarburghense* and the *Perisseiasphaeridium pannosum* Subzones as a subdivision of the *Endoscrinium luridum* Zone. Riding and Thomas (1988) revised the subzones of this zone approximating the first and last appearance datums to the standard ammonite zonal boundaries. However, within the *E. luridum* Zone, this methodology led to an indefensible subdivision. The base of the zone is defined (Riding and Thomas, 1988) by the last appearances of *Scriniodinum crystallinum, Sirmiodiniopsis orbis*, and *Nannoceratopsis pellucida*, and the first appearances of *Cribroperidinium longicorne* and *Oligosphaeridium patulum.* The age is the base of the Cymodoce Zone (Kimmeridgian). However, Woollam and Riding (1983) reported the last appearance of *S. orbis* as the Autissiodorensis Zone (uppermost Kimmeridgian) although only indicated as rare or uncertain. Cox *et al.* (1987) reported the last appearance of *S. crystallinum* as Mutabilis Zone (Kimmeridgian), an occurrence which probably is related to reworking (Riding, oral commun., 1990). The species *N. pellucida* is rare in the Central Trough and is not useful for defining the zone boundary there.

Subzone a was defined by Riding and Thomas (1988) as the interval from the base of the zone to the range tops of *Tubotuberella dangeardii* and *Endoscrinium galeritum* and the range bases of *Subtilisphaera? inaffecta, Subtilisphaera? paeminosa* and *Perisseiasphaeridium pannosum.*

Age: Early Kimmeridgian, Cymodoce Chron (Riding and Thomas, 1988).

However, Woollam and Riding (1983) reported the last appearance of *E. galeritum* as Eudoxus Zone (Kimmeridgian), although they marked the last appearance as rare or uncertain. The last appearance of *T. dangeardii* was reported by Riding (1987) as Autissiodorensis Zone, but this occurrence is now believed to be related to reworking (Riding, oral commun., 1990).

The first appearances of *S?. paeminosa, S?. inaffecta*, and *P. pannosum* reported by Riding and Thomas (1988, text-fig. 4) as mid Mutabilis Zone were also reported by Nøhr-Hansen (1986).

Subzone b was defined by Riding and Thomas (1988) as the interval from the top of Subzone a to the range tops of *Aldorfia dictyota* subsp. *pyra* and *Stephanelytron scarburghense.*

Age: Early Kimmeridgian, Mutabilis Chron (Riding and Thomas, 1988).

However, the last appearance of *S. scarburghense* was reported by Riding and Thomas (1988, text-fig. 4) as mid Mutabilis Zone as it was reported by Nøhr-Hansen (1986). The last appearance of *A. dictyota pyra* is only indicated as the base of Mutabilis Zone (Riding and Thomas, 1988, text-fig. 4). In Riding (1987, text-fig. 5) the last appearance of *A. dictyota pyra* is indicated as mid Mutabilis Zone.

The boundary between Subzone a and b and the boundary between Subzone b and c are apparently the same, i.e. mid Mutabilis Zone. The division of the *E. luridum* Zone proposed by Nøhr-Hansen (1986) is preferred for the Riding and Thomas (1988) alternative. The zone and the two subzones are emended.

Endoscrinium luridum (El) Zone

Revised definition: The interval from the last appearance of *Nannoceratopsis pellucida* Deflandre 1938 emend. Evitt 1961, the last appearance of common *Gonyaulacysta jurassica* (Deflandre) Norris and Sarjeant 1965 emend. Sarjeant 1982 (see Raynaud (1978) concerning common *G. jurassica*) and the first appearance of *Cribroperidinium longicorne* (Downie) Lentin and Williams 1985, to the last appearance of *Endoscrinium luridum* (Deflandre) Gocht 1970 and the first appearance of *Egmontodinium*

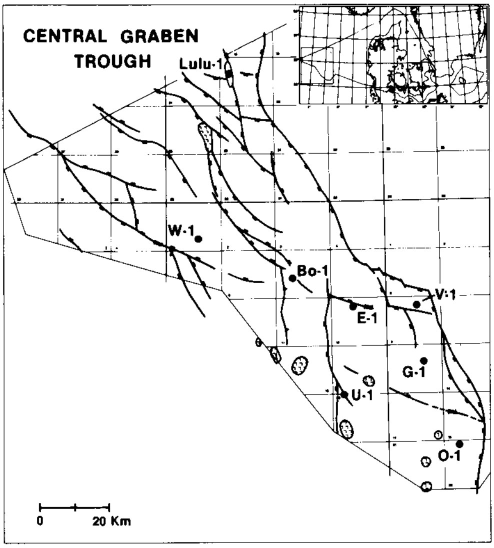

Fig. 4. Location map.

polyplacophorum Gitmez and Sarjeant 1972.

Age: Base of the Cymodoce Chron to the top of the Autissiodorensis Chron (Kimmeridgian).

Stephanelytron scarburghense (Ss) Subzone

Revised definition: The interval from the base of the zone to the last appearance of *Aldorfia dictyota* subsp. *pyra* (Gitmez) Davey 1982 and *Stephanelytron scarburghense* Sarjeant 1961 emend. Stover *et al.* 1977 and the first appearence of *Perisseiasphaeridium pannosum* Davey and Williams 1966, *Subtilisphaera inaffecta* (Drugg) Bujak and Davies 1983, *Subtilisphaera paeminosa* (Drugg) Bujak and Davies 1983.

Age: Cymodoce to mid Mutabilis Chron (Kimmeridgian).

Perisseiasphaeridium pannosum (Pp) Subzone

Revised definition: The interval from the top of the Ss Subzone to the top of the zone.

Age: Mid Mutabilis to Autissiodorensis Chron (Kimmeridgian).

Comments: There is no stratotype selected for the zone. However, the boundary between the two subzones was first described by Nøhr-Hansen (1986) at the clay-pit of Blue Circle Portland Cement, at Westbury, in Wiltshire, England.

Regional aspects: The zone and the two subzones are defined for, and found in the United Kingdom. The zone and at least the Pp Subzone are found in the Central Trough. The zone and the Pp Subzone are also present in the Danish Subbasin, both in several wells in Jutland and in wells in the Sound (between Denmark and Sweden). It is currently uncertain if the Ss Subzone is present in the Danish Subbasin. The zone is also present in East Greenland and again the Pp Subzone is recognized (Piasecki, 1980).

Standard sections and correlations

Two wells, U-1 and E-1 (figs 4 and 5), were chosen by the Geological Survey of Denmark in cooperation with the Geological Institute of the University of Copenhagen as standard section of the Upper Jurassic of the Danish Central Trough. The U-1 well represents the transition from the Middle Jurassic to the Upper Jurassic, and the lower part of the Upper Jurassic, i.e. the Lower Graben Sand, the Middle Graben Shale, the Lola Formations and the lower part of the Farsund Formation. The upper part of the Farsund Formation is missing, probably due to salt-tectonic movements. The well E-1 represents the uppermost Jurassic. More Jurassic strata are probably present, but are not penetrated in this well.

U-1

The Lower Graben Sand Formation was dated as Late Callovian by Hoelstad (1986). Common *Mendicodinium groenlandicum* at the base of the Lola Formation allow a possible correlation to the uppermost Callovian (Riley and Fenton, 1982). The last appearances of *Ctenidodinium continuum* at 10470 feet allow a correlation to the *Wanaea fimbriata* Zone (Piasecki, 1980). The last appearance of *Gonyaulacysta jurassica "hlanc"* (unpublished subspecies of Poulsen, in prep. (a)) at 10420 feet is referred to the *Liesbergia scarburghensis* Zone, Subzone a.

At 9990 feet *Scriniodinium crystallinum* Zone, Subzone a is marked by the last appearances of *Systematophora valensii* and *Compositosphaeridium polonicum*. The occurrence of *Atopodinium prostatum* in the sidewall core at 9806 feet allows its correlation with the *S. crystallinum* Zone, Subzone b. The last appearance of *Ctenidodinium ornatum* at 9740 feet indicates of correlation of this level to the *S. crystallinum* Zone, Subzone c. This subzone indicates the top of the Oxfordian. The occurrence of *Dingodinium tuberosum* together with common *Gonyaulacysta jurassica* in the sidewall core at 9690 feet permits a correlation to the *S. crystallinum* Zone, Subzone d. This subzone indicates the base of the Kimmeridgian. The Oxfordian – Kimmeridgian boundary is in this well found in the uppermost part of the Lola Formation.

All samples of the Farsund Formation in this well are correlated to the *Endoscrinium luridum* Zone. The occurrence of *E. luridum, Endoscrinium galeritum*, and *Perisseiasphaeridium pannosum* in the uppermost sidewall core of the Farsund Formation assigns this level to the *E. luridum* Zone, *P. pannosum* Subzone.

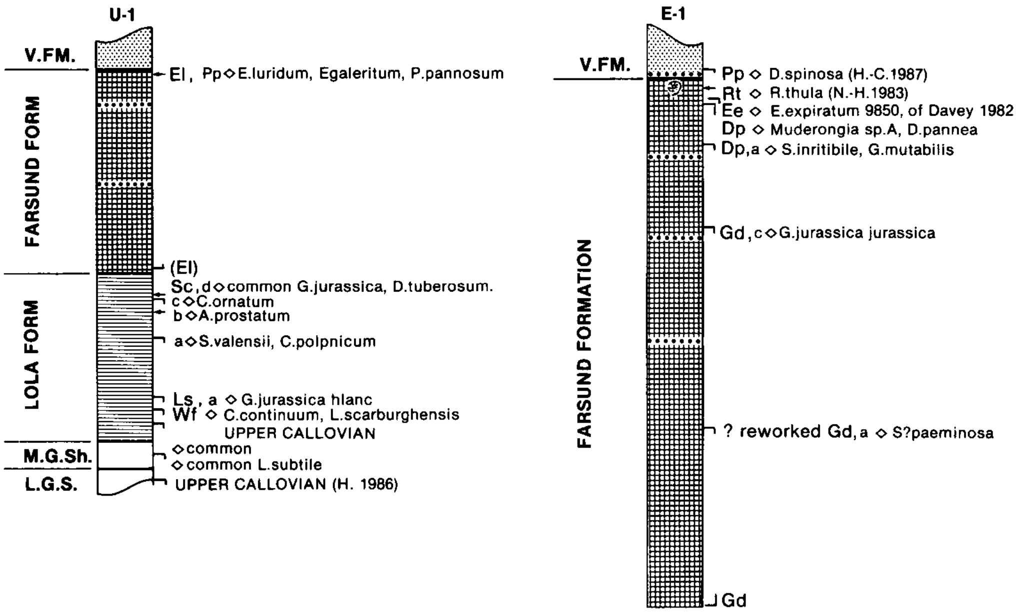

Fig. 5. Zonation of the wells U-1 and E-1. Zones and subzones are given in abbreviations, followed by index species. H. 1986 = Hoelstad, 1986; H-C, 1987 = Heilmann-Clausen, 1987; N-H, 1983 = Nøhr-Hansen, 1983.

E-1

The last appearance of *G. jurassica* at 10750 feet permits a correlation to the *Glossodinium dimorphum* Zone, Subzone c, Lower Volgian. The underlying subzones b and a or Zone El were not traceable. The occurrence of *Subtilisphaera? paeminosa* at 12050 feet is believed to be related to reworking. *Subtilisphaera? paeminosa* has its last appearance in the *G. dimorphum* Zone, Subzone a, lowermost Volgian, which apparently is not present in this well.

The last appearance of *Scriniodinium inritibile* and *Gochteodinia mutabilis* at 10190 feet is referred to the *Dichadogonyaulax panneum* Zone, Subzone a, Middle Volgian.

The last appearance of *Muderongia* sp. A of Davey 1982 and *D. pannea* at 9890 feet places this level at the top of the *D. panneum* Zone, Middle Volgian.

The last appearance of *Egmontodinium expiratum* at 9850 feet permits the correlation to the *Gochteodinia villosa* Zone, *E. expiratum* Subzone, uppermost Middle to Upper Volgian (Nøhr-Hansen, 1983).

The report of *Rotosphaeropsis thula* at 9783 feet close to the top of the Farsund Formation (Nøhr-Hansen, 1983) allows a correlation to the *G. villosa* Zone, *R. thula* Subzone, Lower Ryazanian.

The recorded last appearance of *Dingodinium spinosum* at the base of the Valhall Formation at 9690' (Heilmann-Clausen, 1987) permits a correlation to the *Pseudoceratium pelliferum* Zone, uppermost Ryazanian.

Correlations

Investigations of dinoflagellate cysts (Poulsen, in prep. (b)) have made biostratigraphical correlations between the O-1, U-1, G-1,

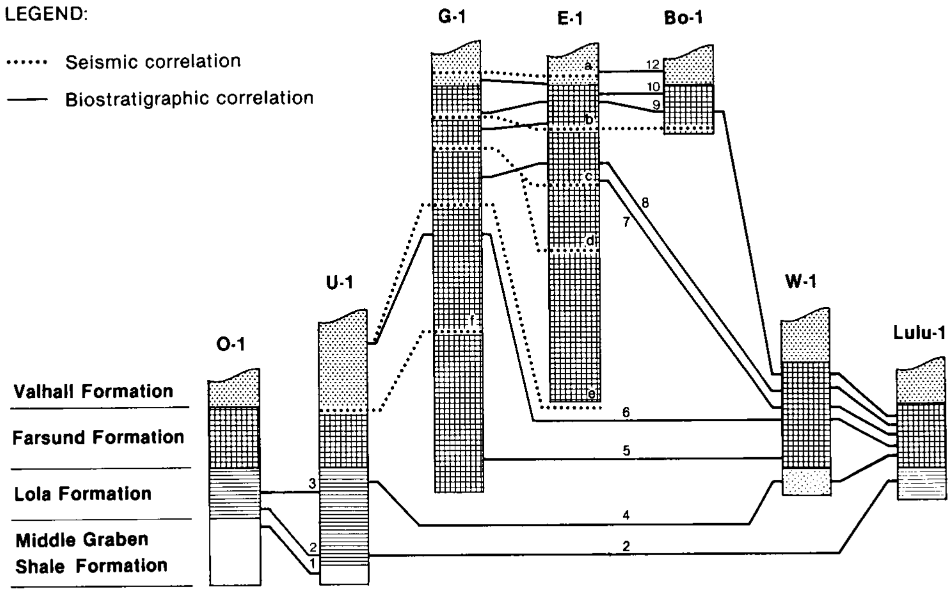

Fig. 6. Correlation between the wells O-1, U-1, G-1, E-1, Bo-1, W-1 and Lulu-1.
Biostratigraphic correlations
1. Late Callovian, 2. Early Oxfordian (Wf-Ls), 3. Middle Oxfordian Sc, a), 4. Late Oxfordian (Sc, c), 5. earliest Kimmeridgian (El/Sc), 6. Late Kimmeridgian (El, Pp), 7. early Middle Volgian (Gd, c), 8. early Middle Volgian (Gd, d), 9. mid Middle Volgian (Dc), 9a. mid Middle Volgian (Dc, a), 10. Late Volgian (Gv, Ee), 11. Early Ryazanian (Gv, Ep), 12. Late Ryazanian (Pp). (Abbreviations in parentheses = zone, subzone).
Seismic correlations
(Møller, 1986) a = LCU, b = UJ7, c = UJ6, d = UJ5, e = UJ3, f = UJ2.

E-1, Bo-1, W-1, and Lulu-1 wells possible (Fig. 4). On Fig. 6 the biostratigraphic correlations are shown in full lines. Seismic correlations after Møller (1986) are shown in dotted lines. As the figure demonstrates, seismic and biostratigraphic correlations are in many cases isochronous.

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I am grateful to Dr. James Riding, at the British Geological Survey, who kindly read an early draft of this manuscript and gave constructive criticism and suggested ways of its improvement.

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BIOSTRATIGRAPHY OF THE JURASSIC STRATA IN THE DUTCH CENTRAL NORTH SEA GRABEN

Extended Abstract

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This contribution presents an extended abstract intended for the proceedings of the symposium: The Jurassic in the southern Central Graben, Hørsholm (Denmark) June 15–16, 1989. The full text entitled "Dinoflagellate, sporomorph, and micropaleontological zonation of Callovian to Ryazanian strata in the Central North Sea Graben, The Netherlands" has been published in the proceedings of the 2nd International Symposium on Jurassic Stratigraphy, Lisbon 1989, p. 745–762.

The palynomorph zonation schemes are based on cored material. Twelve dinoflagellate zones are defined by the extinction datum (top-occurrence) of the nominate species. In general, this zonation can be correlated with information from the British Isles. In the southern part of the Central Graben fewer marine intervals occur, and dating and comparison are based mainly on sporomorphs. The limits of the six sporomorph zones are less precisely known than those of the dinoflagellate zones. Some major boundaries in the sporomorph scheme could be accurately dated with dinoflagellates in marine incursions. The upper boundary of the sporomorph zones is also defined by the first appearance downhole of the eponymous species. One of the most striking conclusions drawn is that genera such as *Cicatricosisporites*, the *Concavissimisporites/Impardecispora* plexus, *Trilobosporites*, and *Pilosisporites* occur in what are sometimes much older strata than is generally accepted in the palynological literature.

Ostracods and foraminifera of the Central Graben formations show little correspondence with those described from equally old strata in England or continental Europe. Marine intercalations provided the framework in which faunas from restricted marine or non-marine environments could be placed. With few exceptions, ostracods are the characteristic elements of the assemblages, and biozonation is mainly based on this microfossil group. Within the Central Graben area, relatively minor local variations in depositional environments gave rise to distinct microfaunal communities. As a result some of the assemblages have coincident ranges. The eleven micropaleontologic assemblages are based on ditch cuttings, and by consequence total ranges are not always precisely known. The typical *Cypridea* assemblages that are of common occurrence in the transitional Jurassic-Cretaceous fresh to brackish water deposits in all parts of the world, are not present.

UPPER JURASSIC-CRETACEOUS STRATIGRAPHY OF THE VLIELAND BASIN, AND ADJACENT AREAS, THE NETHERLANDS

Extended Abstract

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Introduction

This contribution presents an extended abstract intended for the proceedings of the symposium: The Jurassic in the southern Central Graben, Hørsholm, (Denmark) June 15–16, 1989. The full text entitled "Tectonostratigraphic development of the Vlieland Basin. The Netherlands" will appear in the Proceedings 1st Conference European Association of Petroleum Geoscientists (Berlin: May 29th – June 2nd, 1989).

The Vlieland Basin is located in the northern Netherlands; it covers the NW'ern part of the province of Friesland to the offshore area of the Frisian Island of Vlieland. It is a NW-SE striking structure which is bounded to the W, S and SE by the Texel-IJsselmeer High, and flanked by the Vlieland High, an extension of the Schill Grund High, in the north, and the North Netherlands High in the east.

In the Vlieland Basin the major Zuidwal gasfield is located, which recently started production from the Lower Cretaceous Vlieland Sandstone.

Stratigraphic Development

Jurassic-Cretaceous boundary strata of latest Kimmeridgian to Ryazanian age, were mainly deposited in a terrestrial, and partly near coastal, environment. They are assigned to the Delfland Formation. The upper part of the formation is developed in a (?paralic) coal facies in the area between wells Vlieland Oost-1 and Harlingen-1. Volcanic ashes as mentioned in previous publications, are not considered to be primary tuffs, but are thought to represent reworked tuffaceous rocks, the pyroclastic components of which were derived from the Zuidwal-1 Volcano. These strata are included in the Wadden Volcanoclastic Member, of the Delfland Formation (Central Graben Group).

The Delfland strata are concentrated in two depocentres: The prominent northern and southern subbasins which are separated by the Zuidwal-1 volcanic plug and dome. It is apparent from a stripped basement profile, constructed after decompaction and unloading that the northern subbasin subsided more than the southern subbasin. In well Vlieland Oost-1 Delfland deposits of Portlandian-Ryazanian age are underlain by marine strata of the Kimmeridge Clay Formation (Scruff Group), dated as late Early to Late Portlandian.

It is concluded that the Zuidwal-1 volcano acted as a barrier between the two Vlieland subbasins. It separates the marine realm (Scruff Group) of the SE extension of the Central North Sea Graben from the terrestrial environment (Delfland Formation) of the southern Vlieland Subbasin.

In some wells (Vlieland Oost-1 and Harlingen-1) the upper part of the Delfland Formation is of Early Ryazanian age: in several other wells indications for this dating are found. This suggests that a hiatus, representing the pre-*Albidum* Late Ryazanian, may exist throughout the entire study area.

The Vlieland Formation extends to the east as far as Leeuwarden, and hence well beyond the area of sedimentation of the Jurassic/Cretaceous boundary strata of the Delfland Formation. In the Leeuwarden area the Lower Cretaceous rests unconformably on Triassic or Zechstein strata.

The Lower Cretaceous transgression started in latest Ryazanian time, equivalent to the *Albidum* ammonite-zone. Most likely brackish deposits near the base, and nearshore marine sandstones of Valanginian age, form the Vlieland Sandstone Member of the Vlieland Formation. The Vlieland Sandstone is a major reservoir rock for gas in the northern Netherlands.

Around the Valanginian/Hauterivian boundary a remarkably thin sedimentary sequence (e.g. Zuidwal-2) is found within the Vlieland Shale Member. This may be explained by small hiatuses and/or by a condensed sequence. This level concides with a marked hiatus extending from the Late Valanginian to the Early Hauterivian in the Leeuwarden area. The younger Hauterivian and Barremian shales of the Vlieland Shale Member, which were deposited in a more open marine offshore shelf facies, show no major breaks in sedimentation. The Vlieland shales form an effective seal for the Vlieland Sandstone reservoir rock.

The typical tripartite subdivision of the Holland Formation (a mainly marly sequence of Aptian to Albian age) is well developed in the studied area. A major regional hiatus – representing at least the Lower Aptian – is present near the base of the Holland Formation. This unconformity includes the entire Aptian in the Leeuwarden area, where red rocks of Albian age rest on Barremian sediments.

Finally, the Upper Cretaceous Texel and Ommelanden Chalk Formations are remarkably thin (up to about 200 m) in the area of the Vlieland Basin. An unconformity at the top of the Ommelanden Chalk separates Tertiary from Lower Maastrichtian strata; also other hiatuses could be demonstrated in the Upper Cretaceous sequence. Outside the Vlieland Basin, a fairly thick Upper Cretaceous (500 m in Barradeel-1) and Lower Cretaceous sequence occurs, resting on Triassic rocks. The differences in thickness of the Upper Cretaceous limestones reflect tectonic inversion.

Tectonic Development

The structural evolution of the Vlieland Basin is not fully understood. It underwent a number of events related to Variscian, Kimmerian, and Alpine tectonism. It seems likely that a sequence of interrelated factors contributed to the development of this small basin:

1. NW-SE oriented strike-slip faults, initiating the formation of a small pull-apart basin, accompanied by volcanism (Zuidwal-1 volcano);
2. Loading effect of the Zuidwal volcano;
3. Thermal relaxation;
4. Loading by sediments;
5. Minor withdrawal, dissolution or subrosion of Zechstein salt.

It is assumed that there is an interrelationship between the Vlieland Basin and the major geological structures surrounding it, in particular the Central North Sea Graben (CNSG) and the Lower Saxony Basin (LSB). The link is in the form of an as yet ill-defined, partly speculative, transform fault zone passing north of the Texel-IJsselmeer High (TYH). A stable "Northwest German Block" rotated anti-clockwise with respect to the TYH and areas west of the CNSG and south of the LSB, causing right-lateral slip along a diffuse transform fault zone. Approximately NW-SE striking Carboniferous faults are thought to have been reactivated in latest Middle or earliest Late Jurassic times.

Conclusions/Summary

1. The Vlieland Basin is considered to be a pull-apart basin, tectonically related to the Central North Sea Graben and the Lower Saxony Basin.
2. The Vlieland Basin, with mainly Portlandian and Ryazanian infilling, is a relatively young basin as compared with the Central North Sea Graben, where sedimentation started in Callovian time.
3. During the Portlandian the Zuidwal-1 volcano acted as a barrier separating a marine facies, which is related to the Central North Sea Graben, from a terrestrial one in the southeastern part of the basin.
4. There is no evidence for an Upper Jurassic Lower Saxony facies (calcareous and evaporitic).
5. The Wadden Volcanoclastic sediments, previously considered to be of primary volcanic origin, presumably represent reworked material from the Zuidwal-1 volcano.

DISCUSSION OF JURASSIC LITHOSTRATIGRAPY IN THE DANISH, DUTCH, AND NORWEGIAN CENTRAL GRABEN AREAS

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Abstract

Based on recently published data dealing with the Jurassic lithostratigraphy from the Danish, Dutch, and Norwegian sectors of the Central Graben areas, it seems possible to establish a more consistent and dynamic stratigraphic scheme for these regions. A preliminary proposal of a south-north lithostratigraphic section, from the Dutch to the southern Norwegian sector is discussed. It is suggested to initiate an international cooperation in order to study the common geological features in detail.

Introduction

Since the publication of Rhys (1974) on the "lithostratigraphic nomenclature" in the southern North Sea various papers, dealing with the Jurassic lithostratigraphy in the Central North Sea, have appeared. At the same time, the amount of available well data has increased considerably, leading to even more reliable lithostratigraphic subdivisions within each of the national sectors of the North Sea. Correlation between these sectors still needs to be discussed between the geoscientists from the countries involved. This paper, which is a joint contribution of the geological surveys of Denmark and The Netherlands, could be a first step for future international coorperation.

Lithostratigraphy

General

In this chapter we will discuss several Jurassic lithological units from the Danish, Dutch, and southern Norwegian sectors which are thought to surpass national boundaries (see fig.1, for the area dealt with). The discussion is gennerally referring to the following papers:

Jensen et al. (1986) and Michelsen et al. (1987) for the Danish sector. NAM & RGD (1980), Herngreen & de Boer (1984), and Herngreen & Wong (1989) for the Dutch sector. Vollset & Doré (1984) and Bergan et al. (1989) for the Norwegian sector.

Danish sector

The Jurassic-Lower Cretaceous lithological scheme of the Danish Central Trough was described by Jensen et al. (1986) and it will be shortly reviewed below in stratigraphic order, from old to young:

Fjerritslev Formation

This Lower Jurassic formation consists of dark grey claystones interbedded with thin marlstones. It has a very characteristic log-pattern, which allows long distance correlation between the Danish Subbasin (where the formation was established), the Danish

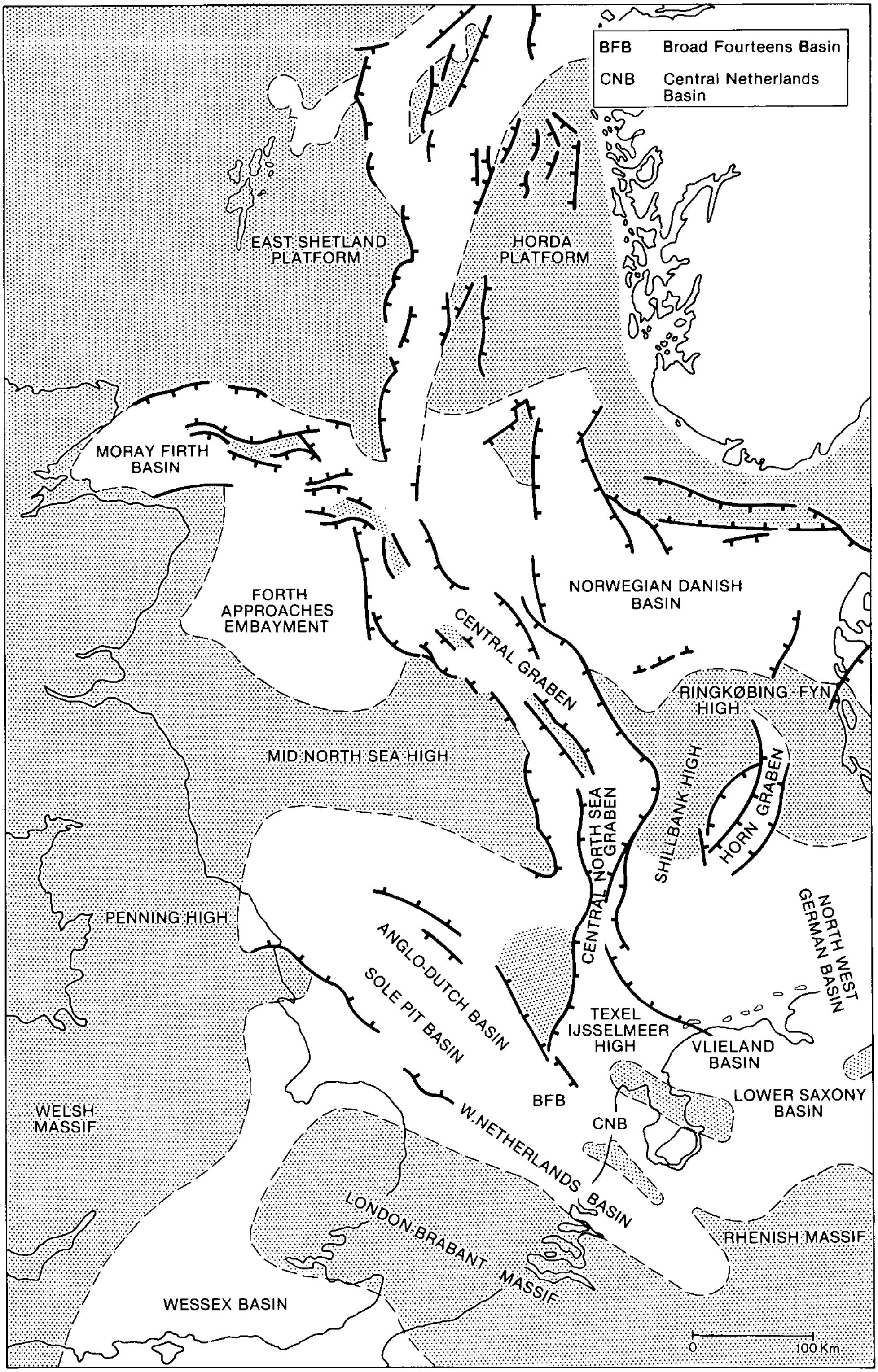

Fig. 1: Structural framework of the North Sea, including the study area (from Herngreen & Wong 1989).

Central Trough, and the southern Norwegian sector.

Lower Graben Sand Formation

In Denmark this formation has a wide-ranging Middle Jurassic age (Bajocian to Callovian), whereas in The Netherlands the age is Middle to Late Callovian only. The formation is characterized by rather thick sandstone units interbedded with claystones, siltstones and heteroliths. Thin coalbeds are intercalated towards the east in the Central Trough. The formation was established in the Dutch sector (NAM & RGD 1980) and extends into the southern Danish sector.

Middle Graben Shale Formation

In Denmark the age of this formation is Callovian, but in The Netherlands only Late Jurassic (Oxfordian) ages have been recorded. This formation comprises claystones with siltstones and sandstones. A few coalbeds may be present in the lower part of the formation. In the Dutch sector, where this formation was established (NAM & RGD 1980), the boundary with the underlying Lower Graben Sand Formation has been placed by Herngreen & Wong (1989) at the base of the lowermost coalbed. The formation extends from the Dutch sector into the southern Danish sector.

Bryne Formation

This Middle Jurassic formation consists of sandstones with numerous interbedded siltstones and claystones. Scattered coalbeds occur and all lithologies contain carbonaceous material of varying sizes. The formation was established in the Norwegian sector (Vollset & Doré 1984), and is known from the Søgne Basin and the Tail End Graben in the Danish sector.

Basal sand

This Oxfordian unit was recognized in the Norwegian sector (Bergan et al. 1989) as an approximately 100 m thick sequence of shallow marine sandstones. The section is probably identical to the one seen in the lowermost part of the Karl-1 and Gert-1 wells in the northern Danish sector. Until further data are available, the sequence is regarded as a coast near deposit, resulting from the transgression following deposition of the Bryne Formation. The basal sand is overlain by the marine claystones of the Lola Formation.

Heno Formation

This Late Oxfordian to Kimmeridgian formation consists of sandstones and siltstones interbedded with claystones and heteroliths. It is locally situated between the Lola and Farsund Formations, representing a period of regression. The formation has been established in the Danish sector at the Heno Plateau (Jensen et al. 1986), but it also seems to be present in the southern Norwegian sector. There, it is preliminarily named the Heno Formation Equivalent (Bergan et al. 1989).

Lola Formation

This Oxfordian to Kimmeridgian formation is characterized by slightly calcareous claystones with organic material of terrestrial origin. The formation is present in the entire Danish sector and, according to Bergan et al. (1989), it is also recognized in the southern Norwegian sector. There it is regarded as a member of the Haugesund Formation.

Farsund Formation

This Kimmeridgian to Ryazanian formation mainly consists of claystones with numerous thin dolomitic or limestone beds which generate the well-known log-motifs. The organic material is predominantly of marine origin. The formation was established in the Norwegian sector (Vollset & Doré 1984) and it is also present in the entire Danish Central Trough.

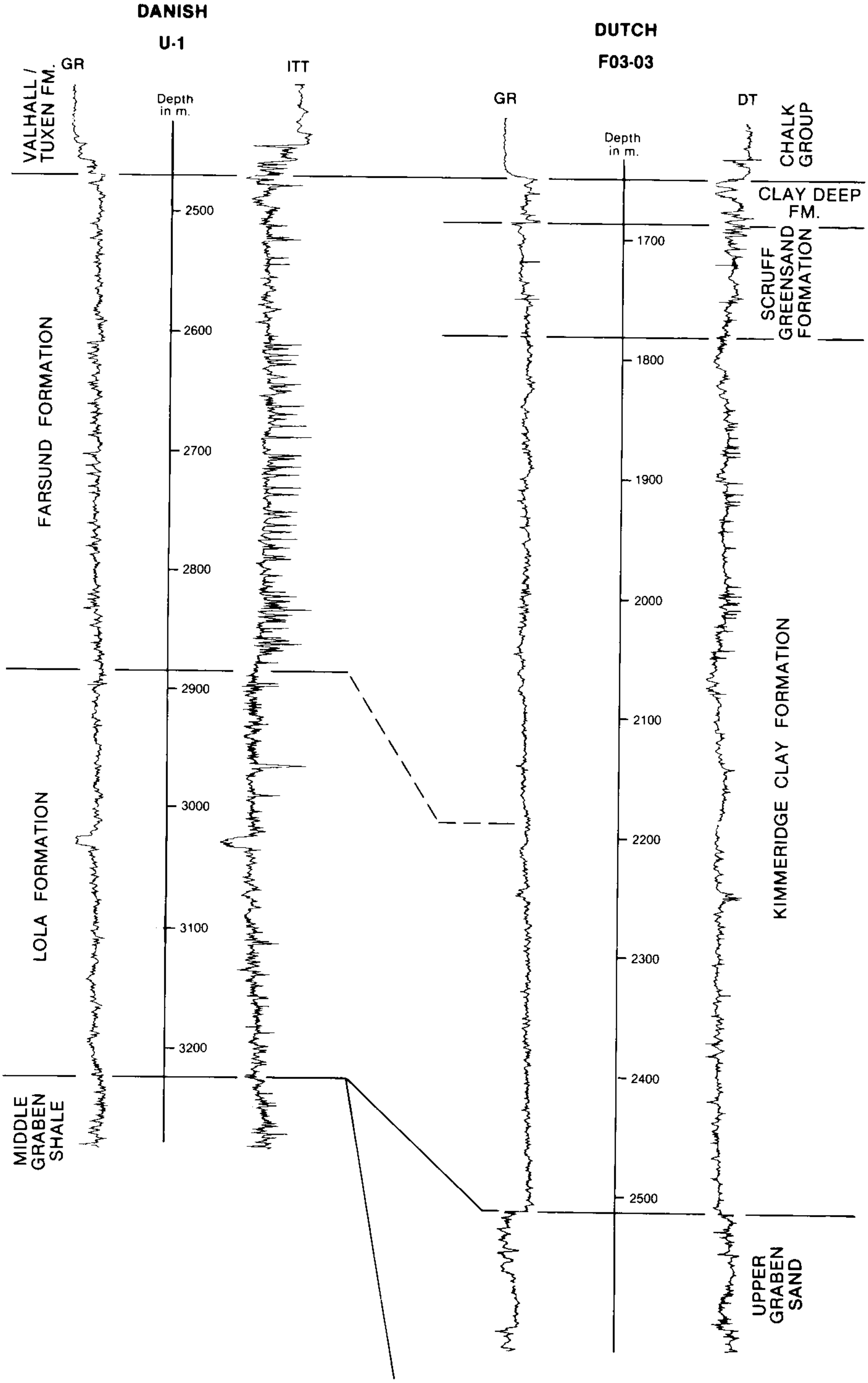

Fig. 2: Preliminary lithostratigraphic correlation of the Lola and Farsund Formations in the Danish U-1 well and the Kimmeridge Clay Formation in the Dutch F3–3 well, indicating a possible extension to the south of the two first-mentioned formations.

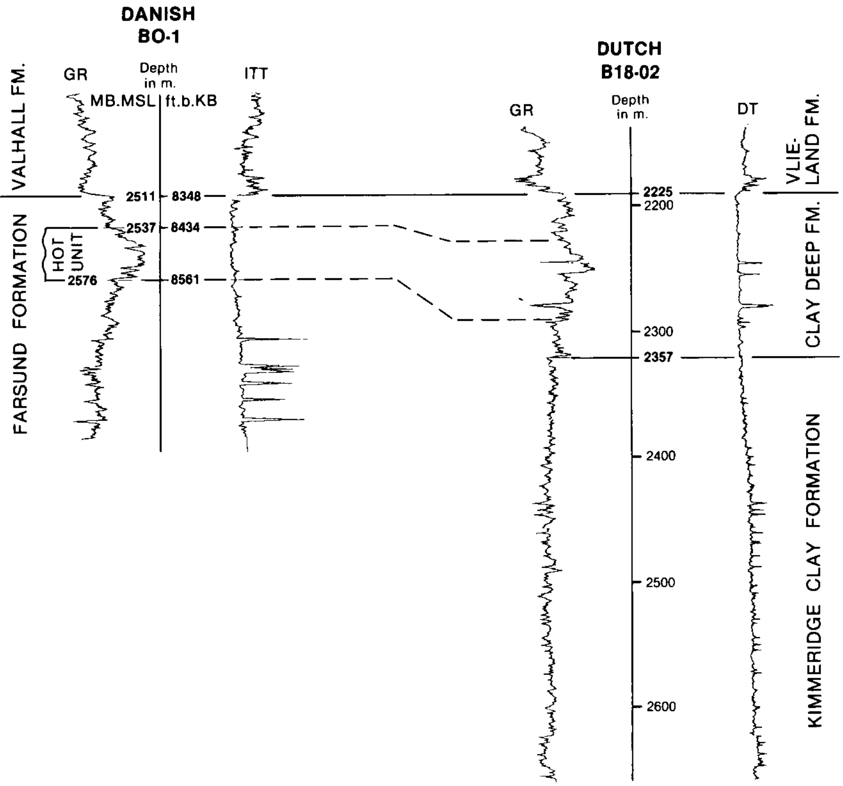

Fig. 3: Preliminary correlation of the hot unit in the Danish Bo-1 well and the carbonaceous part of the Clay Deep Formation in the Dutch B18–2 well. The log-readings suggest that the occurrence of local, highly carbonaceous sedimentary facies at the Jurassic-Cretaceous boundary is a wide-spread feature.

Hot unit

The uppermost, Late Volgian (Late Portlandian) to Early Ryazanian, part of the Farsund Formation may be highly carbonaceous, which is recognized by high gamma ray readings. In the Danish sector, this sector is informally named the hot unit (Jensen et al. 1986). It is equivalent with the Norwegian Mandal Formation, but may not be one single coherent sedimentary body. We merely regard the hot unit as a sedimentary facies variation of the Farsund Formation.

Poul Formation

To complete the review of the Danish Jurassic formations, the Volgian (Late Kimmeridgian to Portlandian) Poul Formation must be mentioned. It consists of partly argillaceous siltstones and fine-grained sandstones, which probably were deposited as gravity flows. It occurs along the eastern margin of the Danish Central Trough, interbedded in the Farsund Formation. This formation will not be further discussed in this paper, since it has a limited lateral extension.

Dutch sector

Recently, Herngreen and Wong (1989) revised the “Late Jurassic” stratigraphy of the Dutch Central North Sea Graben. The sediments discussed, range in age from Callovian to Ryazanian. They are grouped in two, partly time-equivalent, lithological units (see fig. 4): a mainly non-marine Central Graben Group (with the Lower Graben Sand, Middle Graben Shale, Upper Graben

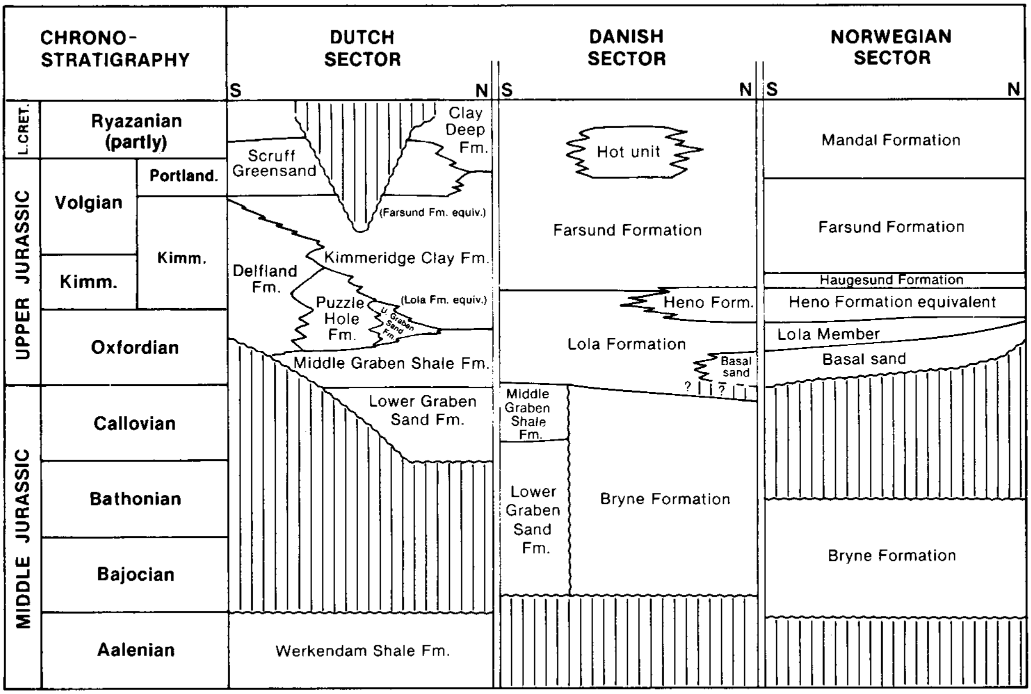

Fig. 4: Combined south-north lithostratigraphic section through the Dutch, Danish, and Norwegian sectors (modified from Bergan et al. 1989, Herngreen & Wong 1989, Jensen et al. 1986, and Vollset & Doré 1984). The section is situated approximately in the central to eastern parts of the Danish and Norwegian sectors. It suggests a possible extension of the rock units across the national borders as discussed in text. Since the German sector is not included, a close tie between the Dutch and Danish sectors can not be expected in this figure.

Sand, Puzzle Hole, and Delfland Formations) and the distinct marine Scruff Group (with the Kimmeridge Clay, Scruff Greensand, and Clay Deep Formations).

As already mentioned, the Lower Graben Sand and Middle Graben Shale Formations can easily be extended into the Danish sector. Therefore, the attention will be focussed here on the overlying Late Jurassic sediments.

Kimmeridge Clay Formation

In the Dutch sector this formation rests conformably on sediments of the Central Graben Group. Generally, the formation is conformably overlain by either the Scruff Greensand or the Clay Deep Formation. In the northern part of the Dutch Central North Sea Graben, the age of the Kimmeridge Clay ranges from mid Oxfordian to Middle Volgian. In this area, Herngreen & Wong (1989) noted that a twofold division can be made of the formation. The upper part is characterized by the presence of numerous dolomitic beds, whereas the lower part is predominantly clayey. The same authors reported the presence of a slight intraformational unconformity which seems to coincide with the boundary between these lithologies. They also emphasized the similarity with the Danish Central Trough in which the upper and lower units are named Farsund and Lola Formations, respectively. Pending further investigation, it was decided not to introduce new formation names but to maintain the well-established Dutch nomenclature.

If we compare the Danish and the Dutch reference wells, respectively U-1 and F3–3, there appears to be a good lithostratigraphic correlation (fig. 2). True lithostratigraphic conclusions can obviously not be drawn from this correlation, but it supports the assumption that further investigations of relevant Danish and Dutch wells possibly may lead to the extension of the Lola and Farsund Formations to the south. Local developments within the Kimmeridge Clay in the Dutch sector (e.g. the disappearance of dolomitic streaks and the increased silty character towards the south) also need to be studied in detail.

Clay Deep Formation

This is a new name proposed by Herngreen & Wong (1989) for a rather bituminous claystone that conformably overlies the Kimmeridge Clay Formation in the northern part of the Dutch Central North Sea Graben. It was also stated that the formation differs from the Kimmeridge Clay by the absence of well-developed dolomite stringers. Furthermore, the bituminous character of the formation decreases toward the south, where the formation is reported to conformably overly the Scruff Greensand Formation. In this southern realm the Clay Deep Formation is rather difficult to recognize because the gamma ray readings are rather low, corresponding to a normal clay level. In general however, these readings are slightly higher than those of the overlying claystones of the Vlieland Formation. As far as the dolomite stringers are concerned, it is known from Danish well data that density and number of these stringers vary greatly. This feature may, therefore, not alone be diagnostic in the lithostratigraphic discussion.

Herngreen & Wong (1989) already pointed to a possible relationship with similar hot units from Norway and Denmark, stating that the Clay Deep Formation represents one of the southernmost occurrences of the Kimmeridge Clay "hot shale" facies of Barnard & Cooper (1981) in the North Sea area. If we compare the only Dutch well showing extremely high gamma ray readings of the Clay Deep Formation, the B18–2 well, with the Danish type section of the hot unit, the Bo-1 well, a close resemblance is apparent (fig. 3). In both sections, the hot unit interval comprises dolomitic stringers.

It is evident that, also in this case, we need to study more data from Danish and Dutch wells before we can make any revision. At present it seems likely that a hot unit is present in the Dutch sector but it is still open for discussion if the remaining (non-bituminous) part of the Clay Deep Formation should be referred to the Kimmeridge Clay (or the Farsund Formation).

Norwegian sector

In fig. 4 the lithostratigraphic scheme of the Jurassic in the southern Norwegian sector is presented.

Basal sand

This is the oldest Late Jurassic (Oxfordian) formation recorded in the southern Norwegian sector. It has been interpreted as shallow marine sands deposited during the transgression, which came from the north. It is covered by the deeper marine deposits of the Lola Formation (ranked as a member of the Haugesund Formation).

Heno Formation Equivalent

In all well sections shown by Bergan et al. (1987), the Lola Formation is separated from the more sandy Haugesund Formation by the Heno Formation Equivalent, which they correlate to the Heno Formation in the Danish Q-1 well. This unit may therefore be regarded as the northern extension of the Heno Formation.

Haugesund Formation

This formation comprises sandy claystones. It has not yet been recognized within the Danish sector. Since it overlies the Heno

Formation it may be approximately time-equivalent to the lower Farsund and upper Lola Formations.

Farsund Formation

Since this formation, including the hot units, has a uniform appearance in the Norwegian and Danish sectors no further discussion is needed.

Mandal Formation

The highly bituminous claystones seem to be comparable to the hot units in the Danish and Dutch sectors, but further research is required to unravel their relationship.

Conclusion

Having identified several common features within the Upper Jurassic stratigraphy of Denmark, the Netherlands, and Norway it seems appropriate to suggest a cooperation across the national boundaries. We think that it should be possible to establish a consistent use of lithostratigraphic names, extending the formations outside the national sectors. In combination with further biostratigraphy and structural studies, a revised lithostratigraphy will contribute to a better and more dynamic description of the basin development.

In fig. 4 we present a preliminary proposal of a south-north lithostratigraphic section (from the Dutch sector to the southern Norwegian sector). At present, we do not have data from the intermediate German sector which makes a close tie between the Dutch and Danish sectors difficult. Despite this drawback, our section seems to represent a consistent picture which we can summarize as follows:

1. On top of the fluvial to shallow marine Middle Jurassic Bryne Formation and Central Graben Group, marine clays (Lola Formation) were deposited in the central part of the area whereas, at structural highs, transgressive sands (Basal sands) accumulated. During the following regression sand of the Heno Formation was deposited in the Danish and Norwegian sectors. Both units are time-equivalent with the Delfland and Puzzle Hole Formations.
2. Marine clays were uniformly deposited over large areas, resulting in the Lola and Farsund Formations.
3. Intercalations of sandy units as the Poul Formation in the Farsund Formation (and probably also in the Dutch Kimmeridge Clay Formation) are due to local sedimentary processes.
4. At the Jurassic-Cretaceous boundary, organic rich clays (hot units) were deposited, probably in local sub-environments.

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DIAGENETIC ASPECTS OF UPPER JURASSIC SANDSTONES IN THE DANISH NORTH SEA SECTOR

Extended Abstract

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Studies of Upper Jurassic sandstone formations, the Heno Formation and the Gert unit, in the Danish North Sea sector have revealed two diverging diagenetic trends, which appear related to sedimentary environments: 1) Distal marine sands (lower shoreface to offshore) end up as reservoirs with fair porosities but low permeabilities, 2) Marginal marine sands (beach, barrier-island complex) create reservoirs with fair to high porosities and fair to high permeabilities.

The critical diagenetic factor is that distal marine environments at late stage diagenesis suffered illitization and thus impairment of permeability, while the marginal marine environment appears non-illitized. From studies elsewhere in the North Sea, Bjørlykke et al. (1986) argue that illitized sandstones arise, when potassium-bearing silicate minerals like feldspars and micas contained in the sand decompose upon burial to temperatures above c. 110°C (cf. Bjørkum & Gjelsvik 1988). Non-illitized sandstones arise if no potassium-donating minerals are present when the critical burial temperatures are reached, i.e. if the sand suffered potassium depletion due to earlier burial dissolution or replacement of the minerals. Support is provided by Lønøy et al. (1986), who reported authigenic kaolinite existing metastably under formation temperatures as high as 150°C, the reason being the lack of potassium feldspar to act as potassium donor for the transformation of the kaolinite into illite. If sands behave roughly as closed systems during deeper burial, it thus appears that early removal of potassium-donating minerals can in some cases delay or possibly even prohibit burial formation of illite. A factor to keep up roughly closed system behaviour may be the high overpressures created in the Upper Jurassic sands by the Upper Cretaceous chalk seal. Such overpressures may help to keep out potassium-carrying exotic fluids.

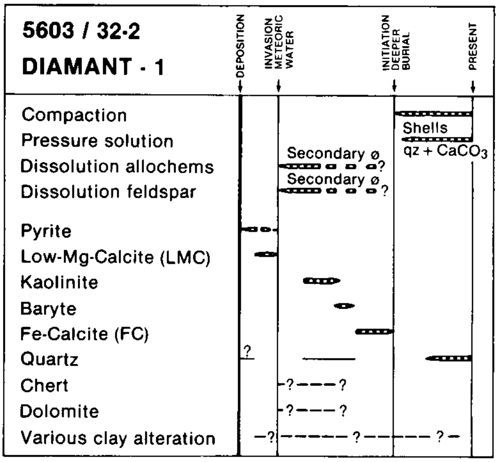
Potassium donators in sand are generally feldspars and micas. Dissolution of feldspars and replacement of micas require neutral to acid porewaters, which are undersaturated with respect to these minerals. Principal sources, as discussed by Bjørlykke et al. (1986), are: (1) meteoric water, (2) acid pore water produced by expulsion of carbon dioxide from maturing kerogen in a source rock. Flushing by meteoric water is a shallow burial incident either following soon after deposition or following uplift, the latter giving the water access to previously deeper buried rocks. Invasion by maturation-generated acid fluids will generally be an intermediate to deeper burial incident. Invasion by maturation generated fluids and invasion by meteoric water following large scale uplift, are hardly likely to be dependent on the sedimentary environment of the invaded sandbodies. Invasion by meteoric water following deposition, however, is. Meteoric water flushing of marine sands will typically occur in marginal marine environments, where an elevated groundwater table in the hinter- lands can act as a pressure head to drive the fresh water into the basin. Such invasion along North Sea sector Jurassic coast lines has been argued to explain feldspar dissolution in marginal marine sands and no dissolution in more distal sands (Bjørlykke et al. 1986).

If the outlined mechanism is a widespread phenomenon it clearly implies that marginal marine environments are the most optimal exploration targets in regions where potential sand reservoirs have been buried deeper than 3–4 km.

The diagenetic alterations which occurred in the barrier island complex sandstones from the Heno Formation in the Danish well Diamant-1 (5603/32–2) illustrate some of the involved processes. The study involves oxygen, carbon and strontium stable isotopes and will be presented more comprehensively elsewhere (Andersen, in prep.) The alterations are conveniently tripartitioned (fig. 1):

Step 1, very shallow burial: Pyrite, low magnesian calcite and subordinate quartz formed. Labile minerals like feldspar and aragonitic shell debris aragonite were stable. Along with isotopic evidence ($\delta^{18}O$, $^{87}Sr/^{86}Sr$) this indicates a pore water regime of evolving marine waters.

Step 2, very shallow burial: Pore filling kaolinite, Fe- calcite and baryte formed along with minor quartz, dolomite, chert and clays. Labile components such as feldspars, shell debris and faecal pellets were intensely dissolved. This sudden break in the line of diagenetic alterations set by step 1 indicates a dramatic shift in pore water composition from marine to meteoric. The $\delta^{18}O$ composition of the Fe-calcite implies pore water ratios of 7–9‰ SMOW, which for a very shallow burial origin is in agreement with a meteoric regime. $^{87}Sr/^{86}Sr$ ratios indicate that the constituents needed for precipitation of Fe- calcite were derived from dissolution of the shell debris.



Step 3, burial: Compaction, pressure solution and overgrowth of quartz. At a certain stage the authigenic quartz stabilized the grain framework of the sand, thus preserving both high porosities and high permeabilities.

Potassium depletion by meteoric water invasion following deposition is thus indicated for the Diamant-1 well. Further, the sandstones are not illitized. Therefore, the alterations fit the model outlined above. However, the Heno Formation in the Diamant- 1 is buried to 3800 m only, and, therefore, this well does not effectively test the possibility of a significant delay of illite formation.

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PRE-LATE CRETACEOUS STRUCTURAL DEVELOPMENT OF THE DANISH CENTRAL TROUGH

Extended Abstract

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The structural development of the Danish Central Trough area from the Carboniferous to the Early Cretaceous was studied to test how far back in geological time a graben development can be justified or proved by data.

The late Hercynian compression seems to have influenced the area. The presence of Rotliegende volcanics may be related to transtensional movements along a right lateral, northwest-southeast strike-slip fault system. The Zechstein, Triassic, and Early Jurassic times are regarded as stable tectonic periods, during which the Central Trough area may have acted as an inter-basinal barrier.

The trough region, and adjacent areas, were uplifted in early Middle Jurassic times, and the subsequent erosion cut into the Lower Jurassic in the southeastern trough area and into the Upper Palaeozoic towards the north-northwest. A major halfgraben developed along the Coffee Soil Fault, bordering the Ringkøbing-Fyn High, and Middle Jurassic coarse-clastic sediments were deposited along this fault zone.

During the Late Jurassic, the Central Trough was broadened probably as a result of slow rifting, and minor individual half-grabens developed during the Kimmeridgian (Feda and Gertrud Grabens) and Volgian (Grensen Nose and Outher Rough Basin). Starvation of the Søgne Basin and footwall uplift of the Mandal High took place late in the Late Jurassic. The Inge and Mads Highs seem to have been parts of the Mid North Sea High until this time.

During the Early Cretaceous, the depocentres generally moved westwards and the subsidence rates decreased. The tectonic regime changed and the first inversion tectonic event occurred in the Mid Hauterivian.

This abstract partly covers the structural geologic aspects of the paper entitled: "Pre-Cretaceous structural development of the Danish Central Trough and its implications for the distribution of Jurassic sands" presented by O. Michelsen, T. E. Mogensen, and J. A. Korstgård at the meeting on "Structural and tectonic modelling and its application to petroleum geology", Stavanger, Oct. 1989. The full text will be printed by Elsevier Science Publishers, Amsterdam.

STRUCTURAL DEVELOPMENT OF THE DUTCH CENTRAL GRABEN

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Introduction

After Heybroek (1975) described the structure of the Dutch Central North Sea Graben and NAM and RGD (1980) published a stratigraphic nomenclature of the Netherlands containing a stratigraphic model for the Jurassic sediments, further work continued, both within the industry and the Geological Survey. Because Herngreen and Wong (1989) set up a revised stratigraphy for the Late Jurassic of the Central Graben and neighbouring areas, it was felt necessary to have a closer look at the structural geology of the Central Graben and to review its hydrocarbon potential. The results of this study have been reported by Wong et al. (1989). This work just about coincided with an increased interest of the industry in the south-eastern extension of the Graben because of the Dutch seventh round of exploration licenses.

In the publication by Wong et al. (1989) the chapter about the structural development of the Dutch Central Graben deals with the observations from seismic interpretation, a proposed subdivision of the area into four structural elements and a brief description of the structural history. Structural geology is illustrated by three regional profiles crossing the Central Graben.

The Central North Sea Graben in the Dutch sector of the North Sea is part of the large Mesozoic North Sea rift system, and can be regarded as the southernmost extension of the Central Graben s.l. which north of the Dutch sector is recognized in the German, Danish and Norwegian sectors (fig. 1). Within the area studied by Heybroek (1975), Clark-Lowes et al. (1987) and Wong et al. (1989) the rift system is very clearly expressed in the north (the Dutch B and F-quadrants), with the main structural trend being NNE-SSW and tapers out toward the south (L and M-quadrants) where a striking change in structural trend takes place. Compared to the simplified rift models described by McKenzie (1978) and Harding (1983), where listric normal faulting is the dominant deformation mechanism (Badley et al. 1984), the Dutch Central Graben shows a much more complicated picture.

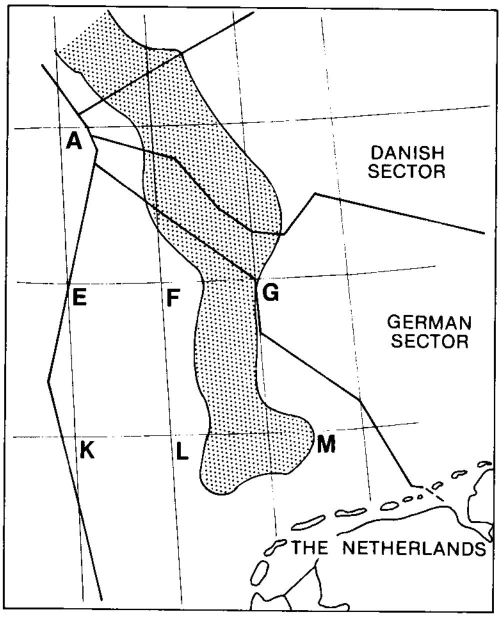

Fig. 1

Observations on seismic profiles.

The three regional profiles published by Wong et al. (1989) which cross the Dutch Central Graben have been constructed from a fair amount of seismic material. In the area it was observed that at least three superimposed effects complicate the simple rift model. First of all severe salt movements took place throughout the Mesozoic resulting in swells, domes and collapse structures. Particularly the major boundary fault systems are often overlain by elongated ridges of Zechstein salt. It should be noted however that the latest high quality seismic sections made it possible to interpret substantially smaller volumes of salt than were preferred in the past. Apart from Zechstein salt also Upper Triassic salt seems to have been subject to halokinesis in the deeper central parts of the Central Graben. Secondly considerable strike slip components of some of the movements led to more complicated appearances. Structures similar to flower structures as described by Harding (1985) have been observed and also changes in the sense of throw along some of the faults – otherwise difficult to explain – indicate that strike slip components played a role. Because the dip slip components still dominate it is best to speak of oblique slip faulting. Finally a major part of the basin underwent Late Cretaceous tectonic inversion.

Other important observations which illustrate the structural development of the basin are the asymmetric development from east to west and the change in the intensity and timing of the rifting from north to south. The Central Graben can in fact be regarded as a half graben. The western margin shows far larger dip slip offsets at the bounding faults, while at the eastern margin a more gradual change can be observed. The intensity of the rifting gradually decreases from the B-quadrant to the L- and M-quadrants, and the timing of events is later in the south. For instance the overstepping of the graben margins by Upper Jurassic sediments takes place later in the south. This is reflected by the age of these units.

Structural elements.

The area has been schematically subdivided into four main structural elements according to typical depth of the pre-rift basement, location of boundary faults, and typical post-Permian stratigraphic sequence. Because of the change in intensity of deformation this subdivision is most easily made in the north and gets more arbitrary toward the south. The elements are platform (characterized by base Zechstein at some 3000 m, little or no Triassic sequence), intermediate platform (base Zechstein at 4000 to 5000 m and a thick Triassic sequence but little or no Jurassic), outer graben (with base Zechstein at least at 5000 m and a complete Triassic sequence overlain by thick Middle and Late Jurassic units) and inner graben (with base Zechstein deeper than 5000 m, and very thick Jurassic sequence) respectively. The structural inversion coincides with the axis of the basin in the F-quadrant but turns to a NW-SE trend where the basin swings suddenly to a WNW-ESE trend at its southern margin. The elements are displayed in the general outline of the area in Wong et al. (1989) and Wong in this volume.

Structural history

The evolution of the basin is essentialy consistent with the two phase model of McKenzie (1978) with the rift phase starting in the Early Triassic and the sag phase starting during the Early Cretaceous, but superimposed are the complications mentioned above like the inversion during the Late Cretaceous, and the strike slip components of faulting also mentioned by Ziegler (1975) and Van Wijhe (1987). It looks like the oblique slip movements are most easily related to the Late Cretaceous inversion phase, thus giving transpressional deformation. Fig. 2 shows the major WNW-ESE trending faults in the south (both at the margins of the south-eastern subbasin in the L and M quadrants and on the platform around the E-quadrant). These faults are thought to have been reactivated several times during geologic history and to have displayed strike slip components particularly during the inversion phase. The junction area where this trend meets the main N-S trending Central Graben remains an area that is intriguing and difficult to interpret.

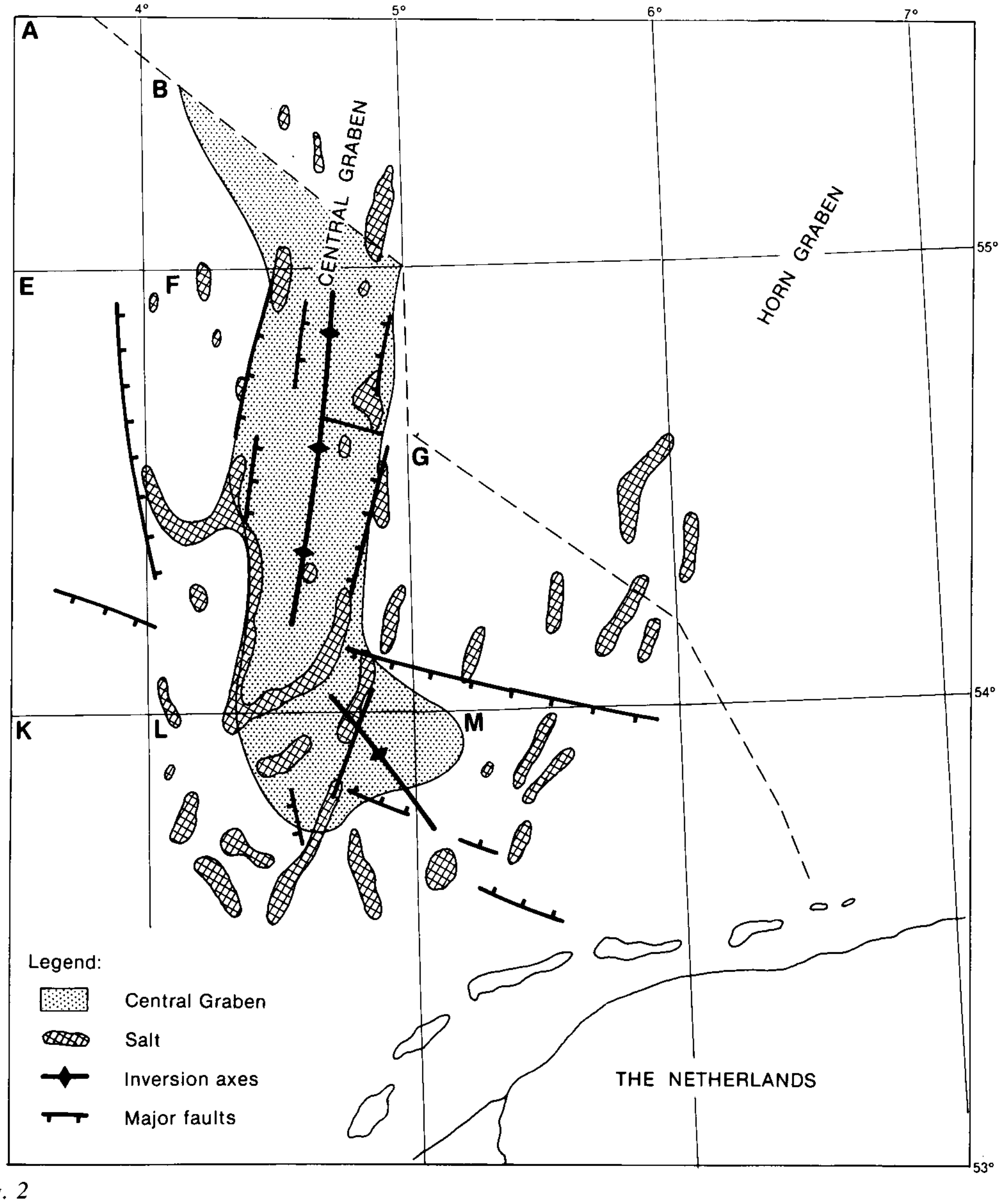

Fig. 2

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PETROLEUM GEOLOGY OF THE DUTCH CENTRAL NORTH SEA GRABEN

Extended Abstract

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This contribution presents an extended abstract intended for the proceedings of the symposium: The Jurrassic in the Southern Central Graben (Hørsholm, Denmark, June 15–16, 1989). It generally covers the stratigraphic and petroleum geological aspects of the paper entitled: "Late Jurassic" petroleum geology of the Dutch Central North Sea Graben presented by Th. E. Wong, Th. H.M. Van Doorn and B.M. Schroot at the 78th annual meeting of the Geologische Vereinigung (Jülich, febr. 24–26, 1988). The full text has been published in Geologische Rundschau, 78, 1989, pp. 319–336. The structural and seismic aspects are delt with in detail by B.M. Schroot in the present volume

Brief Structural and Stratigraphic Setting.

The area has been subdivided into a number of structural elements: platform, intermediate platform, outer graben and inner graben (Fig. 1). Characteristic features defining these elements are: typical depth of the pre-rift basement, boundary fault systems and the post-Permian stratigraphic sequence. In the northern part of the area the elements can be easily recognized because intense rifting caused substantial throw at the faults. Toward the south the situation is less distinct, becoming even rather arbitrary at the southeastern end of the Central North Sea Graben, which was only subjected to limited rifting.

It is evident that the lithological record in the Central North Sea Graben reflects the complex geological history of the area. Superimposed on the normal rifting configuration there are features such as: considerable strike-slip components of the faulting, intensive halokinesis and inversion. Although rifting was apparent since the Triassic, the major rifting phase took place during the Late Jurassic. In this context, the sediments can be grouped as follows (see fig. 2 for more details):

a) Pre-rift sediments (Carboniferous – Middle Jurassic)
b) Syn-rift sediments (Late Jurassic)
c) Post-rift sediments (Cretaceous-Quaternary)

Prospectivity

Source Rocks

Carboniferous

The coal-bearing strata of the Westphalian A-C are the main gas source rocks and are present in the (intermediate) platform areas (fig. 1). In the central part of the graben, wells have never reached Carboniferous rocks so that their presence can only be inferred from the regional geology. The main kerogen type of the coal-bearing strata is vitrinite (type III kerogen). Basin modelling showed that the top of the Carboniferous entered the gas generating window at different times across the Central North Sea Graben. On the intermediate platform in the SE part of the area, the top of the

Westphalian became mature in the Tertiary. In the outer graben, this already took place in the Late Jurassic to Early Cretaceous.

Late Triassic – Early Jurassic

The Late Triassic Sleen Shale and the Early Jurassic Aalburg Shale contain not only marine algal sapropel, but locally also large amounts of land derived organic material. Although both shales can be considered as source rocks mainly for gas, their contribution to known gasfields in the region seems to be rather limited. The overlying Posidonia Shale, occurring in the inner and outer graben areas, is the principal oil source rock

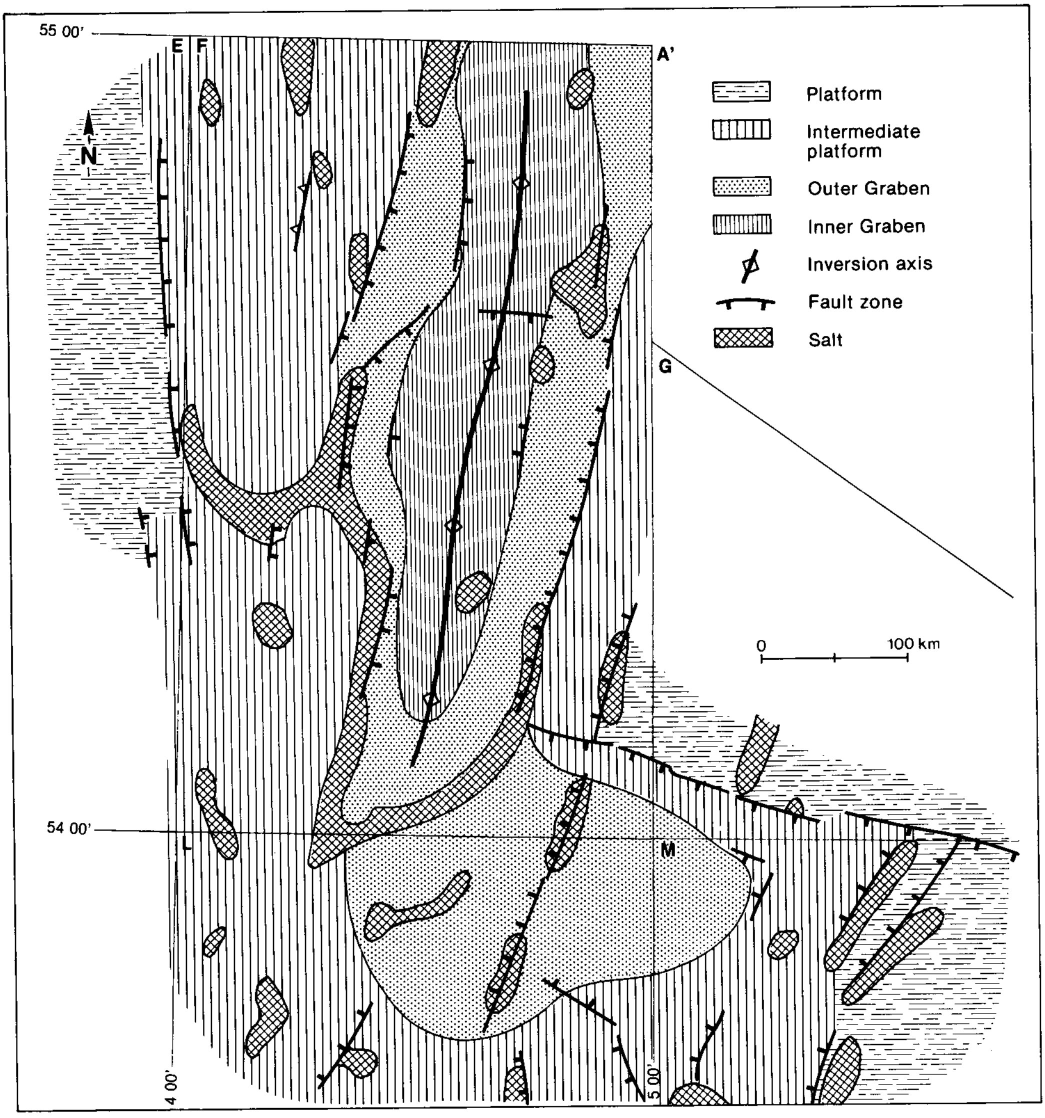

Fig. 1 General outline of the Dutch Central North Sea Graben, showing major structural elements, inversion axes, salt domes and piercements.

in the Netherlands. Both marine algal sapropel and land derived organic material are present (type II kerogen), implying that both oil and gas can be generated, depending on the depth of the burial. This could be the case in the F03 oil/condensate field of the NAM (located in the inner graben) where modelling suggests that the Posidonia and other Altena shales already arrived in the wet gasgeneration phase in the Jurassic.

Late Jurassic – Early Cretaceous

The Middle Graben Shale, Puzzle Hole and Delfland Formations are considered to be gas-prone, but overall they must be ranked among the minor source rocks. The bituminous Clay Deep Formation in the northern F and B quadrants is characterized by marine algal sapropel of the type I kerogen. In this area this formation may have been buried deeply enough to have entered the oil generating window. Contemporaneous "hot shales" in the Norwegian and Danish sectors of the Central Graben constitute the major oil source rock in those areas.

Reservoir Rocks

Carboniferous

Late Carboniferous sandstones are believed to be present in the intermediate areas but the reservoir characteristics may have been destroyed by diagenesis. Moreover, the sandstones are likely to be thin and laterally discontinuous. For these reasons, Upper Carboniferous reservoir potential is considered to be high risk.

Permian

Only a rather thin section of the Lower Slochteren Sandstone (Rotliegend) is expected in the southern part of the Central North Sea Graben. Reservoir quality is expected to be fair to poor.

Triassic

The sandstone units of the Main Buntsandstein Formation constitute one of the primary reservoir objectives for gas in the outer graben and the (intermediate) platform areas. In the western area of the southeastern part of the Central North Sea Graben various Buntsandstein prospects can be identified. Nearby gasfields have demonstrated that the productivity of these sands is good, but deep burial and salt plugging (near salt structures) could have caused significant reservoir degradation.

Jurassic

The Upper Jurassic comprises the following clastic units which have good reservoir characteristics: Lower Graben Sand, Upper Graben Sand, Puzzle Hole, Delfland and Scruff Greensand Formations. The Lower Graben Sand Formation is the main reservoir in the F02 and F03 gas/condensate field. In this area the Upper Graben Sand constitutes a secondary objective. The occurrence of the Lower Graben Sand is limited to the inner and outer graben, not extending south of the F quadrant. Various sub-economic oil occurrences have been recorded from a number of locations in the Delfland and Puzzle Hole Formations. For the latter formation this may be due to the limited lateral extent of the individual sand units. To a lesser degree this may also be the case with the Delfland Formation, but the patchy development of the Posidonia source rock below this formation could also explain the poor oil shows. The prospectivity of the Scruff Greensand Formation has been disappointing so far. This may be explained by the rapid changes in permeabilities within this formation. It is assumed that both Delfland and Scruff Greensand may be gasbearing in the southeastern extension of the Central North Sea Graben. Significant sections of these formations have been identified on seismic sometimes in a favourable setting for the trapping of Carboniferous

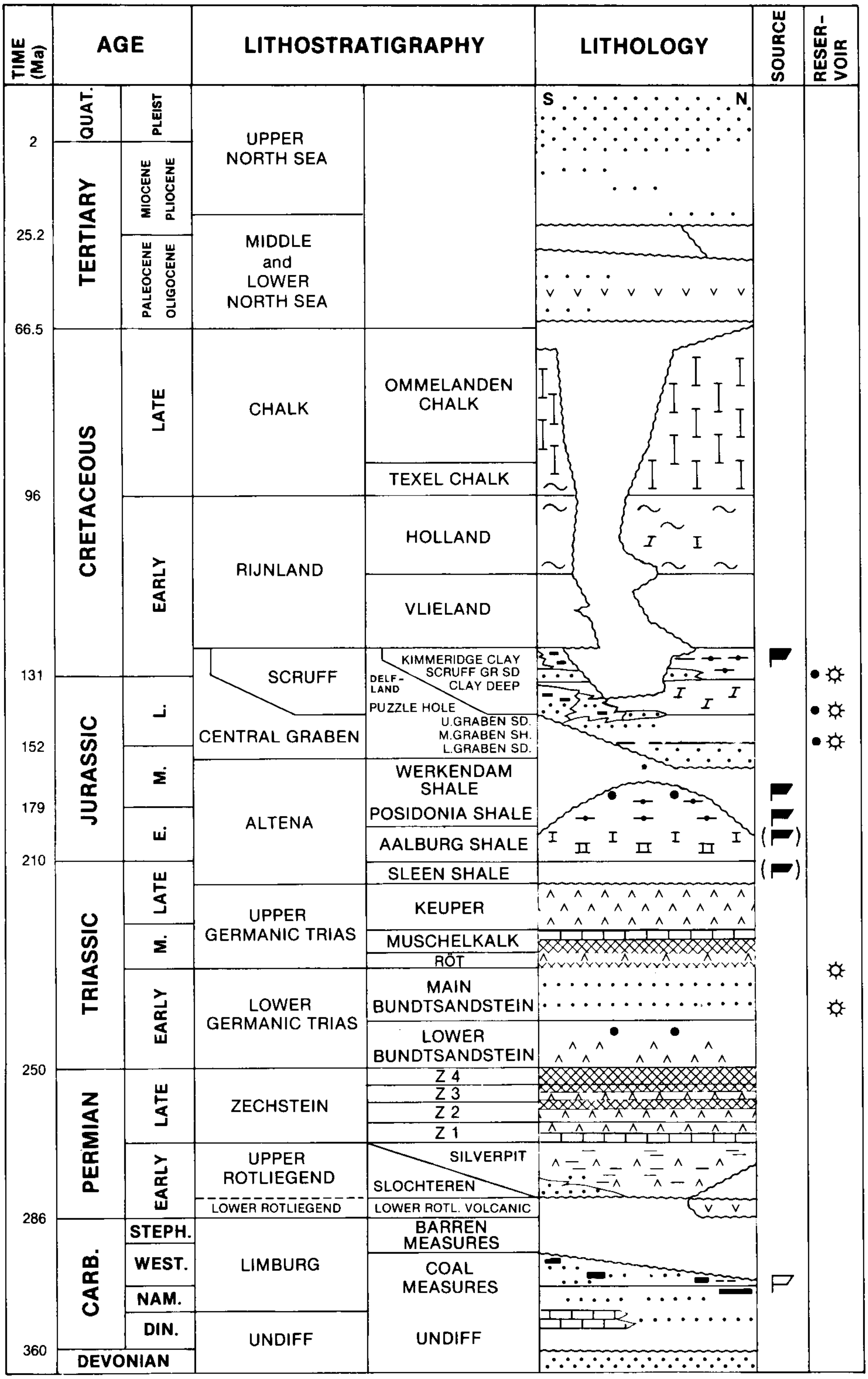

Fig. 2 Stratigraphic diagram of the Dutch Central North Sea Graben, showing gas (open symbol) and oil (solid symbol) source rocks, and reservoir rocks.

gas. Consequently, this forms a new play concept in the Dutch offshore exploration.

Cretaceous

Although only minor oil shows have been reported in the Chalk from this area, there still remains a theoretical possibility of hydrocarbon accumulations within this unit. Especially, when specific conditions like redeposition or fracturing have enhanced the porosities and permeabilities.

Tertiary and Quaternary

Since this interval comprises major sand developments which have hardly been deformed, it may contain stratigraphic traps. These traps may have been charged with gas leaking up along major faults.

Conclusion

In the inner and outer graben areas of the Dutch Central North Sea Graben, various oil accumulations in Upper Jurassic sands have been recorded. The oil originated from the Posidonia Shale, an organic-rich Lower Jurassic unit. Outside this area this unit will not contribute much to oil generation due to its patchy development. The remaining prospective area in the Central North Sea Graben is its relatively unexplored southeastern extension which, as part of a military shooting zone, has formerly been closed for exploration activities (it has been included, under special restrictions, in the Dutch 7th bidding round for off-shore exploration licences).

Structurally this area is part of the outer graben and intermediate platform which have good prospectivity for gas (sourced from the Carboniferous Coal Measures) in Triassic (Main Buntsandstein) and Late Jurassic (Delfland and Scruff Greensand) reservoir rocks.

This publication presents various papers on the Jurassic stratigraphy of the North Sea Central Trough.
Special attention is paid to aspects of correlation between the Dutch, Danish and Norwegian sectors.

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