



**L A P** LABORATORIUM FOR ANVENDT PALYNOLOGI

LABORATORY FOR APPLIED PALYNOLOGY

TOR BJÆRKE P.O.BOX 118 3290 STAVERN NORWAY TLF.: 034 98 522

STATOIL WELL 6407/1-3

BIOSTRATIGRAPHY

KEROGEN ANALYSIS

PREPARED FOR:

STATOIL, DEN NORSKE STATS OLJESELSKAP A.S

FEBRUAR 1984

PREPARED BY:

T. BJÆRKE

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## CONTENTS

Stratigraphical succession	p. 1
Summary	p. 3
Introduction	p. 9
Remarks on palynology	p. 10
Remarks on micropaleontology	p. 11
Remarks on kerogen analysis	p. 12
Biostratigraphy and kerogen analysis	p. 13
Quaternary	p. 13
Tertiary	p. 14
Cretaceous	p. 34
Jurassic	p. 54
Triassic	p. 69
Depositional history	p. 70
Quaternary foraminiferal stratigraphy	p. 73
Legend to enclosures	p. 76

ENCLOSURES:

- 1A Stratigraphical summary log  
Tertiary ( 420 - 2350m)
- 1B Stratigraphical summary log  
Mesozoic (2350 - 4468m TD)
- 2A Foraminiferal range chart  
Quaternary - Tertiary (420 - 2350m)
- 2B Foraminiferal range chart  
Cretaceous (2350 - 3546m)
- 3A Palynological range chart  
Early Tertiary - Cretaceous (1990 - 3521.9m)
- 3B Palynological range chart  
Jurassic - Late Triassic (3521.9 - 4468m TD)
- 4A Kerogen analysis  
Early Tertiary - Cretaceous (1990 - 3521.9m)
- 4B Kerogen analysis  
Jurassic - Late Triassic (3521.9 - 4468m TD)
- 5 Detailed Quaternary foraminiferal stratigraphy

## STRATIGRAPHICAL SUCCESSION

<u>Top of intervals</u>	<u>Age</u>	<u>Thickness</u>
QUARTERNARY		
420m (top not seen)	Pleistocene	200m+
TERTIARY		
- 620m	Pliocene, late	840m
1460m	Late Miocene- Early Pliocene	90m
1550m	Miocene, late	180m
1730m	?Early Miocene	100m
1830m	Miocene, early	40m
1870m	Oligocene, late	20m
----- ? Unconformity -----		
1890m	?Early Oligocene	40m
1930m	Eocene, late	60m
1990m	Eocene, middle	60m
2050m	Eocene, early	120m
2170m	Eocene, early	45m
2215m	Late Paleocene- Early Eocene	60m
2275m	Paleocene, late	30m
2305m	Paleocene, early	28m
2333m	Paleocene, early	17m
----- Unconformity -----		
CRETACEOUS		
2350m	Late Maastrichtian	
2350m	Early Maastrichtian- Late Campanian	45m
----- ? Unconformity -----		
2395m	Campanian, early	90m
2485m	Campanian, early	100m
----- ? Unconformity -----		
2585m	?Cenomanian	360m
2945m	Late Albian- Early Cenomanian	195m
3140m	Albian, late	322m
----- Unconformity -----		
3462m	Aptian	33.1m

## Stratigraphical succession cont.

<u>Top of intervals</u>	<u>Age</u>	<u>Thickness</u>
3495.1m	Aptian, early (?Barremian)	26.8m
-----	Unconformity -----	-----
3521.9m	Ryazanian, early (?Portlandian)	24.1m
-----	Unconformity -----	-----
JURASSIC		
3546m	Oxfordian	52m
-----	Unconformity -----	-----
3598m	?Bajocian ?Bathonian	111.4m
-----	Unconformity -----	-----
3709.4m	Late Toarcian- Aalenian	110.6m
3820m	Toarcian, late	105m
3925m	Late Pliensbachian- Early Toarcian	162m
4087m	?Pliensbachian	30.9m
-----	Unconformity -----	-----
4117.9m	Hettangian- Early Sinemurian	317.1m
-----	? Unconformity -----	-----
Triassic		
4435m 4468 TD	Rhaetian	33m+

The stratigraphical breakdown is based on uncorrected sample depths.

Electric logs were not available for this study.

SUMMARY

1. This report is based on micropaleontological examination of 122 ditch cuttings samples covering the interval 420m to 3545m and palynological and kerogen analysis of 253 ditch cuttings samples, sidewall cores and conventional cores from the interval 1990m to 4468m TD.

A brief lithological examination was carried out on all samples studied to support stratigraphical interpretations.

Electric log information was not available for the present study.

2. The youngest sediments studied were of Pleistocene age recorded between 420 and 620m. The interval is formed by mud deposited in an open marine environment.
3. A thick Late Pliocene sequence is present between 620 and 1460m. Unconsolidated mud with silt and sand material was deposited in a marine shelf environment.
4. A Late Miocene to Early Pliocene interval is defined between 1460 and 1550m. Mud and mudstone deposited under normal marine conditions constitute this interval.
5. Brownish and grey mudstone and silty claystone of Late Miocene age is present between 1550 and 1730m. Glauconite and quartz grains are characteristic. An open marine environment was established during deposition of this interval.

12. A Late Paleocene - Early Eocene interval is defined between 2215 and 2275m. Grey claystone with increased terrestrial plant debris is typical. An open marine environment also prevailed during deposition of this interval.
13. Definitely Paleocene sediments are penetrated at 2275m consisting of grey claystone and minor siltstone deposited in an open marine environment.
14. Early Paleocene sediments are present between 2305 and 2350m. They consist of grey siltstones deposited in an open marine environment. Increased terrestrial input is recorded towards the base of the sequence.
15. An unconformity probably separates the early Paleocene from the underlying Late Maastrichtian at 2350m. Two separate stratigraphical units are represented within the ditch cuttings sample at 2350m, one of Late Maastrichtian age and one of Late Campanian - Early Maastrichtian age. Both intervals were deposited under marine conditions. The Late Campanian - Early Maastrichtian interval comprises red claystones. The stratigraphical relationship between these thin units is uncertain, but unconformities probably separates the Late Maastrichtian both from underlying and overlying intervals.
16. An unconformity again separates the Late Campanian - Early Maastrichtian from the Early Campanian interval at 2395m. Siltstones and minor sandstones were deposited in an open marine environment. A general decrease in energy took place up through this interval.

The early Campanian is subdivided into an upper interval (2395 - 2485m) and a lower interval (2485 - 2585m).



17. Sediments of Cenomanian age is suggested to underly the Early Campanian at 2585m. Fossil evidence is extremely poor and the age is only tentative. If correct it implies a considerable unconformity at this depth.

The sequence referred to the Cenomanian between 2585 and 2945m was deposited in an open marine environment partly under high energy conditions. Rapid sedimentation is suggested.

18. Late Albian - Early Cenomanian sediments are present between 2945 and 3140m. Sand and siltstone deposited in an open marine environment also characterize this interval.
19. A thick Late Albian sequence of shales and siltstones deposited in an open marine environment is present between 3140 and 3460m.
20. An unconformity separates the Late Albian sequence from the dark shales and red claystones of Aptian to possibly Barremian age penetrated at 3462m. An oxydative marine environment was established during deposition of this interval. Below 3500m plant debris is absent except for inertinite. Extreme degradation is probably due to sedimentary processes related to the transgressive development after a considerable Lower Cretaceous hiatus.
21. A thin interval of Early Ryazanian (?Portlandian) sediments is present between 3521.9 and 3546m. Unconformities are present both below and above this interval. Shales and silty shales deposited in a marginal marine environment are present within this interval. The kerogen assemblage observed is typical for the Late Jurassic - earliest Cretaceous 'hot shales'.

22. Sediments of Oxfordian age are present between 3546 and 3598m. Kerogen assemblages show a complete change in depositional environment compared with the interval above. A marginal marine environment with deposition of shales and siltstones was established during the Oxfordian.
  
23. The interval 3698 to 3709.4m is poorly dated. It is given a Bajocian or Bathonian age on the presence of Middle Jurassic palynomorph assemblages. Reworking from the interval below is observed. A restricted marginal marine environment was established in the upper part of the interval, while the sandstones below 3632m were deposited in a high energy, possibly fluvial environment.
  
24. An unconformity separates the Late Toarcian - Aalenian interval (3709.4 - 3820m) from the overlying interval. Siltstones and shales from the upper part of the interval were deposited in a marginal marine environment while sandstones from the lower part were found in a high energy marginal marine or fluvial environment.
  
25. Late Toarcian sediments are penetrated at 3820m. A restricted marginal marine environment prevailed during deposition of this interval.
  
26. Sandstones with minor shale and siltstone intercalations between 3925 and 4087m are of Late Pliensbachian - Early Toarcian age. A shallow restricted marine environment also prevailed during deposition of this interval.

27. A sandstone interval between 4087 and 4117.9m is given a tentative Pliensbachian age. It is characterized by the presence of acritarch species showing a marginal marine environment. It was probably deposited during a transgressive development at the beginning of the Late Pliensbachian - Toarcian sedimentary cycle.
  
28. Hettangian - ?Early Sinemurian sediments are present from 4117.9m. Deposition of sandstones, bituminous shales and coal beds took place in a top delta/coastal plain environment.
  
29. The well terminated in sediments of Late Triassic, Rhaetian age identified between 4435 and 4468m TD. Facies evidence is poor due to caving, but a top delta or coastal plain environment is also suggested for the Rhaetian interval. An unconformity probably separates the Rhaetian and Hettangian sequences.

## INTRODUCTION

This report summarizes the palynological and micropaleontological results from Well 6407/1-3 (420 - 4468m TD).

122 ditch cuttings samples were studied for micropaleontology covering the interval 420 to 3545m. The micropaleontological study was carried out by Oddvar Skarbø, now working with STRATLAB a.s.

Palynological examination was carried out on 174 ditch cuttings samples, 58 sidewall cores and 28 conventional cores. Results from 'hot shot' analysis are included in the report.

A summary log is presented in Enclosures 1A and 1B. Stratigraphical distribution of foraminifera is found in Enclosures 2A and 2B and of palynomorphs in Enclosures 3A and 3B. Results of kerogen analysis are given in Enclosures 4A and 4B. A detailed range chart showing the distribution of foraminifera within the Pleistocene sequence is presented in Enclosure 5.

We would like to thank STATOIL geologists at the Bergen office and at the biostratigraphical division at Forus, Stavanger, for their cooperation.

REMARKS ON PALYNOLOGY

Palynological examination started at 1990m. Sample quality is good throughout the studied sequence, except for considerable caving within the Cretaceous sequence.

Productivity of supposed 'in situ' sediments vary considerably. Especially within the thick Late to late lower Cretaceous sequence the stratigraphical significance of palynomorph assemblages is low. This is reflected in the broadly defined stratigraphical breakdown. High sedimentation rates and/or unfavourable facies in combination with caving are probably the reason for the relatively low productivity. No systematic relationship between different drilling techniques and sample quality is observed.

REMARKS ON MICROPALAEONTOLOGY

Samples were washed on 1mm and 0.125mm test sieves, and the sediment from the lower sieve was examined for microfossils. Sediments older than Pliocene were additionally soaked in 5% H<sub>2</sub>O<sub>2</sub> for a few hours before washing and drying.

Analyses were interrupted when significant numbers of fossils were obtained to yield proper datings or describe assemblages. In cases of poor intervals entire samples were examined. Index fossils within other fossil groups (e.g radiolarians, diatoms) were included where they improved precision of stratigraphy.

Micropaleontological investigations performed on sediments from an earlier drilled well within concession block 6407/1 were carried out by K.-L. Knudsen and K.Ulleberg. With the purpose of making the present results (Well 6407/1-3) comparable with their results, we have accepted their taxonomic concepts as stated in the biostratigraphical report on Well 6407/1-2 with some minor exceptions. Their biostratigraphical zones are also applied in this study as far as possible. Additionally the Tertiary zones defined by King (1984) are included in the present report. The age interpretations are mainly based on the latter.

REMARKS ON KEROGEN ANALYSIS

Kerogen analysis was carried out on strew mounts of residue remaining after HF/HCl treatment, floatation ( $\text{ZnBr}_2$ , sp.gr.2.2) and screening (20 micron net).

The kerogen components were referred to the following eight categories:

Finely dispersed debris, terrestrial palynomorphs, marine palynomorphs, wood fragments, inertinite, membranous material (mainly cuticle fragments), degraded fragments and aggregates (clusters of heterogeneous composition).

The amount of each category was estimated semiquantitatively as absent, rare, common, abundant or dominating.

The amount of finely dispersed debris was estimated from unsieved residues relatively to all other components. The relative amount of the remaining kerogen categories were obtained from sieved residues.

BIOSTRATIGRAPHY AND KEROGEN ANALYSISQUATERNARYINTERVAL 420 - 620m

Age: Pleistocene

## MICROPALEONTOLOGY

Elphidium excavatum - Cassidulina laevigata (teretis) Zone.

This zone is characterized by high frequencies of Elphidium excavatum and other species of this genus in association with Bulimina marginata and Cassidulina laevigata. Other species like Nonion labradoricum, Melonis (Nonion) barleeanum, Islandiella helenae, Uvigerina peregrina and Cibicides lobatulus are abundant in the upper part of the interval.

A detailed study of the samples between 420 and 500m was carried out in order to establish a more refined stratigraphy. The results are discussed in a separate chapter (see p. 73).

## DEPOSITIONAL ENVIRONMENT

This interval consists of mud deposited in an open marine shelf environment.



TERTIARYINTERVAL 620 - 1460m

Age: Late Pliocene

## MICROPALAEONTOLOGY

Cassidulina laevigata (teretis) - Cibicides grossa Zone.

The top of this interval is placed at the first downhole appearance of common Cibicides grossa. Elphidiella hannai is a characteristic element in all assemblages from 740m.

Most of the species common in the interval above continue down through this interval.

On the basis of C.grossa throughout the interval, it is referred to zone NSB 15 of Late Pliocene age.

## DEPOSITIONAL ENVIRONMENT

The interval consists of unconsolidated mud with variable amounts of silt and sand material deposited in a marine shelf environment. Poor representation of planktonic specimens show that fully marine conditions were not established.

The thick late Pliocene sequence show a remarkable homogeneous composition.

INTERVAL 1460 - 1550m

Age: Late Miocene - early Pliocene

#### MICROPALAEONTOLOGY

Melonis (Nonion) - Trifarina (Angulogerina) Zone.

The top of this zone is defined by a distinct increase in the amount of Melonis (Nonion) affine/barleeanum and Trifarina (Angulogerina) fluens.

Towards the base there is an increased diversity with the appearance of Eponides pygmeus, Cibicides tenellus and Fissurina castanea at 1520m. This represents a gradual transition to the late Miocene assemblages recorded below.

#### DEPOSITIONAL ENVIRONMENT

The ditch cuttings samples from this interval are dominated by mud. Poorly consolidated mudstone is also represented.

Normal marine conditions were established in the lower part of the interval. A development towards more nearshore conditions is observed up through the interval, but still show higher salinity than within the interval above.

INTERVAL 1550 - 1730m

Age: Late Miocene

#### MICROPALEONTOLOGY

Cibicides dutemplei - Martinottiella communis Zone.

This interval is defined by the first downhole appearance of Bolboforma metzmacheri and C. dutemplei. It is further characterized by the appearance of Bolboforma spiralis and M. communis at 1640m, and Bolboforma clodiusi at 1700m. This subdivides the Late Miocene into the three subzones NSP 14b, NSP 14a and NSP 13.

#### DEPOSITIONAL ENVIRONMENT

DCSs from this interval consist of abundant free quartz and glauconite in addition to brownish and grey mudstone and silty claystone. An open marine environment prevailed during deposition of this interval.

INTERVAL 1730 - 1830m

Age: ?Early Miocene

#### MICROPALEONTOLOGY

This interval is extremely poor in foraminifera, most of the specimens recorded are regarded as caved. The continued presence of persistent Melonis (Nonion) affine/barleeanum, Pullenia bulloides, Martinottiella communis and probably also Cibicides limbatosuturalis is suggested to represent the 'in situ' fauna. This assemblage represents a facies similar to that observed within the Early Miocene below. The absence of diagnostic Early Miocene species makes the reference to the Early Miocene uncertain.

#### DEPOSITIONAL ENVIRONMENT

This interval is dominated by brownish silty and sandy claystone. Volcanic glass occur throughout the interval. A marine environment prevailed during deposition of this interval, but the poor fauna suggests environmental restrictions possibly due to volcanic activity.

INTERVAL 1830 - 1870m

Age: Early Miocene

#### MICROPALAEONTOLOGY

The appearance of Diatom sp. 5 of King and Rzehakina sp. 1 at 1830m defines the top of this interval. The poor fauna recorded above continues down into this interval. The assemblage defines Zone NSP 10 of Early Miocene age. The lower part of this interval is poorly defined, but the presence of Rzehakina sp. 1 also at 1850m may indicate that the Early Miocene continues down to this depth.

#### DEPOSITIONAL ENVIRONMENT

Brownish silty and sandy claystone deposited in marine environments dominates the DCSs. An environment similar to that above continues down into this interval. Volcanic glass is also present here.

INTERVAL 1870 - 1890m

Age: Late Oligocene

#### MICROPALAEONTOLOGY

The top of this interval is defined by the appearance of Diatom sp. 3 of King. Pullenia bulloides, Cibicides limbato-  
suturalis and Martinottiella communis continue down from the intervals above. This shows the presence of Late Oligocene sediments belonging to Zone NSP 9.

#### DEPOSITIONAL ENVIRONMENT

Again sandy and silty claystone is the characteristic lithology. The same type of restricted marine environment is suggested by the foraminiferal fauna.

INTERVAL 1890 - 1930m

Age: ? Early Oligocene

#### MICROPALEONTOLOGY

The fauna recorded from this interval is extremely poor with rare agglutinated foraminifera. The interval is tentatively referred to the Early Oligocene, but positive biostratigraphic evidence is lacking.

#### DEPOSITIONAL ENVIRONMENT

Grey silty mudstone appearing within this interval were deposited in a marine environment. The impoverished fauna suggests environmental restrictions.

INTERVALL 1930 - 1990m

Age: Late Eocene

#### MICROPALEONTOLOGY

##### Haplophragmoides - Recurvoides - Spiroplectammina Zone

An abrupt change in foraminiferal assemblage is observed at 1930m with the appearance of agglutinated species dominating through this interval. The assemblage is identical to the widely distributed Early Tertiary flysch type fauna. Top Eocene is defined by appearance of Ammolagena clavata.

The agglutinated fauna is dominated by Bathysiphon - like fragments, Haplophragmoides spp., Recurvoides spp. and Cyclamminia spp.. Spherical reticulate radiolarians are present throughout the interval but become abundant from 1970.

#### DEPOSITIONAL ENVIRONMENT

Greenish mudstone appears within this interval probably representing the 'in situ' lithology. The foraminiferal fauna indicates environmental restrictions, possibly reduced bottom water circulation. Presence of radiolarians show an open normal marine environment.



INTERVAL 1990 - 2050m

Age: Middle Eocene

#### MICROPALEONTOLOGY

The top of this interval is defined by the appearance of Cyclammina amplexans diagnostic of Zone NSB 4, giving a Middle Eocene age. The agglutinated assemblage continues down from the interval above. Abundant ?Sorosphaera appears at 2010m. Radiolarians are also common to abundant within this interval.

#### PALYNOLOGY

Palynological examinations started at 1990m. Diverse dinoflagellate assemblages typical for the Middle to Late Eocene are present within this interval. Species like Dinocyst sp. II of Manum, Svalbardella cooksoniae, Corrudinium incompositum and Chiropteridium dispersum are caved from the Late Eocene and Oligocene intervals above.

#### KEROGEN ANALYSIS

Kerogen analysis started at 1990m. The assemblages are characterized by common to dominating wood fragments and marine palynomorphs. Inertinite is rare in all assemblages.

Terrestrial palynomorphs are rare in the uppermost assemblage increasing to common and abundant downwards. Finely dispersed debris is dominating in the uppermost assemblage, reduced to common in the middle part of the interval and again increasing to abundant in the lower assemblage.

## DEPOSITIONAL ENVIRONMENT

A low energy open marine environment with medium to low terrestrial input prevailed during deposition of this interval. Greenish claystone became the dominating lithology within this interval. The foraminiferal fauna indicates environmental restrictions, possibly due to reduced bottom water circulation.

INTERVAL 2050 - 2170m

Age: Early Eocene

#### MICROPALEONTOLOGY

The same fauna as recorded above continues down into this interval.

#### PALYNOLOGY

The top of this interval is defined by the appearance of Eatonicysta ursulae and Hafniasphaera septata diagnostic of the Early Eocene. Other more longranging species like Tityrosphaeridium cantharellum, Rhombodinium draco, Dracodinium pachyderma and Samlandia chlamydophora appear in the upper part of this interval. The appearance of Deflandrea oebisfeldensis in DCS at 2090m is further evidence for an Early Eocene age for this interval.

#### KEROGEN ANALYSIS

Wood fragments occur abundantly throughout the interval, while inertinite is rare increasing to common in the lowermost assemblage at 2150m. Marine palynomorphs are abundant except for the assemblage at 2150m where they are reduced to common, while terrestrial palynomorphs are rare in the upper part, increasing to common towards the base of the interval. Finely dispersed debris is common to abundant.

#### DEPOSITIONAL ENVIRONMENT

This interval was deposited in an environment similar to that above. Greenish claystone deposited in an open normal marine low energy environment dominates this interval.

Again foraminiferal fauna indicates environmental restrictions which may be due to reduced bottom water circulation.

#### COMMENTS

This interval correlates with the lower part of the Middle to Late Eocene interval defined in Well 6407/1-2. The species used here to define top Early Eocene were not recorded from that well.

INTERVAL 2170 - 2215m

Age: Early Eocene

### Micropaleontology

Globigerina linaperta Zone.

The top of this interval is marked by a distinct change in foraminiferal fauna. Planktonic species like Globigerina linaperta - group (common), Acarinina pentacamerata (common) and Pseudohastigerina wilcoxensis define the Zone NSP 5 of Early Eocene age. The appearance of calcareous benthonic species recorded down through this interval is typical for this stratigraphic event, e.g. Cibicides sp., Eponides plummerae, Lenticulina cultrata and Anomalinoides (Melonis) nobilis. The fauna is typically red stained.

### PALYNOLOGY

The appearance of Alisocysta rugolirata, Dracodinium condylos and D. varielongitudum at 2170m and 2190m supports a lower Early Eocene age for this interval. The appearance of Azolla sp. at the top of the interval may be of stratigraphical significance.

### KEROGEN ANALYSIS

Wood fragments dominate the kerogen assemblages from this interval. Inertinite and marine palynomorphs are common, while terrestrial palynomorphs and finely dispersed debris are common at the top of the interval and reduced to rare at 2190m.

## DEPOSITIONAL ENVIRONMENT

Red claystone appears at the top of this interval and becomes common at 2190m. It probably represents the dominating 'in situ' lithology. An open normal marine low energy environment with medium to low terrestrial input was established during deposition of this interval.

INTERVAL 2215 - 2275m

Age: Late Paleocene -  
Early Eocene

#### PALYNOLOGY

The appearance of Apectodinium augustum and Alisocysta margarita at 2215m defines the top of this interval. They are characteristic of the earliest Eocene to latest Paleocene. The appearance of Caryapollenites sp. at 2245m shows a change in sedimentary environment.

#### MICROPALEONTOLOGY

The sample at the top of this zone at 2215m produced a mixed assemblage. The calcareous assemblage typical for the interval above is still a prominent feature at this horizon, but the appearance of Coscinodiscus sp. 1 of Bettenstaedt shows that an older unit has been penetrated. This species defines Zone NSP 4 close to the Paleocene - Eocene boundary. This is in accordance with the palynological evidence.

#### KEROGEN ANALYSIS

Inertinite shows a distinct increase within this interval from rare in the uppermost part to dominating in the lower. This development is probably due to masking by caved material in the upper part, and increased amount of inertinite is regarded as characteristic for this interval.

Wood fragments are abundant throughout the interval.

Marine palynomorphs are reduced from abundant at the top of the interval to common and rare in the lower, while terrestrial palynomorphs show the inverse development increasing from rare

in the upper part to abundant at 2245m. They are again reduced to rare at 2260m.

Finely dispersed debris is rare at the top of the interval showing a maximum at 2230m and drops to common in the lower part.

#### DEPOSITIONAL ENVIRONMENT

Light grey poorly consolidated claystone with varying amounts of red and green claystone are present in the DCSs over this interval. An open marine environment with moderate to high terrestrial input is suggested for this interval. Presence of diatoms indicate a silica-rich environment due to volcanic activity.



INTERVAL 2275 - 2305m

Age: Late Paleocene

#### MICROPALEONTOLOGY

This interval is defined by the persistent and partly common occurrence of Spiroplectamina spectabilis corresponding to Zone NSB 1b giving a Late Paleocene age for this interval. A characteristic feature of Late Paleocene sediments is also the common occurrence of Ammodiscus cretaceus (incertus). The fauna obtained from this interval show a partly greenish stain. Apart from these elements the faunas show close similarity to that recorded above.

#### PALYNOLOGY

No new elements appear within this interval.

#### KEROGEN ANALYSIS

The two ditch cuttings samples from this interval produced kerogen assemblages with abundant inertinite and common to abundant wood fragments. Marine palynomorphs are common to abundant while terrestrial palynomorphs are common.

Finely dispersed debris is rare to common.

#### DEPOSITIONAL ENVIRONMENT

The same depositional environment as described for the interval above also prevails through this interval. In addition to the lithologies recorded above minor siltstone appears within this interval.

INTERVAL 2305 - 2333m

Age: Early Paleocene

#### MICROPALEONTOLOGY

The same fauna as recorded above continues down into this interval. The interval is defined on palynological information.

#### PALYNOLOGY

The top of this interval is based on the appearance of several characteristic species like Eisenackia crassitabulata, Palaeocystodinium benjaminii/australinum, Glaphyrocysta ordinata, Palaeoperidinium pyrophorum and Ceratiopsis striata. Maxima of Deflandrea oebisfeldensis and Alisocysta margarita is characteristic for this interval. This assemblage defines an Early Paleocene age.

#### KEROGEN ANALYSIS

Inertinite is abundant to dominating within this interval. Wood fragments are common while marine palynomorphs are common to abundant. Terrestrial palynomorphs are common. Finely dispersed debris shows an increase from the intervals above being dominating.

#### DEPOSITIONAL ENVIRONMENT

A grey siltstone dominating the DCSs are regarded as the 'in situ' lithology. It was deposited in a low energy normal marine environment.

INTERVAL 2333 - 2350m

Age: Early Paleocene

#### MICROPALAEONTOLOGY

The same fauna as above is recorded also from this interval. Questionable specimens of Alabamina midwayensis are recorded at 2335m. This species is usually associated with calcareous fauna defining the earliest Paleocene.

#### PALYNOLOGY

The SWC from 2333m produced an assemblage with abundant bisaccate pollen and appearance of Areoligera senonensis, Isabelidinium victorianum and Ceratiopsis cf. striata.

The Alisocysta and Eisenackia spp. characteristic of the interval above disappear while P. benjaminii/australinum shows a maximum at 2340m.

This assemblage defines an earliest Paleocene age close to the Cretaceous - Tertiary boundary.

#### KEROGEN ANALYSIS

Two SWCs were examined from this interval. They produced assemblages with abundant to dominating inertinite and abundant terrestrial palynomorphs. Marine palynomorphs are rare to common and wood fragments are common. Finely dispersed debris is rare. The DCS at 2335m produced an assemblage similar to those from SWCs. Inertinite is dominating the assemblage while wood fragments are common. Marine palynomorphs are rare and terrestrial palynomorphs are common. Finely dispersed debris is dominating.

## DEPOSITIONAL ENVIRONMENT

A dark grey mudstone was deposited within this interval. An open marine environment with considerable terrestrial input was established.

## CRETACEOUS

INTERVAL 2350m

Age: Late Maastrichtian

## MICROPALAEONTOLOGY

The DCS at 2350m yielded two distinct faunal elements. The youngest element is recognized on the presence of the distinct species Abathompalus mayaroensis. This shows that sediments of Late Maastrichtian age are present. The older element of Late Campanian - Early Maastrichtian age is used to define a separate unit discussed below.

## PALYNOLOGY

The palynomorph assemblage appearing in the DCS at 2350m probably originates from the Late Campanian - Early Maastrichtian interval (see below).

## DEPOSITIONAL ENVIRONMENT

Information from this unit is poor. The foraminifera used to define the interval show that open marine conditions were established during the Late Maastrichtian.

INTERVAL 2350 - 2395m

Age: Late Campanian -  
Early Maastrichtian

#### MICROPALAEONTOLOGY

A rich and diverse foraminiferal fauna with calcareous benthonic and planktonics and agglutinated species appears at 2350m. The assemblage composition is diagnostic of the Late Campanian - Early Maastrichtian. Reussella szajnochae, Globorotalites michelinianus and Hedbergella cf. holmdelensis are the most characteristic species. Gavelinella parvula (laevigata), Globigerinelloides asper and Bathysiphon - like fragments dominate the assemblage. Of stratigraphical significance are also Biglobigerinella multispira, Heterohelix globulosa and H. lata.

#### PALYNOLOGY

The top of this interval is defined by the appearance of several species characteristic of the Cretaceous including Aquilapollenites spp., Isabelidium microarmum, I. acuminatum, Diconodinium psilatum and Palaeostomocystis fragilis.

Red claystones appear at the top of the interval. This interval probably correlates with the Maastrichtian sediments recorded between 2320m and 2347.5m in Well 6407/1-2.

#### COMMENTS

The species Palaeocystodinium benjaminii/australinum, Ceratiopsis striata (=D.dieblii) and Palaeostomocystis laevigata were referred to a correlative unit in Well 6407/1-2. Better SWC coverage in the present well, however, clearly shows that these species belong to a separate unit just above this interval. They are characteristic elements of earliest Paleocene to Maastrichtian sediments and as they appear in SWCs stratigraphically higher

than the Cretaceous markers, they are defining the top of a separate unit (2333 - 2350m) referred to the Early Paleocene.

#### KEROGEN ANALYSIS

The kerogen assemblages from this interval are completely dominated by inertinite. The samples are nearly barren of palynomorphs and finely dispersed debris content is low. The DCS at 2350m shows a high palynomorph productivity and dominating finely dispersed debris. This is mainly due to material originating from the interval above. As we go down through the interval there is a continuous decrease in finely dispersed debris and an abrupt decrease in palynomorph productivity and wood fragments.

A single SWC from this interval at 2367m shows the characteristic composition with rare finely dispersed debris, common wood fragments and completely dominating inertinite.

Rare dinocysts recorded from this SWC show a marine environment.

#### DEPOSITIONAL ENVIRONMENT

An open marine shelf environment with intense oxydation and low sediment input characterizes this interval.

INTERVAL 2395 - 2485m

Age: Early Campanian

#### PALYNOLOGY

The top of this interval is defined by the appearance of Odontochitina costata, Chatangiella granulifera/verrucosa and Trichodinium castaneum at 2395m. It is further characterized by the appearance of Raphidodinium fucatum and Hexagonifera suspecta at 2425m and Xenascus ceratioides at 2440m. Several other Cretaceous elements like Odontochitina striatoperforata/operkulata, Palaeoperidinium cretaceum and Palaeohystrichophora infusorioides appear within this interval. This dinocyst association together with species of Aquilapollenites give an Early Campanian age for this interval.

#### KEROGEN ANALYSIS

This interval contrasts sharply with that above by producing kerogen assemblages with abundant to dominating finely dispersed debris and common to abundant wood fragments and rare to common palynomorphs, marine elements dominating over terrestrial. Inertinite is still dominating the kerogen assemblages. The increase in finely dispersed debris and wood fragments seem to be somewhat delayed by the influence of caving.

A single SWC was examined from this interval at 2455m producing an assemblage dominated by inertinite with abundant wood fragments, common marine palynomorphs and rare terrestrial palynomorphs and finely dispersed debris.

#### MICROPALAEONTOLOGY

No age diagnostic species were recognized. Most of the specimens recorded are believed to be caved. Rare ostracods were recorded in the lower part of the interval.



## DEPOSITIONAL ENVIRONMENT

Siltstone and minor sandstone was deposited in an open marine shelf environment. A low to medium energy oxygenated environment prevailed during deposition.

INTERVAL 2485 - 2585m

Age: Early Campanian

#### PALYNOLOGY

The appearance of Dinogymnium acuminatum and Dinogymnium nelsonense at 2485m and 2500m defines the top of this interval. The dinocyst assemblages recorded from the interval above continue down into this interval, which is probably a direct continuation of that sequence.

#### KEROGEN ANALYSIS

This interval is again dominated by inertinite with common to abundant wood fragments. Marine palynomorphs are abundant in the upper part and common in the lower, while terrestrial palynomorphs are rare throughout. Finely dispersed debris is reduced compared to the interval above and is rare in most assemblages.

Abundant aggregates at 2530m is probably indicating calcareous horizons within the interval.

The SWCs at 2476m and 2507m show the same kerogen composition as seen from the DCSs with dominating inertinite, common wood fragments, common to abundant marine palynomorphs and rare terrestrial palynomorphs and finely dispersed debris.

#### DEPOSITIONAL ENVIRONMENT

The siltstone with sandstone laminae was deposited in an open marine shelf environment. A low to moderate energy regime prevailed. Increased concentration of resistant material is observed in the lower part of the interval showing a higher energy regime.

## MICROPALAEONTOLOGY

The interval is nearly barren of foraminifera except for a significant increase of Bathysiphon- like fragments below the 2555m level. The interval is otherwise characterized by regular occurrence of Diatom sp. H (internal name). The age significance of this small diatom is however, unceratin.

INTERVAL 2585 - 2945m

Age: ?Cenomanian

#### PALYNOLOGY

This interval is poorly defined palynologically. The appearance of Appendicisporites spp. at 2585m and Aequitriradites baculatus at 2630m suggest that an older Upper Cretaceous sequence is penetrated. However, only a few new species appear down through the interval. The dinocyst assemblages established within the Early Campanian above continue down through the interval to SWC at 2695m. This may probably be due to heavy caving as Tertiary elements are also recorded throughout the Cretaceous sequence.

A tentative Cenomanian age is given for this interval implying an unconformity around 2585m. The lower part of the interval shows reduced palynomorph productivity.

#### COMMENTS

The species Impardecispora trioreticulosus and I. marylandensis used to characterize a supposed age correlative unit in Well 6407/1-2 were not recorded from this well.

#### MICROPALAEONTOLOGY

The interval is characterized by common to abundant occurrence of Bathysiphon - like fragments and the income of a number of calcareous foraminiferal species. The latter component is represented by Allomorphina cretacea, Gyroidinoides sp. and Nodosariinae, of which Nodosaria sp. (fine longitudinal striae) show the most regular occurrence. A number of agglutinated species have also top occurrence within the interval, e.g. Gaudryina cf. dividens, Spiroplectammina cf. navarroana, Marssonella cf. ozawayi and Textularia foeda (at 2645m). The two latter support a Cenomanian or older age suggested from palynological evidence.

## KEROGEN ANALYSIS

Inertinite is the dominating element throughout the interval, especially between 2700m and 2900m where other components are strongly reduced. Wood fragments are mainly common to abundant down to 2750m, and is then reduced to rare to common.

Marine palynomorphs are common above 2690m and rare from 2705m except for one assemblage at 2915m where they are abundant. Terrestrial palynomorphs are rare throughout.

Finely dispersed debris is common to abundant in the upper part and rare from 2675m to 2900m. At 2915m and 2930m finely dispersed debris is again abundant.

Three SWCs were examined from this interval at 2585m, 2695m and 2870m. Inertinite is abundant to dominating and wood fragments are abundant in the assemblages from these SWCs. Marine palynomorphs are abundant in the two upper assemblages, while in the lowermost assemblage at 2870m they are reduced to common. Terrestrial palynomorphs and finely dispersed debris are rare in all three assemblages.

## DEPOSITIONAL ENVIRONMENT

Sand- and silt-stones dominate over this interval. High to moderate energy regimes in an open marine shelf environment is suggested by inertinitic kerogen assemblages and persistent marine palynomorphs. Kerogen analysis show that sorting was more intense below 2700m.

INTERVAL 2945 - 3140m

Age: Late Albian -  
Early Cenomanian

#### PALYNOLOGY

The top of this interval is defined by the appearance of Subtilisphaera pirnaensis and reappearance of abundant Palaeohystrichophora infusorioides. The appearance of Hystrichodinium pulchrum/voigtii and H. oligocanthum also characterizes the top of this interval together with the reappearance of several species recorded higher up in the Cretaceous sequence showing a generally higher palynomorph productivity from this interval.

Fromea amphora and Cribroperidinium sp. appear further down in this interval. A Late Albian to Early Cenomanian age is given for this interval.

#### MICROPALAEONTOLOGY

The interval is extremely poor or barren of foraminifera above 3065m where an increase of agglutinated specimens are noted. Reophax minuta and Conorotalites aptiensis top at the 3095m level. Both species occur higher than the Albian in the southern North Sea Basin. Their occurrence is, however, in agreement with a Late Albian - Early Cenomanian age.

#### KEROGEN ANALYSIS

Inertinite is again dominating the kerogen assemblages throughout the interval. Wood fragments are common in the upper part of the interval, but an increase to abundant is observed below 3040m. Marine palynomorphs are abundant in the upper part of the interval but are reduced to common and rare below 3035m. Terrestrial palynomorphs are rare throughout the interval.

Finely dispersed debris is dominating to abundant above 3035m and reduced to rare and common between 3035m and 3095m. In the two lowermost assemblages at 3110m and 3125m finely dispersed debris is abundant and dominating.

A SWC at 3090m produced an assemblage with abundant inertinite, wood fragments and marine palynomorphs. Terrestrial palynomorphs were rare and finely dispersed debris common at this horizon.

#### DEPOSITIONAL ENVIRONMENT

Sand- and silt-stones dominate the lower part of this interval, while shale dominates in the upper part. An open marine oxygenated environment prevailed throughout the interval with a high energy regime and increased terrestrial input in the lower part.

INTERVAL 3140 - 3462m

Age: Late Albian

#### PALYNOLOGY

This interval is defined by the appearance of Ovoidinium sp. at 3140m and Ovoidinium scabrosum at 3215m. In addition the appearance of Dinogymnium spp. and abundant P. infusorioides shows an age not older than Late Albian. The appearance of Cribroperidinium cf. edwardsii and Cribroperidinium orthoceras at 3335m and 3350m also indicates that the Albian has been penetrated.

The appearance of Ovoidinium ostium in the lower part of the interval at 3425m shows an age not older than the late Albian.

#### MICROPALAEONTOLOGY

A poor foraminiferal fauna of mainly agglutinated taxa is recorded similar to that from the interval above. Rare occurrences of Verneuilinoides sp. and Textularia foeda in the upper part of this sequence may be used to distinguish a separate zone. The two agglutinants are not stratigraphically restricted, but the co-occurrence may be of importance for local correlation purposes.

The stratigraphical significance of the two rare calcareous elements tentatively referred to ?Charltonina and ?Anomalinoidea at 3230m and 3260m is uncertain, but these may also bear a stratigraphical potential. A single specimen of Tritaxia cf. singularis at 3230m is probably supporting the age obtained by palynomorphs, as the species (sensu stricto) are restricted to the Albian.

Below 3260m the interval is probably barren of 'in situ' microfossils.



## KEROGEN ANALYSIS

Inertinite is abundant to dominating through this interval, except for the two lowermost assemblages at 3440m and 3455m where it is absent. Wood fragments show a general increase compared to the intervals above being abundant down to 3300m. Below 3300m the amount of wood fragments varies between common and abundant.

Marine palynomorphs are rare to common in most assemblages, but occasionally increase to abundant. Terrestrial palynomorphs are rare. Finely dispersed debris is rare or absent from the upper part of the interval down to 3230m. Between 3230m and 3290m it is abundant and again reduced to rare and common in the lower part.

The two lowermost samples at 3440 and 3455m produced kerogen assemblages completely different from those above. They are dominated by finely dispersed debris and wood fragments.

Aggregates are present through most of the interval being abundant in several assemblages. This is probably due to calcareous sediments within this interval .

Five SWCs were examined from this interval. Inertinite is abundant to dominating in these samples, while wood fragments are abundant in the uppermost sample at 3160m and rare to common in the other samples.

The sample at 3160m produced abundant marine and common terrestrial palynomorphs. Palynomorph productivity is reduced in the other four samples, marine palynomorphs being rare to common and terrestrial palynomorphs rare.

Finely dispersed debris is rare except for the lowermost assemblage examined from 3424m where it is abundant.

## DEPOSITIONAL ENVIRONMENT

This interval is dominated by shales and siltstones deposited in an open marine oxygenated environment. A high to moderate terrestrial input characterizes this interval.

INTERVAL 3462 - 3495.1m

Age: Aptian

### Palynology

A distinct change in palynomorph assemblage is observed at the top of this interval. The appearance of Scriniodinium campanulum, Gonyaulacysta sp. of Duxbury, ?Aptea anaphrissa and abundant Spiniferites membranaceae at 3462 and 3470m defines this interval.

### MICROPALAEONTOLOGY

Two ditch cuttings samples were analysed. The upper yielded a poor fauna and the lower a fairly rich, low diversity agglutinated assemblage. The common feature is the presence of abundant ?Sorosphaera. Whether these represent foraminifera or in-organic concretions is still under debate, but nevertheless they define a characteristic horizon.

The sample at 3485m yielded common occurrences of Texturaria foeda, Recurvoides spp. and Glomospira spp., in addition to presence of Marssonella sp. 1 (Bartenstein & Bettenstaedt) and a questionable specimen of Uvigerinammina moeisiana. The age significance of these species is uncertain, but the deep red staining of the specimens within the 'in situ' fauna make it a very characteristic horizon.

## KEROGEN ANALYSIS

This interval is well covered with SWCs. Inertinite is dominating all the assemblages obtained from the SWCs. Wood fragments and marine and terrestrial palynomorphs are rare to common while finely dispersed debris is absent from two of the assemblages and rare and common in the two other assemblages.

The two DCSs from this interval are dominated by wood fragments which are probably to some extent caved from the interval above. Inertinite is abundant at 3470m and dominating at 3485m. Palynomorphs, both marine and terrestrial are rare to common, while finely dispersed debris is rare in the upper assemblage at 3470m and abundant in the lower at 3485m.

## DEPOSITIONAL ENVIRONMENT

Open marginal marine conditions were established during deposition of this interval. Dominance of inertinite suggests an oxydative environment with considerable concentration of resistant plant debris.

INTERVAL 3495.1 - 3521.9m

Age: Early Aptian (?Barremian)

#### PALYNOLOGY

This interval is defined by the appearance of common Gardodinium trabeculosum and Batioladinium longicornutum in the SWC at 3495.1m and of Sirmiodinium grossi in the SWC at 3499m. Although the last two species have previously been regarded as Barremian key species, they may probably range up into the earliest Aptian. A maximum in G. trabeculosum is characteristic of the earliest Aptian. An Early Aptian age is favoured for this interval, although a Barremian age can not be excluded.

The lower part of the interval between 3507m and 3521.9m is barren of palynomorphs.

#### MICROPALAEONTOLOGY

The interval is characterized by rich assemblages of both agglutinated and calcareous benthonic foraminifera, which possess reddish stained shells (the staining is typically lighter than in the interval above). Common occurrences of ostracods are also noted, all with a smooth shell surface.

The foraminiferal assemblages are dominated by different species within the genus Lenticulina, of which L. heiermanni and L. cf. gaultina are the most prominent taxa. Of stratigraphical importance are also Gavelinella barremiana, Astacolus schloenbachi, Marssonella sp. 1 (Bartenstein & Bettenstaedt) and Haplophragmium aequalis, which are suggested to limit the age to middle Barremian - Early Aptian. The two latter taxa may be in favour of the older stage. However, presence of Valvulineria cf. gracillima in the upper part of the interval is more likely to be found in Aptian sediments.

Other characteristic species recorded from the interval are Uvigerinamina moeisiana (common), Glomospirella gaultina, Trocholina infragranulata and different species within the calcareous genera Lagena, Sarracenaria and Lingulina.

## KEROGEN ANALYSIS

Six SWCs were examined from this interval. The two uppermost samples at 3495.1m and 3499m produced assemblages dominated by inertinite in association with abundant wood fragments, common marine palynomorphs and common to abundant terrestrial palynomorphs mainly represented by bisaccate pollen. Finely dispersed debris is common to abundant in these two assemblages.

The other SWCs from this interval are characterized by extremely low organic productivity, producing assemblages totally dominated by inertinite.

The DCS from 3500m produced an assemblage dominated by inertinite. Wood fragments are abundant, while palynomorphs are rare in this assemblage. Finely dispersed debris is common.

Finely dispersed debris is common also in the assemblage from the DCS at 3515m. Organic productivity was too low to produce slides of screened residue from this sample.

## DEPOSITIONAL ENVIRONMENT

The lower part of this interval below 3500m consists of highly oxydized sediments totally dominated by inertinite. The true nature of these sediments are not completely understood, but they were probably formed during a transgressive episode in a marginal marine environment. Open marginal marine conditions were established in the upper part of the interval.

INTERVAL 3521.9 - 3546m

Age: Early Ryazanian  
(?Portlandian)

#### PALYNOLOGY

The SWC at 3521.9m produced an assemblage completely different from those above, both regarding palynomorph assemblage and kerogen composition. The appearance of Gochteodinium villosum, Endoscrinium pharo and Adnatosphaeridium caulleryi defines a Ryazanian or possibly Portlandian age for this interval. The presence of Halosphaeropsis sp. and Pterospermopsis spp. regarded to be controlled by facies, is characteristic for the Late Jurassic - earliest Cretaceous 'hot shale' facies (see below under Kerogen composition). The dating of this interval is further supported by the appearance of Tubotuberella egemenii and dinocysts belonging to the G.nuciformis-complex in the SWC at 3537m. Egmontodinium polyplacophorum recorded at 3605m (DCS) is caved from this interval.

#### MICROPALAEONTOLOGY

A single DCS was examined from this interval. A rich fauna composed of agglutinated taxa was recorded. Rare calcareous species are probably caved, including T.foeda. The assemblage is completely dominated by Haplophragmoides spp. of which H.cf.infracalloviensis is noteworthy. This species is characteristic of the black shale facies of Ryazanian - Late Jurassic age. The co-occurrence of Verneuilioides neocomiensis suggests an age restriction to the Cretaceous, as the species is only known from Ryazanian - Barremian sediments. Common occurrence of Trochammina spp. are also noted.

The fauna is typically brownish stained.

## KEROGEN ANALYSIS

Four SWCs were examined from this interval. The kerogen assemblages obtained from this interval are dominated by degraded material contrasting sharply with all other intervals. Other kerogen categories are rare or common except for abundant wood fragments in the uppermost assemblage from 3521.9m and dominating finely dispersed debris in the assemblage at 3537m.

The DCSs at 3530m and 3545m also produced kerogen assemblages dominated by degraded debris. Wood fragments are common at 3530m and abundant at 3545m, palynomorphs are rare in both assemblages, while finely dispersed debris is common.

## DEPOSITIONAL ENVIRONMENT

Shales and silty shales were deposited within this interval in a marginal marine environment with high terrestrial input. The characteristic degraded kerogen assemblage was formed by intense but incomplete degradation, probably due to stagnant conditions just below sediment surface.

## COMMENTS

The kerogen assemblages recorded from this interval are typical for Late Jurassic to earliest Cretaceous shales, usually associated with increased gamma-activity.



INTERVAL 3546 - 3598m

Age: Oxfordian

## PALYNOLOGY

The SWC at 3546m again brings a complete change in palynomorph assemblage. Productivity is increased drastically and the appearance of Endoscrinium luridum and Hystrichogonyaulax cladophora together with abundant Cerebropollenites mesozoicus and Callialasporites dampieri show that sediments of Oxfordian age have been penetrated. An Oxfordian age is further supported by the appearance of Nannoceratopsis pellucida and Gonyaulacysta jurassica at 3555m (SWC) and Scriniodium crystallinum, Chytroeisphaeridia chytroeides and Tubotuberella eisenackii at 3565m (SWC).

There is some uncertainty about the age of the lower part of this interval as species diagnostic of this interval were not recorded below 3565m . Assemblages used to define the interval below were, however, not recorded above 3598m (SWC). This problem may be due to poorer sample quality around the casing set at 3595m.

## KEROGEN ANALYSIS

This interval contrasts sharply from that above regarding kerogen composition. Four SWCs have been examined from this interval. Degraded material dominating the interval above is absent. Wood fragments are rare to common in the three upper assemblages and abundant in the lower at 3579.9m. Inertinite is common to abundant. Terrestrial palynomorphs are abundant to dominating in the three upper assemblages and common in the lowermost assemblage, while marine palynomorphs are rare throughout.

Finely dispersed debris is rare to common in the upper two assemblages at 3546m and 3555m and abundant at 3565m.

The DCSs show considerable caving from the interval above in the upper part of the interval with abundant degraded material at 3560m decreasing rapidly downwards and disappearing at 3600m. Inertinite is common to abundant while wood fragments are abundant. Marine palynomorphs are rare to common in four of the five assemblages examined, but increase to abundant in the middle part of the interval at 3575m.

Terrestrial palynomorphs are rare and common at 3550m and 3560m due to masking by caved material. From 3575m they are abundant.

Finely dispersed debris is common to abundant within this interval.

#### DEPOSITIONAL ENVIRONMENT

The shales and siltstones within this interval were deposited in an open marginal marine environment dominated by input of terrestrially derived plant debris.

INTERVAL 3598 - 3709.4m

Age: ?Bajocian-?Bathonian

#### PALYNOLOGY

The appearance of several spore and pollen species in the SWC at 3598m including the species Quadraeculina anellaeformis together with the disappearance of diagnostic species of the interval above show that sediments not younger than the Bathonian have been reached at this depth. A few more spore and pollen species giving a Middle Jurassic aspect to the assemblages are recorded from the core samples at 3621.0m. The presence of extremely rare Nannoceratopsis gracilis at 3621.0m indicates if 'in situ' an age not younger than the Bajocian. However, we are inclined to regard N.gracilis as reworked at this horizon since reworking from the interval below which produced assemblages with abundant N.gracilis, is clearly demonstrated from the lower part of the interval.

The core sample taken at 3704.55m, consisting of homogeneous sandstone, was barren of palynomorphs. However, a well rounded pebble of grey shale was embedded in the sandstone. This pebble was carefully polished to remove contamination and processed separately. It produced an extremely rich palynomorph assemblage contrasting sharply with the host rock which was barren. The assemblage is characterized by Nannoceratopsis gracilis (abundant), Baculatisporites comaumensis (common), Lycopodium-sporites spp. (common), Sentusidinium sp. (common), Ovalicysta sp. (common) and a number of spore and pollen species typical for the Middle Jurassic. Additional stratigraphically important species are Scriniocassis weberi, Parvocysta contracta and Mancodinium cf. semitabulatum. This assemblage is of latest Toarcian - Aalenian age.

The pebble was brought into the sandstone at this horizon at least in a semiconsolidated state and belongs to the stratigraphical interval defined below 3709.4m. This suggests an unconformity between 3704.65m and 3709.4m.

A distinct difference in sedimentary environment is also seen by the barren samples dominated by inertinite above and the relatively rich assemblages below. All the samples processed from cores 3, 4 and 5 down to 3709.4m were barren of palynomorphs.

#### KEROGEN ANALYSIS

Inertinite is totally dominating over this interval except in the upper part above 3632m where wood fragments and terrestrial palynomorphs are common to abundant in assemblages obtained from SWCs and CCs. Marine palynomorphs are rare in the upper part and absent below 3632m.

Finely dispersed debris is rare to common in most samples but is abundant near the top of the interval.

A single DCS was examined from 3610m. It showed extremely low organic productivity and the kerogen assemblage was totally dominated by inertinite.

#### DEPOSITIONAL ENVIRONMENT

This interval is dominated by sandstone deposited in a high energy oxydative environment resulting in strongly sorted kerogen assemblages dominated completely by inertinite.

Siltstone and shale intercalations above 3632m show slight marine influence and were deposited in a restricted marginal environment.

INTERVAL 3709.4 - 3820m

Age: Late Toarcian-Aalenian

PALYNOLOGY

Productive samples are found from 3709.4m containing persistent N.gracilis and a number of spore and pollen species of Middle Jurassic aspect like Osmundacidites spp., Lycopodiumsporites semimuris, Caytonipollenites pallidus, Chasmatosporites major, C.apertus, Tripartina variabilis, Duplexisporites problematicus, Callialasporites dampieri, C.minus and Klukisporites (Ishyosporites) variegatus. The appearance of Mancodinium semitabulatum at 3710.1m and maximum of N.gracilis around 3750m in association with the spore and pollen assemblage give a Late Toarcian to Aalenian age for this interval. Abundant Botryococcus are observed at 3735m.

The assemblage recorded from a pebble at 3704.55m and regarded as reworked from this interval produced an assemblage with N.gracilis, Sentusidinium sp., M.cf.semitabulatum, Kalyptea halosa, Scriniocassis weberi, Parvocysta contracta, Baculatisporites comaumensis, Classopollis classoides, Lycopodiumsporites spp., Osmundacidites wellmanii, Cibotiumsporites jurienensis, Iraquispora laevigata, Quadraeculina "minor", Quadraeculina anellaeformis, Deltoidospora minor, D.australis, Callialasporites dampieri, C.turbatus, C.segmentatus, C.trilobatus, Perinopollenites elatoides, Stereisporites antiquasporites, Todisporites minor, Cerebropollenites mesozoicus, Neoraistrickia suratensis, N.truncata, Dictyophyllidites mortonii, Exesipollenites sp., L.semimuris, Ishyosporites cf.variegatus, Densoisporites crassus and several acritarch species.

## KEROGEN ANALYSIS

The upper part of this interval down to 3756m is covered by CCs and SWCs. Inertinite is dominating in most samples from the upper part of the interval, wood fragments are common to abundant.

Marine palynomorphs are present in most samples as rare to common, while terrestrial palynomorphs are common to abundant. Membraneous material is abundant at 3751m (CC).

Finely dispersed debris is rare in the uppermost part of the interval, increases to dominating between 3720m and 3740m and again decreases to rare just below 3750m.

A single SWC was examined from the lower part of the interval at 3794m. Inertinite is dominating the assemblage. Wood fragments and terrestrial palynomorphs are rare and marine palynomorphs absent. Finely dispersed debris is abundant at this horizon.

Kerogen assemblages obtained from DCSs from 3760m to 3707m show a high stability with common to abundant inertinite, abundant wood fragments and abundant terrestrial palynomorphs. Marine palynomorphs and finely dispersed debris are rare or absent.

## DEPOSITIONAL ENVIRONMENT

Siltstones and shales from the upper part of the interval were deposited in a restricted marginal marine environment dominated by input of terrestrially derived plant debris. Sandstones from the lower part of the interval were deposited under high energy oxydative conditions in a marginal marine or possibly non-marine environment.

INTERVAL 3820 - 3925m

Age: Late Toarcian

#### PALYNOLOGY

The top of this interval is defined by the appearance of Comparodinium punctatum at 3820m (DCS). It is present in most assemblages from this interval. The continued presence of Callialasporites dampieri restricts the age to the Late Toarcian. Additional stratigraphically important elements are Phallocysta cf. eumekes and questionable Parvocysta contracta.

#### KEROGEN ANALYSIS

DCSs from this interval show high stability in kerogen assemblages over this interval. Inertinite is dominating in the uppermost assemblage at 3820m and is abundant in all the other assemblages. Wood fragments are abundant throughout the interval.

Marine palynomorphs vary between rare and common, while terrestrial palynomorphs are abundant in most samples.

Finely dispersed debris is absent from the upper part of the interval, but increases from rare at 3855m and 3870m to dominating at 3910m.

The amount of finely dispersed debris observed in the assemblages obtained from DCSs contrasts with that from the SWCs being abundant to dominating. Inertinite is abundant in assemblages while wood fragments are common in the upper part and abundant in the lower.

Marine palynomorphs are present as rare elements in all four assemblages and terrestrial palynomorphs are common to abundant.

An increase in membranous material is observed in the lowermost assemblage at 3915m.

## DEPOSITIONAL ENVIRONMENT

The shales, siltstones and sandstones from this interval were deposited in a restricted marginal marine environment. A regressive development is observed through this interval.



INTERVAL 3925 - 4087m

Age: Late Pliensbachian -  
Early Toarcian

#### PALYNOLOGY

A distinct change in palynomorph assemblages is observed between 3925m and 3944m with the appearance of Cerebropollenites cf. thiergartii, Quadraeculina "major", Nannoceratopsis senex, abundant Chasmatosporites major and a second maximum in N. gracilis. Additional characteristic species are Parvocysta sp. B of Bjærke, Comparodinium cf. perpunctatum and Lycopodiacidites rugulatus. The appearance of Kraeuselisporites reissingerii at 3970m may indicate that Pliensbachian sediments have been penetrated at this depth.

Abundant Nannoceratopsis tricerias at 3937m (SWC) form a very characteristic element.

The lower part of the interval shows reduced fossil productivity, but N. senex and N. tricerias are present in SWC at 4047m showing that sediments of Late Pliensbachian age are present at this depth.

#### KEROGEN ANALYSIS

The upper part of this interval above 3987m, is covered by SWCs. Kerogen assemblages from this part show common to abundant inertinite increasing to dominating at 3987m. Wood fragments are common to abundant.

Marine palynomorphs are common to abundant in the uppermost part and decrease downwards to rare at 3954m and are absent at 3982m and 3987m. Terrestrial palynomorphs are abundant in the uppermost part of the interval, but is reduced to common at 3982m and 3987m.

A downward decrease is also observed for finely dispersed debris from dominating at 3928m to rare at 3987m.

Membraneous material is rare to common in these assemblages.

A SWC was also examined from 4047m. Inertinite is common at this horizon, while wood fragments and terrestrial palynomorphs are abundant. Marine palynomorphs and finely dispersed debris are common.

The DCSs over this interval show common to abundant inertinite in the upper part. Below 4000m inertinite is persistently abundant, but again reduced to common in the lowermost two assemblages at 4060m and 4075m.

Wood fragments are abundant throughout the interval, increasing to dominating in two assemblages at 4015m and 4075m.

Marine palynomorphs are common in the uppermost part of the interval at 3925m and 3940m, but reduced to rare or absent further down. Terrestrial palynomorphs are abundant over this interval. Finely dispersed debris is abundant at 3925m, but reduced downwards to common and rare below 4000m.

Membraneous material forms a characteristic element within this interval being common to abundant throughout.

#### DEPOSITIONAL ENVIRONMENT

The sandstones with intercalated siltstones present within this interval, were deposited in a restricted marginal marine environment. Kerogen analysis show decreasing energy up through the sequence and increasing marine influence. This is interpreted as a transgressive development.

INTERVAL 4087m - 4117,9m

Age: ?Pliensbachian

#### PALYNOLOGY

The top of this interval is defined by the appearance of sand/sandstone with rich acritarch assemblages including several species belonging to the genus Micrhystridium, Domasia liassica and spherical acritarchs.

This interval probably represents a transgressive phase at the beginning of the Late Pliensbachian to Aalenian sedimentary cycle and is suggested to unconformably overly the Hettangian - ?Early Sinemurian below. The presence of Monosulcites punctatus which is a characteristic element of the Hettangian assemblages at 4087m may be due to re-working.

Age diagnostic palynomorphs were not recorded and a Pliensbachian age is suggested tentatively for this interval.

#### KEROGEN ANALYSIS

Two SWCs were examined from this interval. Both produced assemblages dominated by inertinite. Wood fragments are abundant. Marine palynomorphs are common in the upper assemblage mainly due to presence of small acritarchs. They are reduced to rare in the lower assemblage.

Terrestrial palynomorphs are common in both assemblages and finely dispersed debris is rare in the upper assemblage and absent from the lower.

DCSs over this interval produced assemblages dominated by wood fragments. Inertinite is abundant.

Marine palynomorphs are rare and terrestrial palynomorphs are common, while finely dispersed debris is rare.

#### DEPOSITIONAL ENVIRONMENT

The sandstones within this interval were formed in a high energy, oxydative marginal marine environment probably during a transgressive episode.

INTERVAL 4117.9 - 4435m

Age: Hettangian.  
?Early Sinemurian

#### PALYNOLOGY

In the SWCs at 4117.9m and 4125m the characteristic Hettangian - Early Sinemurian spore and pollen assemblage is established with the appearance of Monosulcites punctatus, Deltoidospora toralis, Calamospora nathorstii and Eucommiidites granulatus together with the reappearance of Quadraeculina "minor", Eucommiidites troedsoni and Caytonipollenites pallidus. Additional diagnostic species like Pinuspollenites minimus, Trachysporites fuscus and Marattisporites scabratus appear at 4165m (DCS). These species belong to the Trachysporites/Pinuspollenites zone of Hettangian age. Aratrisporites minimus is probably present from 4367.5m, although definitely identified specimens were not recorded until 4445m. This shows that Early Hettangian sediments are present in the lower part of the interval.

The interval may be subdivided into three units. The upper unit defined as described above while the middle unit of unspecified Hettangian age is defined by abundant Eucommiidites spp. at 4270m and Pinuspollenites minimus at 4297.5m. Persistent presence of Marattisporites scabratus is recorded from the top of this interval at 4270m.

The lowermost unit is characterized by Aratrisporites minimus probably present from 4367.5m

## KEROGEN ANALYSIS

This interval is mainly covered by DCSs. Only two SWCs from the uppermost part of the interval were examined.

The interval is characterized by high amounts of inertinite, wood fragments and terrestrial palynomorphs.

Wood fragments dominate the assemblages down to 4255m. Between 4255m and 4345m wood fragments vary between common and dominating and from 4360m they are abundant. Inertinite varies inversely with wood fragments being abundant in the upper part of the interval above 4270m and abundant to dominating in the lower part of the interval.

'In situ' marine palynomorphs are absent from this interval, apart from a single specimen of Veryhachium sp. recorded at 4270m, which may indicate slight marine influence.

Terrestrial palynomorphs are well represented throughout the sequence varying between common and abundant in most assemblages. There are three maxima in terrestrial palynomorphs, one at 4165m, one at 4270 to 4285m and one at 4390 to 4405m.

The amount of finely dispersed debris varies considerably. It is rare or absent near the top of the interval between 4120m and 4135m. Between 4150m and 4195m there is a maximum in finely dispersed debris where it is common to abundant. Between 4210m and 4255m it is absent or rare but again reaches a maximum between 4270m and 4300m increasing to common to abundant. From 4315m down to the base of the interval finely dispersed debris is rare to common.

Two SWCs were examined near the top of the interval at 4117.9m and 4125m. Both assemblages are dominated by inertinite. Wood fragments are abundant.

Rare marine palynomorphs are present at 4117.9m, but this is probably due to contamination. Terrestrial palynomorphs are common at 4117.9m and abundant at 4125m.

True vitritic coal is present within the sequence. This is seen from kerogen residues obtained from picked cuttings totally dominated by wood fragments.

#### DEPOSITIONAL ENVIRONMENT

The sandstones, coals and bituminous shales dominating this interval were deposited in a top delta or coastal plain environment. Extremely rare marine palynomorphs are present at 4117m and 4270m indicating possible weak marine influence at these horizons.

Palynology, kerogen analysis and sediment distribution clearly show three different units. The upper unit between 4117 and 4270m is dominated by sandstone deposition. Between 4270 and 4365m deposition of coal and bituminous shales is dominating, while below 4365m sandstone is again dominating over coal and bituminous shale.

TRIASSICINTERVAL 4435 - 4468m TD

Age: Rhaetian

## PALYNOLOGY

The appearance of Limbosporites lundbladii and Ricciisporites tuberculatus in DCS at 4435m is taken as evidence for the penetration of Late Triassic Rhaetian sediments. L.lundbladii becomes common at 4450m and is associated with rare Ricciisporites tuberculatus, Ricciisporites sp. and Taenia-sporites rhaeticus between 4450m and 4468m. The assemblages from this interval are dominated by species present within the interval above. A considerable part of this material is probably caved into the Rhaetian interval.

## KEROGEN ANALYSIS

The kerogen assemblages recorded from the DCSs over this interval is heavily contaminated by material from the interval above and are not representative.

However, a kerogen assemblage dominated by inertinite and wood with rare terrestrial palynomorphs is probably characterizing this interval.

## DEPOSITIONAL ENVIRONMENT

Although the samples from this interval are heavily contaminated by caved material, sandstones, siltstones and possibly coal deposited in a non-marine top delta or coastal plain environment are indigeneous to this interval. This is supported by the presence of a terrestrial palynomorph assemblage and inertinitic kerogen assemblage.



## DEPOSITIONAL HISTORY

Based on the information and interpretations presented in this report the depositional history of the sequence penetrated by Well 6407/1-3 may be outlined as follows:

A top delta or coastal plain environment was established during Rhaetian times with deposition of sandstones, siltstones and possibly coal beds. A minor unconformity probably separates the Late Triassic Rhaetian from the Early Jurassic Hettangian sediments (4435m).

Sedimentation continued during the Hettangian - ?early Sinemurian with the deposition of coal, bituminous shales and sandstones in a top delta/coastal plain environment (4117 - 4435m). Slight marine influence may have occurred in the middle and upper part of the interval. Coal and shale deposition dominates between 4270 and 4365m, while sandstones dominate in the upper part indicating that fluvial processes were dominating during deposition of the upper part of the interval.

The Hettangian - ?early Sinemurian sequence is overlain by a marginal marine sandstone (4087m - 4117m). This sandstone is probably separated from the underlying sequence by a Late Sinemurian - early Pliensbachian hiatus and is thought to represent a transgressive episode at the beginning of the Late Pliensbachian - Toarcian sedimentary cycle.

Shallow marine conditions were established in the Late Pliensbachian and siltstones and sandstones were deposited. This sedimentary cycle terminated with the deposition of Late Toarcian - Aalenian sandstones (3750 - 3820m). Shales and siltstones of Aalenian age above the sandstone interval (3709.4 - 3750m) were deposited in a restricted marginal marine or brackish environment.

An unconformity separates this interval from the overlying sandstone sequence at 3709.4m. The sandstones of Bajocian or Bathonian age (3598 - 3709.4m) were deposited in a fluvial environment. Marine influence is seen in the shale and siltstone intercalations near the top of the interval.

Another unconformity separates the Bajocian - Bathonian interval from the overlying Oxfordian interval (3545 - 3598m). Open marginal marine conditions were established during the deposition of the Oxfordian sequence.

A thin shale interval of Early Ryazanian or possibly Portlandian age (3521.9 - 3545m) shows that the area was transgressed at least once between the Oxfordian and the Aptian. A marginal marine environment was established and sediments presenting typical 'hot shale' facies were deposited. The interval is separated from both underlying and overlying sediments by unconformities.

Sedimentation continued with the deposition of Early Aptian shales and red claystone in a marginal marine environment (3495.1 - 3521.9m). A thick Aptian - ?Cenomanian sequence was deposited in an open marine shelf environment with a medium to high energy regime (2585 - 3495m). A considerable subsidence occurred in the area and high sedimentation rates were probably created.

The age relationships within the Late Cretaceous sequence are poorly documented. However, well dated Early Campanian sediments are present between 2395m and 2585m. Laminated shales, siltstones and sandstones were deposited during this interval in an open marine shelf environment.

The Early Campanian is overlain unconformably at 2395m by black and red claystones of Late Campanian - Early Maastrichtian age. They were deposited in an oxydative marine environment with low sediment input.

Evidence for a Late Maastrichtian transgression is present at 2350m. Unconformities are probably present both below and above this thin interval.

Marine conditions are again established in the Early Paleocene. An Early Tertiary Paleocene to ?Early Oligocene sedimentary cycle is introduced with deposition of marine claystones, greenish and red clays and minor silt- and sandstones (1890 - 2350m).

Sedimentation continued in the Late Oligocene under open marine conditions, and a complete Late Oligocene and Miocene sequence was deposited (1550 - 1890m). Evidence of volcanic activity is observed in the Early Miocene sequence.

Open marine shelf conditions also prevailed at the Miocene - Early Pliocene transition (1460 - 1550m). During the Late Pliocene (620 - 1460m) the basin subsided rapidly and a thick sequence of sandy and silty mud was deposited in a marine shelf environment.

Sedimentation continued into the Pleistocene with deposition of mud in an open marine shelf environment (420 - 620m).

## QUATERNARY FORAMINIFERAL STRATIGRAPHY

Above the 500m level foraminiferal analyses were carried out at 10m sampling intervals in order to establish a more detailed biostratigraphical subdivision.

The interval 420 - 500m covers only Pleistocene sediments. The time stratigraphical breakdown (as reflected by e.g. foraminifera) during this epoch is extremely poor, and a biostratigraphical subdivision must be based on local ranges (range zones; RZ) and assemblages (assemblage zones; AZ). To establish bio-zones for correlation purposes a number of sections in the area should be investigated, as no relevant literature is available.

In this early phase we regard the documentation of the observed distribution more valuable than the more or less tentative interpretations. The results are shown in Enclosure 5 as semi-quantitative data.

The Pleistocene sequence in Well 6407/1-3 is continuing down to the 620m level. The detailed foraminiferal analyses cover the middle part of the Pleistocene, the upper part being removed during drilling operation.

The most prominent feature is seen at the top of the investigated section, here named the Uvigerina - Cibicides AZ, in the interval 420 - 440m. A number of species only tolerating warm or temperate water were recorded, e.g. U.peregrina, Uvigerina sp. 1, Hyalinea balthica, Trifarina angulosa and Gyroidinoides soldanii. The upper assemblage zone is defined by more than 5% representation of both U.peregrina and C.lobatulus.

The Elphidium AZ (450 - 480m) is characterized by 30-40% of both E. excavatum and Bulimina marginata, partly common E. groenlandicum, less than 5% Cassidulina laevigata and less than 2% C. lobatulus. Most other species present in this zone are also present in the assemblage zones above and below, and variations could more easily be explained by patchy occurrences than a proper biostratigraphical succession.

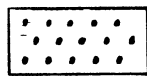
The Cassidulina AZ (490 - 500m) is characterized by more than 10% of C. laevigata, in contrast to less than 5% in the AZ above. A similar increase is noted for Melonis barleeaanum, though less pronounced. Otherwise the two lower assemblage zones have many similarities, i.e. mainly composed of cold water indicators and species tolerating wide environmental variations.

The assemblage zones are probably controlled by facies variations in terms of the character of the bottom water body. The zones are thus thought to be diachronous and of little value to chrono-stratigraphy. However, they would be of great importance to environmental interpretations. The two lowermost zones were deposited in normal marine shelf conditions during cold water conditions. Such conditions were present during the glacial periods of the Pleistocene. In contrast the upper assemblage zone, was deposited during temperate water conditions, reflecting an interglacial period. The studied sequence is probably of Eem or older age. This is supported by the presence of Uvigerina sp. 1, which as far as we know, has not been recorded from Holocene sediments in the area.

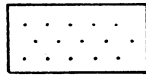
The range zones suggested must be regarded as preliminary. We have tentatively indicated an upper Islandiella norcrossi - Hyalina balthica RZ (420 - 450m) and a lower Stainforthia loeblichii - Bolivina spathulata RZ (460 - 500m). These are more based on persistent occurrences than on limited ranges. From our experience in adjacent areas the persistent occurrence of S. loeblichii below common occurrences of specimens of the genus

Islandiella is the most important characteristic for regional stratigraphy. Also Nonion labradoricum seems to be concentrated in the upper part together with Islandiella spp.

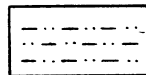
A more complete interpretation of our observations must await further information from additional wells in the area.

LEGEND TO ENCLOSURESLITHOLOGY

SAND/SANDSTONE  
MEDIUM - COARSE



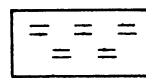
SAND/SANDSTONE  
FINE/MEDIUM



SILT/SILTSTONE



CLAY/SHALE



MUD

SAMPLES

Ditch cuttings sample (DCS)



Sidewall core (SWC)



Conventional core (CC)

FOSSIL OCCURRENCE

## Palynological range charts:

- Rare - persistent (DCS)
- Common - abundant (DCS)
- × Rare - persistent (SWC)
- + Common - abundant (SWC)
- Rare - persistent (CC)
- Common - abundant (CC)

## Foraminiferal range charts:

- Present (DCS)
- Common (DCS)
- Abundant (DCS)
- ↓ Regarded as caved if recorded below this horizon