

# **REPORT**

## **Jurassic depositional sequences, palynofacies and organic facies of the Troms III Area**

**23.1620.00/01/91**



Institutt for kontinentalsokkelundersøkelser og petroleumsteknologi A/S  
Continental Shelf and Petroleum Technology Research Institute A/S

Håkon Magnussensgt. 1B • P.O.Box 1883, Jarlesletta • N-7002 Trondheim, Norway  
Tel.: + 47 7 920611 • Telex: 55 434 iku n • Telefax: + 47 7 92 09 24 (aut)





Institutt for kontinentalsokkelundersøkelser og petroleumsteknologi A/S  
Continental Shelf and Petroleum Technology Research Institute

S.P. Andersen veg 15 b \* N-7034 Trondheim, Norway  
Tel.: + 47 7 591100 \* Telex: 55 434 iku n \* Telefax: + 47 7 591102 (aut.)

# REPORT

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REPORT TITLE:

JURASSIC SEQUENCES, PALYNOFACIES AND  
ORGANIC FACIES OF THE TROMS III AREA

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AUTHORS:

Morten Smelror

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| CLIENT:   |               |                    | APPROVED,<br>Tom Bugge | SIGN.:                |
| Statoil   |               |                    |                        | <i>Tom Bugge</i>      |

SUMMARY:

The report presents the results of a follow up study on the Jurassic succession exposed during the IKU Shallow Drilling Troms III 1990 project. Time/depth diagrams of lithostratigraphic events have been prepared in order to help recognize sequence boundaries and to identify the extent of time gaps.

Palynofacies analyses have been carried out in cores 7018/05-U-06, -02 and -01, and the data are presented as palynodebris frequency diagrams.

The new information from the palynofacies analyses are, combined with organic facies data, discussed in relation to the depositional environments of the recognized sequences. A Jurassic sequence correlation of the Barents Sea area is briefly discussed.

|              |                |
|--------------|----------------|
| KEY WORDS:   |                |
| JURASSIC     | ORGANIC FACIES |
| STRATIGRAPHY | TROMS III      |
| PALYNOFACIES |                |

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## 1. INTRODUCTION

During the summer 1990 IKU drilled five shallow cores in the Mesozoic and Lower Cenozoic succession in the Troms III area. Three of the cores (7018/05-U-06, -05 and -02) cover the lower/middle Jurassic to lower Cretaceous sequences (Figure 1). These cores which comprise a total of 735 m of recovered bedrock, are undoubtedly important reference sections for the geological description and evaluation of the Hekkingen, Fuglen and Stø Formations in the Troms III area. Considering stratigraphic overlap, the three cores penetrated 100 m, 210 m and 260 m of these formations, respectively. After the presentation of the main report in the IKU Shallow Drilling Troms III 1990 project (Weiss et al. 1991), a project on palynofacies on the Jurassic sequences was initiated. The major objective of this study was to provide a new set of detailed information, which in combination with sedimentological, stratigraphical and organic geochemical data, will be useful in reconstructions of the deposition history of the Stø, Fuglen and Hekking Formations.

In the main report of Weiss et al. (1991), the cored succession was described (and discussed) according to the lithostratigraphical subdivision of Worsley et al. (1988). Lithostratigraphical units do not necessarily coincide with genetic stratigraphic analyses or organic facies segmentation of a basin. In the present report biostratigraphic and sedimentological evidences has been used to subdivide the cored Jurassic succession of the Troms III area into sequences, and in the following the palynofacies and organic facies data are related to the recognized sequences rather than to the formal lithostratigraphic subdivision. The biostratigraphic, lithostratigraphic, sedimentological and organic geochemical information used in this study is throughoutly presented in Weiss et al. (1991) and the appendix volumes of the IKU Shallow Drilling Troms III 1990 report. However, in the present report the biostratigraphic marker events have been tied to an absolute time scale, and the quantitative set of biostratigraphic events have been presented as depth versus time plots. This is in order to help the recognition of sequence boundaries.



## 2. DESCRIPTION OF THE JURASSIC SUCCESSION

Following the stratigraphical subdivision of Worsley et al. (1988) the cores penetrated approximately 100 m of the Lower to Middle Jurassic Stø Formation, 210 m of the Middle Jurassic Fuglen Formation and 260 m of the Upper Jurassic to Lower Cretaceous Hekkingen Formation. Detailed descriptions of these cores are found in Weiss et al. (1991), and in the following only a brief description of the cored Jurassic succession is given.

### Stø Formation (Toarcian - Bajocian)

Core 7018/05-U-06 penetrated approximately 100 m of sandstones referable to the Stø Formation. The lower part of the core (4 m thick) consists of slightly bioturbated, lenticularly bedded siltstone interpreted as lagoonal deposits. The unit is dated to Toarcian - Aalenian. A 9 m thick, strongly bioturbated sandstone of lower shoreface/offshore transition zone setting is transgressively overlying the lagoonal deposits. This transgression is contemporaneous with a regional transgressive event occurring within the Stø Formation in the Troms I area (cf. Olaussen et al. 1984, Gjeldberg et al. 1987, Worsley et al. 1988).

The remainder of the Stø Formation (above the strongly bioturbated sandstone) toward the top, consists of predominantly clean, fine to medium-grained, cross-bedded and massive sandstone. Bioturbation is only slight and mainly vertical, suggesting a high energy nearshore environment. Erosively based fining upward sequences with mud-drapes have been interpreted as tidal inlets, whereas cleaning upward sequences have been attributed to progradation from lower shoreface to foreshore.

The main part of the Stø Formation consists of very clean and well sorted quartz arenite, and comprises an excellent reservoir unit which demonstrates high permeability in the range of 1000 - 7000 mD and porosity of 24-33%. A southeastern and southern provenance area was inferred from the diverse sedimentary and metamorphic lithic clasts, resembling Upper Paleozoic sediments and various basement rocks in the Troms area.

### **Fuglen Formation (Bathonian - Callovian)**

The Fuglen Formation has a composite thickness of 210 m (core 7018/05-U-06 penetrated the basal 120 m and core 7018/05-U-02 the upper 193 m, with 103 m overlap). In core 7018/05-U-06 a gradational transition from the Stø Formation to the Fuglen Formation occurs, contrasting with the abrupt transition from sandstones to mudstones reported by Worsley et al. (1988) in the Hammerfest and Tromsø Basins. The base of the Fuglen Formation is reported as Callovian in the type area by Worsley et al. (1988), while the basal beds of core 7018/05-U-06 contain palynomorphs of early Bajocian age. The transition from the Stø to the Fuglen Formation therefore took place earlier in this area than in the Hammerfest and Tromsø Basins.

Generally, the Fuglen Formation consists of strongly bioturbated, muddy siltstones deposited under open shelf conditions. Abundant pelagic fossils and extensive bioturbation show that good living conditions prevailed in the sea water as well as at the seabed during deposition. In the uppermost part of the formation an Early Oxfordian age is documented by palynomorphs.

The mudstones of the Fuglen Formation are of fair to good organic richness, but contain thermally immature type-III and type IV kerogen with no significant hydrocarbon generation potential. Significant concentrations of non-indigenous hydrocarbons appear to be present in the lower part of the Fuglen Formation in core 7018/05-U-06, and staining with thermally early mature, partly biodegraded oil was also observed in the upper part of the formation (core 7018/05-U-02).

### **Hekkingen Formation (Oxfordian - Boreal Berriasian)**

With a sharp contact on top of the bioturbated silty mudstones of the Fuglen Formation, very dark shales of the Hekkingen Formation occur. Late Oxfordian fossils occur in the lower part of the formation.

The composite thickness of the Hekkingen Formation in cores 7018/05-U-02 and 7018/05-U-01 is 260 m, a value between the reported thickness in the type well (359 m) and the reference well (113 m) in the Hammerfest Basin (Worsley et al. 1988).

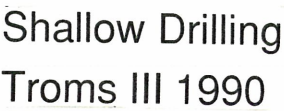
The lower 50 m show very high gamma ray values due to high content of uranium. This is accompanied by a high content of organic carbon (mostly



between 8 and 15% TOC), and this part of the formation is referred to the Alge Member. Pelagic fossils as ammonites and belemnites occur in this part of the unit, and although benthic bivalves are sporadically present, this finely laminated unit represents deposition in dominantly anoxic environment with a very high organic production in the water masses.

The upper 210 m are referred to the Krill Member. This unit also consists of dark grey laminated (unbioturbated) organic rich shale. The fossil content is sparse in the lower part, but relatively high in the upper 50 m, where ammonites and benthic bivalves are present. The upper part of the formation is ammonite dated as Boreal Berriasian. Abundant thin carbonate cemented beds occur throughout, and as in the Fuglen Formation they contain a diverse carbonate mineralogy. The lack of evidences of any current activity and the high organic content indicate deposition in deep shelf conditions, possibly in a somewhat restricted basin. The few occurrences of benthic bivalves and foraminifera show only sporadic ventilation of the sea bottom, and the deposition mainly took place under anoxic to dysoxic conditions.

The dark grey and black claystones of the Hekkingen Formation contain fair to excellent concentrations of thermally immature organic matter with a moderate hydrogen content (type-II/III and type-III kerogen). Regarding thermal maturity, organic richness and kerogen type, the shale of the Hekkingen Formation in the cores from Troms III appear to be broadly similar to those in Troms I well 7120/12-1. Higher TOC contents in the Alge Member at Troms III and poorer kerogen quality in the upper part of the Krill Member at Troms I seem to be the main difference. Non-indigenous hydrocarbons were found at different levels in this formation.



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### 3. NUMERICAL BIOSTRATIGRAPHY

#### 3.1 Definition of biostratigraphic events

Cores 7018/05-U-06, 7018/05-U-02 and 7018/05-U-01 have been analysed for macrofossils, microfossils and palynomorphs. Range charts for each of these fossil groups were presented in Appendix A.3.1 to A.3.5 of Weiss et al. (1991), while the biostratigraphic interpretation of these cores were discussed in chapters 3.1.4, 3.2.4 and 3.3.4, respectively. In order to help the recognition of sequence boundaries (as defined in Section 4.1) in the cored Jurassic succession, a new biostratigraphic approach has been used in the present study. At IKU this method was first applied to the Cenozoic succession of Haltenbanken and the western Barents Shelf (Goll et al. 1989, 1990) and has recently been used on the Paleogene succession in the south Viking Graben (Goll 1991). For the biostratigraphically important species a system of numerical ages for termination event (Earliest occurrence=Eo; Latest occurrence=Lo) has been designated. In the Cenozoic successions there are generally a high diversity of foraminifera, siliceous microfossils and dinoflagellates. Many of these have short ranges and well-defined biostratigraphic terminations, and consequently it has been possible to identify a relatively high number of numerical biostratigraphic events in the examined sequences.

In the Jurassic succession of the Troms III area the microfossil and dinoflagellate biotas are less diverse, and the ranges are generally less well-defined. This means that the number of biostratigraphic events to which it has been possible to assign numerical ages, is definitely lower in the Jurassic than in the Cenozoic. These Jurassic numerical biostratigraphic datums (which have been extracted from the literature) have been related to the standard Boreal ammonite zonation and subsequently correlated to the chronostratigraphy and absolute time scale of Haq et al. (1987). Where possible, the ammonite and dinoflagellate appearance and extinction datums shown on the Haq et al. cycle chart are applied directly. It is important to emphasize, however, that there are a large number of uncertainties linked to these correlations. The local stratigraphic ranges of the Jurassic Barents Sea biotas are not precisely known, and the exact chronostratigraphic positions of many of the biozones (i.e. ammonite zones, foraminiferal zones and dinoflagellate zones) are not well established. A tentative correlation chart of published dinoflagellate zones and ammonite zones within the Toarcian to Upper Oxfordian is given in Figures 2 and 3. A correlation chart of Kimmeridgian and Volgian ammonite zones and stage



nomenclature of NW Europe, East Greenland and Northern Siberia is shown in Figure 4.

Being aware of these limitations, I have subjectively chosen the below listed biostratigraphic events as the most "reliable". No confidence limits are given, but I will stress that the accuracy of the numerical ages assigned to these termination events may vary significantly. This should be kept in mind when interpreting the time versus depth plots of the biostratigraphic events and "sedimentation curve" (Appendices I to III).

The biostratigraphic events used in the present interpretations are shown in Tables I-III.

Table I Numerical biostratigraphic events recognized in core 7018/05-U-06.

Core 7018/05-U-06 (Appendix I)

| Ammonites                      | Code    | Stratigraphic level | Age    |
|--------------------------------|---------|---------------------|--------|
| ? <i>Arcticoceras</i> sp.      | A?A 159 | 70.68 m             | 159 Ma |
| <i>Arctocephalites</i> (?) sp. | AAc 160 | 78.93 m             | 160 Ma |

| Dinoflagellates                     |          |          |        |
|-------------------------------------|----------|----------|--------|
| ? <i>Sirmiodinium grossii</i>       | ?DSg 159 | 17.96 m  | 159 Ma |
| <i>Cassiculosphaeridia dictydia</i> | DCd 159  | 52.74 m  | 159 Ma |
| <i>Dichadogonyaulax sellwoodii</i>  | DDs 166  | 109.91 m | 166 Ma |
| <i>Parvocysta bullula</i>           | DPb 169  | 121.23 m | 169 Ma |
| <i>Phallocysta eumekes</i>          | DPe 170  | 140.95 m | 170 Ma |
| <i>Mancodinium semitabulatum</i>    | DMS 171  | 183.15 m | 171 Ma |
| <i>Moesiodinium raileanui</i>       | DMr 171  | 202.95 m | 171 Ma |
| <i>Parvocysta</i> spp. (common)     | DPe 177  | 241.62 m | 177 Ma |
| <i>Susadinium scrofoides</i>        | DSs 180  | 245.13 m | 180 Ma |

Table II Numerical biostratigraphic events recognized in core 7018/05-U-02.

Core 7018/05-U-02 (Appendix II)

| Ammonites                      | Code    | Stratigraphic level | Age    |
|--------------------------------|---------|---------------------|--------|
| <i>Amoeboceras</i> (A.) ex gr. |         |                     |        |
| <i>alternans</i>               | AAa 145 | 74.93 m (Lo)        | 145 Ma |
| "                              | "       | 82.70 m             | 145 Ma |
| "                              | "       | 99.27 m (Eo)        | 145 Ma |
| <i>Pseudocadoceras</i> sp.     |         |                     |        |
| (cf. <i>mudum</i> )            | APm 159 | 202.06 m            | 159 Ma |
| <i>Arcticoceras</i> sp.        |         |                     |        |
| (cf. <i>krylowi</i> )          | AAk 159 | 158.96 m            | 159 Ma |
| <i>Arcticoceras</i> sp.        |         |                     |        |
| (ex gr. <i>ischmae</i> )       | AAi 160 | 260.30 m            | 160 Ma |

| Dinoflagellates                      |         |          |        |
|--------------------------------------|---------|----------|--------|
| <i>Pareodinia cappilosa</i>          | DPc 140 | 52.74 m  | 140 Ma |
| <i>Liesbergia scarburghensis</i>     | DLs 150 | 105.88 m | 150 Ma |
| <i>Wanaea fimbriata</i>              | DWf 150 | 107.89 m | 150 Ma |
| <i>Endoscrinium galeritum</i>        | DEg 155 | 146.45 m | 155 Ma |
| <i>Gonyaulacysta petinigera</i>      | DGp 155 | 151.59 m | 155 Ma |
| <i>Lagenadinium callovianum</i>      | DLc 156 | 220.36 m | 156 Ma |
| <i>Glomodinium cerebraloides</i>     | DGc 156 | 174.43 m | 156 Ma |
| <i>Cassiculosphaeridia dictyidia</i> | DCd 159 | 220.36 m | 159 Ma |
| <i>Sirmiodinium grossii</i>          | DSg 159 | 251.76 m | 159 Ma |

| Foraminifers                    |          |          |        |
|---------------------------------|----------|----------|--------|
| <i>Evolutinella emeljanzevi</i> | FEE 140  | 48.49 m  | 140 Ma |
| <i>Recurvoides disputabilis</i> | FRd 153  | 127.90 m | 153 Ma |
| <i>Riyadhella sibirica</i>      | FRsi 157 | 183.60 m | 157 Ma |
| <i>Riyadhella shapkinaensis</i> | FRsh 157 | 183.60 m | 157 Ma |

| Other  |         |       |        |
|--------|---------|-------|--------|
| Pseudo | D0p 144 | ~50 m | 144 Ma |

Table III Numerical biostratigraphic events recognized in core 7018/05-U-01.

Core 7018/05-U-01 (Appendix III)

| Ammonites                                 | Code       | Stratigraphic level | Age    |
|-------------------------------------------|------------|---------------------|--------|
| <i>Borealites</i> sp.                     | ABo 130    | 84.03 m (Lo)        | 130 Ma |
| <i>Laugeites</i> cf. <i>groenlandicus</i> | ALg 134    | 102.11 m (Lo)       | 134 Ma |
| Dorsoplatinae                             | ADo 136    | 149.65 m            | 136 Ma |
| <i>Rasenia?</i> sp. indet                 | AR? 145    | 264.50 m            | 145 Ma |
| <i>Amoeboceras</i>                        |            |                     |        |
| (? <i>Priondoceras</i> ) sp. indet        | AA?(P) 146 | 270.96 m            | 146 Ma |

| Bivalves              |         |         |        |
|-----------------------|---------|---------|--------|
| <i>Buchia okensis</i> | BBo 130 | 83.60 m | 130 Ma |

| Dinoflagellates                   |         |          |        |
|-----------------------------------|---------|----------|--------|
| <i>Nelchinopsis kostromiensis</i> | DNk 121 | 48.50 m  | 121 Ma |
| <i>Oligosphaeridium complex</i>   | D0c 126 | 48.50 m  | 126 Ma |
| <i>Oligosphaeridium patulum</i>   | D0p 144 | 256.38 m | 144 Ma |

| Nannofossils                 |         |         |        |
|------------------------------|---------|---------|--------|
| <i>Chiastozygus striatus</i> | NCs 121 | 48.50 m | 121 Ma |
| <i>Nannoconus bermudezii</i> | NNb 127 | 48.52 m | 127 Ma |

| Foraminifers                       |         |          |        |
|------------------------------------|---------|----------|--------|
| <i>Trochammina septentrionalis</i> | FTs 133 | 118.13 m | 133 Ma |
| <i>Evolutinella emaljanzevi</i>    | FEE 140 | 243.63 m | 140 Ma |



| BOREAL SUBSTAGES | NORTHWEST EUROPE | ENGLAND                                       |   | NW-GERMANY                            | EAST GREENLAND | BARENTS SEA AREA                                              |                              | NORTHERN SIBERIA            |                                              | SVERDRUP BASIN                                                           | NORTHERN YOUKON                  |            |                        |  |
|------------------|------------------|-----------------------------------------------|---|---------------------------------------|----------------|---------------------------------------------------------------|------------------------------|-----------------------------|----------------------------------------------|--------------------------------------------------------------------------|----------------------------------|------------|------------------------|--|
|                  | AMMONITE ZONES   | DINOFLAGELLATE ZONES<br>(Woollam & Riding'83) |   | DINOFLAGELLATE ZONES<br>(Prauss 1989) | AMMONITE ZONES | DINOFLAGELLATE ZONES<br>(Smelror & Below, in press.)          | AMMONITE ZONES<br>(Svalbard) | AMMONITE ZONES              | DINOFLAGELLATES<br>(Ityina 1986)             | DINOFLAGELLATE ZONES<br>(Davies 1983)                                    | AMMONITE ZONES<br>(Poulton 1987) |            |                        |  |
| LOWER BAJOCCAN   | TENUI-PLICATUS   | <i>Ctenidodinium combazii</i>                 | a | <i>Pareodinia ceratophora</i>         |                | <i>Nannoceratopsis gracilis</i>                               |                              | PSEUDO-BOREALIS             |                                              | <i>Glomodinium tripartitum</i><br>—<br><i>Comparodinium aquilonium</i>   | POMPECKJI                        |            |                        |  |
|                  | ZIGZAG           | <i>Ctenidodinium sellwoodii</i>               |   |                                       |                |                                                               |                              | INDISTINCTUS                |                                              |                                                                          |                                  |            |                        |  |
| UPPER BAJOCCAN   | PARKINSONI       | <i>Acanthaulax crispa</i>                     |   |                                       | Cct.r          |                                                               |                              | BOREALIS                    |                                              |                                                                          |                                  |            |                        |  |
|                  | GARANTIANA       |                                               |   |                                       |                |                                                               |                              |                             |                                              |                                                                          |                                  |            |                        |  |
|                  | SUB-FURCATUM     | <i>Nannoceratopsis gracilis</i>               | c | De                                    |                |                                                               |                              |                             |                                              | — ? —                                                                    |                                  |            |                        |  |
| MIDDLE BAJOCCAN  | HUMPHRIES-IANUM  |                                               |   |                                       |                |                                                               |                              |                             |                                              | <i>Wallodinium elongatum</i>                                             |                                  |            |                        |  |
|                  | SAUZEI           |                                               | b |                                       | Dp             |                                                               |                              |                             |                                              | — ? —                                                                    | TOZERI                           |            |                        |  |
| LOWER BAJOCCAN   | DISCITES         | a                                             |   | <i>Kallosphaeridium inornatum</i>     |                | <i>Dodekovia bullula</i><br>—<br><i>Nannoceratopsis senex</i> |                              | TUGURITES FASTIGATUS strata |                                              | <i>Phallocysta eumekes</i><br>—<br><i>Dapcodinium coalitum</i>           |                                  |            |                        |  |
|                  |                  |                                               |   |                                       |                |                                                               |                              |                             |                                              |                                                                          |                                  | TUGURENSIS |                        |  |
| AALENIAN         | CONCAVUM         | e                                             |   |                                       | Np             |                                                               |                              |                             |                                              |                                                                          |                                  | MCLINTOCKI | <i>Pareodinia spp.</i> |  |
|                  | MURCHI-SONAE     |                                               |   |                                       |                |                                                               |                              | P.ALIENUM strata            | <i>Pareodinia spp. — Nannoceratopsis sp.</i> |                                                                          | MC-LINTOCKI                      |            |                        |  |
|                  | OPALINUM         | d                                             |   |                                       |                |                                                               | OPALINUM                     |                             |                                              |                                                                          | OPALINUM                         |            |                        |  |
| UPPER TOARCAN    | LEVESQUEI        | c                                             |   | <i>Nannoceratopsis gracilis</i>       | Sp<br>Nt       | <i>Mikrocysta erugata</i>                                     | ROSEN KRANTZI                |                             | <i>Nannoceratopsis gracilis strata</i>       | <i>Susadinium scrofoides</i><br>—<br><i>Nannoceratopsis senex</i> var. C |                                  |            |                        |  |
|                  | THOUAR-SENSE     | b                                             |   |                                       |                |                                                               |                              |                             |                                              |                                                                          | POLARE                           |            |                        |  |
|                  | VARIABILIS       |                                               |   |                                       |                |                                                               |                              |                             |                                              |                                                                          |                                  |            |                        |  |
|                  | BIFRONS          | a                                             |   |                                       |                |                                                               |                              | MONESTIERI                  |                                              | — ? —                                                                    |                                  |            |                        |  |
| LOWER TOARCAN    | FALCIFERUM       |                                               |   |                                       |                |                                                               |                              |                             | ATHLETICUM                                   |                                                                          |                                  |            |                        |  |
|                  | TENUI-COSTATUM   |                                               |   |                                       |                |                                                               |                              |                             | FALCIFER                                     |                                                                          |                                  |            |                        |  |
|                  |                  |                                               |   |                                       |                |                                                               |                              | PROPINQUUM                  |                                              | <i>Lithodinia serrulata</i>                                              |                                  |            |                        |  |

| BOREAL SUBSTAGES | NORTHERN YUKON AMMONITE ZONES | BROOKS-MACKENZIE BASIN DINOFLAGELLATE ZONES | SVERDRUP BASIN DINOFLAGELLATE ZONES                                        | BARENTS SEA AREA DINOFLAGELLATE ZONES                                        | EAST GREENLAND    |                                       |                                      | NORTHERN SIBERIA |                                                                                                      | ENGLAND                                 | NORTHWEST EUROPE | STANDARD SUBSTAGES |
|------------------|-------------------------------|---------------------------------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------------|-------------------|---------------------------------------|--------------------------------------|------------------|------------------------------------------------------------------------------------------------------|-----------------------------------------|------------------|--------------------|
|                  | (Poulton 1987)                | (Davies, in Poulton 1989)                   | (Davies 1983)                                                              | (Smelror & Below, in press.)                                                 | AMMONITE ZONES    | DINOFLAGELLATE ZONES (Smelror, 1988a) | DINOFLAGELLATE ZONES (Piasecki 1980) | AMMONITE ZONES   | DINOFLAGELLATES (Ilyina 1986)                                                                        | DINOFLAGELLATE ZONES (Wool. & Rid. '83) | AMMONITE ZONES   |                    |
| UPPER OXFORDIAN  |                               |                                             | <i>Stephanelytron redcliffense</i>                                         |                                                                              | ROSEN-KRANTZI     |                                       | <i>Ambonosphaera "utera"</i>         |                  | <i>Gonyaulacysta sp.</i>                                                                             | <i>Gonyaulacysta jurassica</i>          | ROSEN-KRANTZI    | UPPER OXFORDIAN    |
|                  |                               |                                             |                                                                            |                                                                              | REGULARE          |                                       |                                      |                  |                                                                                                      |                                         | REGULARE         |                    |
|                  |                               |                                             |                                                                            |                                                                              | SERRATUM          |                                       |                                      |                  |                                                                                                      |                                         | SERRATUM         |                    |
| MIDDLE OXFORDIAN |                               |                                             |                                                                            |                                                                              | GLOSENSE          |                                       |                                      |                  |                                                                                                      | <i>Scriniodinium crystallinum</i>       | GLOSENSE         |                    |
|                  |                               |                                             |                                                                            |                                                                              | TENUI-SERRATUM    |                                       | <i>Adnatosphaeridium aenulum</i>     |                  |                                                                                                      |                                         | TENUI-SERRATUM   | MIDDLE OXFORDIAN   |
| LOWER OXFORDIAN  |                               | <i>Paragonyaulacysta borealis</i>           |                                                                            | <i>Crussolia deflandrei</i><br><i>Wanaea fimbriata</i>                       | DENSI-PPLICATUM   | <i>Liesbergia scarburghensis</i>      |                                      |                  |                                                                                                      | <i>Acanthaulax senta</i>                | b                |                    |
|                  |                               | <i>Occisucysta thulia</i>                   |                                                                            |                                                                              | CORDATUM          | <i>Wanaea fimbriata</i>               | b                                    |                  |                                                                                                      | a                                       | CORDATUM         | LOWER OXFORDIAN    |
| UPPER CALLOVIAN  |                               |                                             |                                                                            | <i>Liesbergia scarburghensis</i><br><i>Wanaea thysanota</i>                  | MARIAE            | a                                     | <i>Wanaea fimbriata</i>              |                  |                                                                                                      | <i>Wanaea fimbriata</i>                 | MARIAE           |                    |
| MIDDLE CALLOVIAN |                               |                                             |                                                                            |                                                                              | LAMBERTI          | <i>Mendicodinium groenlandicum</i>    | <i>Gonyaulacysta scarburghensis</i>  | SUBORDI-NARUM    | <i>Pareodinia ceratophora</i>                                                                        | <i>Wanaea thysanota</i>                 | b                | LAMBERTI           |
|                  |                               |                                             |                                                                            |                                                                              | ATHLETA           | <i>Wanaea digitata</i>                |                                      | KEYSER-LINGI     |                                                                                                      | a                                       | ATHLETA          |                    |
| LOWER CALLOVIAN  |                               |                                             |                                                                            | <i>Meiourogonyaulax planoseptata</i><br><i>Chlamydophorella ectotubulata</i> | CORONATUM         | <i>Ambonosphaera calloviana</i>       | <i>Gonyaulacysta jurassica</i>       | MILA-SCHEVICI    |                                                                                                      | <i>Ctenidodinium ornatum</i>            | CORONATUM        |                    |
|                  |                               |                                             |                                                                            |                                                                              | JASON             |                                       |                                      |                  |                                                                                                      |                                         | JASON            | MIDDLE CALLOVIAN   |
|                  |                               |                                             |                                                                            |                                                                              | CALLOVIENSE       |                                       |                                      |                  |                                                                                                      | <i>Ctenidodinium continium</i>          | CALLOVIENSE      |                    |
|                  | BODYLEVSKYI                   | <i>Nannoceratopsis pellucida</i>            | <i>Paragonyaulacysta calloviensis</i>                                      |                                                                              | NORDENSKJO        | <i>Lacrymodinium warrenii</i>         | c                                    | EMILIAN-ZEVI     | <i>Pareodinia ceratophora</i><br><i>Gonyaulacysta spp.</i> -<br><i>Chytroeisphaeridia pericompso</i> |                                         | MACRO-PHALUS     | LOWER CALLOVIAN    |
|                  | BARNSTONI                     |                                             |                                                                            |                                                                              | APERTUM           |                                       | b                                    | 'ELATMAE'        |                                                                                                      | <i>Ctenidodinium combazii</i>           |                  |                    |
|                  |                               |                                             |                                                                            | <i>Sirmiodinium grossii</i>                                                  | CALYX             |                                       | a                                    |                  |                                                                                                      |                                         | b                | DISCUS             |
| UPPER BATHONIAN  |                               |                                             |                                                                            |                                                                              | VARIABLE          |                                       |                                      |                  |                                                                                                      |                                         |                  |                    |
|                  | ISHMAE                        | <i>Nannoceratopsis sp. cf. N. pellucida</i> | <i>Hystrihogonyaulax cladophora</i><br><i>Nannoceratopsis senex var. A</i> |                                                                              | CRANOCE-PHALOIDES |                                       |                                      |                  |                                                                                                      |                                         | ASPIDOIDES       | UPPER BATHONIAN    |
|                  | HARDLANDI                     |                                             |                                                                            |                                                                              | ISHMAE            |                                       |                                      | ISHMAE           |                                                                                                      |                                         | HODSONI          |                    |
| MIDDLE BATHONIAN |                               | <i>Chytroetisphaeridia sp.</i>              | <i>Glomodinium tripartitum</i>                                             |                                                                              |                   |                                       |                                      |                  |                                                                                                      | <i>Ctenidodinium sellwoodii</i>         |                  |                    |
|                  | FRAMI                         | <i>Phallocysta, Aldorfia spp.</i>           |                                                                            |                                                                              | GREENLANDI-CUS    |                                       |                                      |                  |                                                                                                      |                                         | a                | MORRISI            |
|                  | AMUNDSENI                     |                                             |                                                                            | <i>Nannoceratopsis gracilis</i>                                              |                   |                                       |                                      | ELEGANS          |                                                                                                      |                                         |                  | SUBCON-TRACTUS     |
|                  | PROCUPIN-ENSIS                | <i>Energlynia sp.</i>                       | <i>Comparodinium aquilonium</i>                                            |                                                                              | ARCTICUS          |                                       |                                      | JUGATUS          |                                                                                                      |                                         |                  | PROGRA-CILIS       |
|                  | SPATHI                        |                                             |                                                                            |                                                                              |                   |                                       |                                      |                  |                                                                                                      |                                         |                  |                    |

Figure 3 Tentative correlation chart of Late Bathonian to Oxfordian dinoflagellate zones and ammonite zones of the Boreal Realm (After Smelror & Below, in press.)

|  | ENGLAND                                   | E GREENLAND                                              | N & NW SIBERIA                           | VOLGA BASIN                     |           |
|--|-------------------------------------------|----------------------------------------------------------|------------------------------------------|---------------------------------|-----------|
|  | Kochi                                     | Kochi J W                                                | Kochi                                    | Kochi                           | RYAZANIAN |
|  | Runctoni                                  | (Maynci) J W<br>(Chetaites sp) J W                       | Sibiricus                                | Rjazenensis                     |           |
|  | Lamplughii                                |                                                          | Chetae                                   | ?                               |           |
|  | Preplicomphalus                           |                                                          | Taimyrensis                              | Nodiger Nodiger<br>Mosquensis   | UPPER     |
|  | Primitivus                                | (Tenuicostatus) W                                        | Originalis                               | Subditus                        |           |
|  |                                           |                                                          | Okensis                                  | Fulgens Okensis<br>Fulgens      |           |
|  | Oppressus Oppressus<br>Anguiformis        |                                                          | Exoticus                                 |                                 |           |
|  | Kerberus                                  |                                                          | ?                                        | Blakei                          |           |
|  | Okusensis                                 |                                                          |                                          | ?                               |           |
|  | Glaucolithus                              | (Vogulicus) J W<br>Groenlandicus 47<br>Anguinus 46<br>45 | Vogulicus<br>Groenlandicus               |                                 |           |
|  | Albani                                    | Pseudapertum 43 44<br>41 42<br>Gracilis 39 40<br>38      | Crendonites spp<br>Maximus<br>Ilovaiskii | Nikitini                        | MIDDLE    |
|  | Fittoni                                   | Liostracus 37<br>36                                      | ?                                        | Virgatus Rosanovi<br>Virgatus   |           |
|  | Rotunda                                   | Communis 35<br>34                                        |                                          | Panderi Zaraiskensis<br>Pavlowi |           |
|  | Pallasioides                              | Rugosa 33<br>Iatriensis 32<br>Primus 31                  | Strajevskiyi<br>Iatriensis               | ?                               |           |
|  | Pectinatus Paravirgatus<br>Eastlecott'sis | Pectinatus 29 30<br>28 27                                | Lideri                                   | Tenuicostata                    |           |
|  | Hudlestoni Encombensis<br>Reisiformis     | Hudlestoni 26                                            | ?                                        | Pseudoscythica                  |           |
|  | Wheatley'sis Wheatley'sis<br>Smedmor'sis  | Wheatleyensis 25                                         | Subcrassum<br>Magnum                     | Sokolovi                        | LOWER     |
|  | Scitulus                                  | Scitulus                                                 |                                          |                                 |           |
|  | Elegans                                   | Elegans 24                                               | ?                                        | Klimovi                         |           |

Figure 4 Correlation chart of Kimmeridgian and Volgian ammonite zones and stage nomenclature of the Boreal Realm. (After Birkelund et al. 1984).

### 3.2 Recognition of unconformities

The first and last occurrences of the biostratigraphic important species listed in Section 3.1, have been selected from the range chart data for each well. These termination events are plotted in the depth versus time diagrams (Appendix I-III) to determine the position of unconformities, as shown schematically in Figure 5. In this figure the uppermost illustration shows an interval of continuous sedimentation in which seven marker events are recorded. The slope of the line joining these events in the depth vs. time plot is a function of the sedimentation rate. If, however, a hiatus is present in the section (middle illustration), the plot of the six remaining events shows an abrupt discontinuity, and the horizontal width of this line represents the duration of the hiatus (lower part of Figure 5). The total absence of the short ranging species is further supporting evidence of this hiatus.

As mentioned, this plotting technique of biostratigraphic events has proved very useful in sequence recognition and description of the Cenozoic successions of the western Barents Sea and off Mid Norway. Although this method may be regarded as less reliable for the Jurassic succession of the Troms III area (due to the reasons pointed out on p. 8 and 9), we believe that the interpretations presented below, might serve as a useful working model at this early stage in the exploration of this area.

#### **Core 7018/05-U-06:**

The lowermost unit between TD and 241.10 m in core 7018/05-U-06 consists of a slightly bioturbated, dark grey clayey siltstone. This unit yields rich dinoflagellate assemblages, dominated by *Nannoceratopsis gracilis*. The dinoflagellate diversity is only moderate, and only two confident biostratigraphic events have been identified, i.e. DSs 180 and DPl 177. These datums suggest a maximum age 180 Ma (evident by the presence of *Susadinium scrofoides*) and minimum age of 177 Ma (based on the presence of common *Parvocysta* spp.) for Unit A. In overall composition the dinoflagellate assemblages in Unit A are similar to those described from the Polare to Opalinum ammonite zones (Late Toarcian - Aalenian, see Figure 2) on Spitsbergen.

A 9 m thick strongly bioturbated sandstone, interpreted as lower shoreface/offshore transition zone deposits, is transgressively overlying the lowermost siltstone unit. Since this sandstone yielded only few



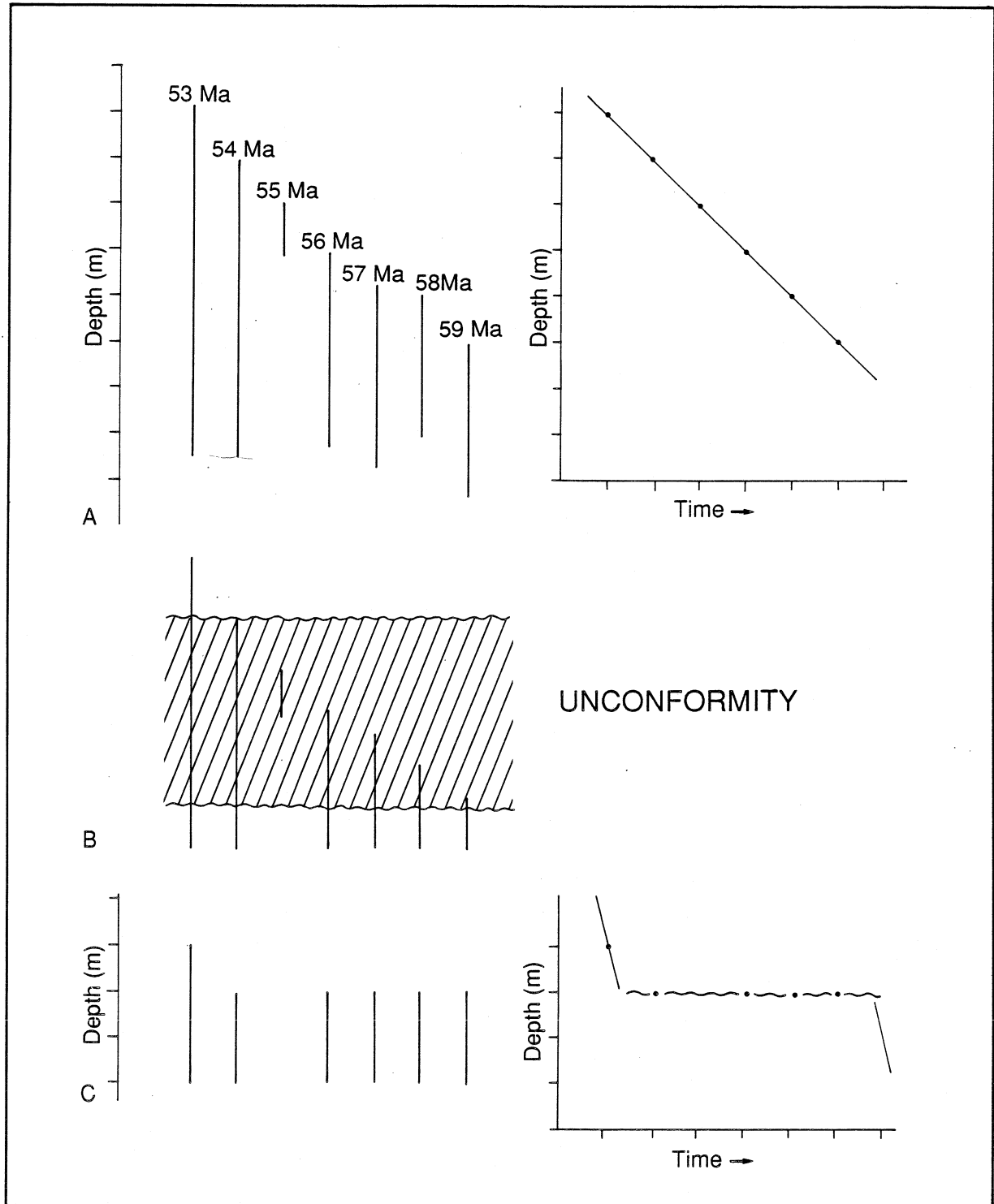
dinoflagellates and is virtually barren of other age-diagnostic fossils, a confident age for this sandstone unit cannot be given. The absence of the same age-diagnostic fossils found in the lowermost siltstone unit, however, suggests that the sandstone are probably deposited in the same time interval as the overlying succession of well sorted nearshore (lower shoreface-foreshore) sandstone. This sandstone succession also yield only few dinoflagellates, but three biostratigraphic events are recognized in this nearshore succession; DMr 171 at 207.95 m, DMs 171 at 183.15 m and DPe 170 at 140.9 m.

Assuming that the lower shoreface/offshore transition zone sandstone is contemporaneous with (or only slightly older than) the overlying nearshore sandstone, a hiatus of approximately 6 Ma is inferred between the lowermost siltstone unit and the overlying sandstone succession in core 7018/05-U-06. This hiatus is here termed the LT/A unconformity (Appendix I).

The DPe 170 event suggests a minimum age of 170 Ma for the top of the sandstone succession assigned to the Stø Formation. The last occurrences of the dinoflagellates *Moesiodinium raileanui* at 202.95 m and *Mancodinium semitabulatum* at 183.15 m indicate a minimum age of 171 Ma at these levels (i.e. the DMr and DMs events in Appendix I). The biostratigraphic datums thus suggest that the entire sandstone unit of Stø Formation penetrated in core 7018/05-U-06 was deposited during Late Aalenian to Early Bajocian time.

In core 7018/05-U-06 the sedimentary facies show a gradational transition from the Stø Formation sandstone to the muddy siltstones of the overlying Fuglen Formation (Weiss et al. 1991). This is different from the situation described from the Hammerfest and Tromsø Basins, where there is an abrupt transition and the boundary represents a profound hiatus between these two formations (Worsley et al. 1988). The base of the Fuglen Formation is reported as Callovian in the type area, while the basal beds of the formation in core 7018/05-U-06 contain Bajocian palynomorphs.

In Appendix I the last occurrence of *Parvocysta bullula* at 121.23 m is plotted as the DPb169 event, whereas the earliest appearance of *Dichadogonyaulax sellwoodii* at 109.91 m is shown as the DDs 166 event. At 78.93 m the presence of *Arctocephalites*(?) sp. indicates an approximate age of 160 Ma, whereas the occurrence of ?*Arcticoceras* sp. at 70.68 m indicates a slightly younger age of 159 Ma at this level. The earliest occurrences of *Cassiculosphaeridia dictydia* at 52.74 m and ?*Sirmiodinium grossii* at 17.96 m suggest an age not older than 159 Ma for the upper part of the cored succession.



**Figure 5** An explanation for the affect of unconformities on biostratigraphic range data and time vs. depth plots.

The perhaps most obvious interpretations (both from a sedimentological and a biostratigraphic point of view) would be to draw the depth vs. time curve from event DPe 170 at the top of the Stø Formation directly through the events DPb 169 and DDs 166 to the late Bathonian events AAc 160 and A?A 159 in the middle and upper part of the core. As shown by the dashed line in Appendix I, this situation implies a marked decrease in sedimentation rate from the base of the unit upwards within the offshore transition zone in the lower Fuglen Formation.

However, an alternative and more speculative interpretation is also shown on the depth vs. time plot in Appendix I. Here, I assume that the depth vs. time curve through events D?Sg 159 to AAc 160 continues with the same slope down to the boundary of the Fuglen and Stø Formation, i.e. to about 136 m where there is a distinct increase in the gamma log readings. This would imply that the sedimentation rate was approximately the same through the whole Fuglen Formation in this core. To justify this interpretation, we would have to regard *Parvocysta bullulla* as reworked in the lowermost part of the Fuglen Formation. To the earliest occurrence of *Dichadogonyaulax sellwoodii* at 109.91 m we have assigned a maximum age of 166 Ma. This species is, however, most prominent in the Late Bathonian - earliest Callovian and the DDs 166 event may very well be "too far to the right" on the depth vs. time plot. If we consider the estimated overlap of 103 m between this core and core 7018/05-U-02 where *D. sellwoodii* has its earliest appearance at 242.00 m, a Late Bathonian age for this event (DDs 166) is very likely since it would occur only some 20 m below the record of *Arcticoceras* sp. (ex gr. *ischmae*) (i.e. the AAi 160 event).

If we assume that the last interpretation is the correct, a profound stratigraphic gap of approximately 10 Ma of missing sediments is found at the boundary between the Stø and Fuglen Formation in this core. This would be a situation more similar to that observed elsewhere in the western Barents Sea area (including Svalbard). The interpreted hiatus between these formations in core 7018/05-U-06 is here named the LB unconformity.

#### Core 7018/05-U-02:

The oldest biostratigraphic event recognized within the bioturbated grey siltstone deposits of the Fuglen Formation in this core is the presence of *Arcticoceras* sp. (ex gr. *ischmae*) at 260.30 m, i.e. the AAi 160 event on the depth vs. time diagram in Appendix II. Upwards in the core the records of

the ammonites *Pseudocadoceras* sp. (cf. *mudum*) at 202.06 m (i.e. the APm 159 event) and *Arcticoceras* sp. (cf. *krylowi*) at 158.96 m (the AAk 159 event) suggest a Late Bathonian age for the lower and middle part of the Fuglen Formation. The dinoflagellate events DSg 159 at 251.70 m, DLc 156 at 220.36 m and DGc 156 at 174.43 m indicate slightly younger ages for these deposits. These biostratigraphic datums are, however, considered less reliable than the ammonite datums. This is also true for the foraminifera datums FRsi 157 and FRsh 157 at 183.60 m. The datums defined below ~195 m in core 7018/05-U-02 coincide well with those recognized within the overlapping interval of the Fuglen Formation in core 7018/05-U-06. Above the AAk 159 event (i.e. the youngest ammonite event recognized in the Fuglen Formation) the latest appearance of the dinoflagellates *Gonyaulacysta pectinigera* at 151.59 m (the DGp 155 event) and the earliest appearance of *Endoscrinium galeritum* (the DEg 155 event) at 146.45 m are suggestive of an age of 155 Ma at these levels. At 127.90 m the earliest appearance of the foraminifera *Recurvoides disputabilis* indicate a maximum age of 153 Ma (i.e. the FRd 153 event in Appendix II). Rich dinoflagellate assemblages are recovered in the upper Fuglen Formation. The occurrence of *Wanaea fimbriata* between 111.47 m (DWf 152Eo event) and 107.89 m (DWf 150Lo) delimits the age of this interval to 152-150 Ma. The latest occurrence *Liesbergia scarburghensis* (the DLs 150 event) at 107.81 supports an age not younger than 150 Ma at this level. These evidences suggest that the cored Fuglen Formation at site 7018/05-U-06 was deposited during late Bathonian to earliest Oxfordian time. This is approximately comparable to what was described for this formation in the Hammerfest and Tromsø Basins.

At 105.68 m in core 7018/05-U-02 there is a sharp boundary between silty mudstones of the Fuglen Formation and the overlying dark shales of the Hekkingen Formation. This transition is also marked by a distinct peak in the gamma log readings at this level. No age-diagnostic fossils has been recovered from the basal bed at the base of the Hekkingen Formation, but the ammonite *Amoeboceras* (A.) ex gr. *alternans* occurs between 99.27 m and 74.93 m. These are shown as the AAa 145 events on the depth vs. time diagram in Appendix II, suggesting an age of 145 Ma for most of the Algae Member. The present biostratigraphic evidence suggest an unconformity of maximum 5 Ma (150-145 Ma) between the Fuglen and the Hekkingen Formation. The hiatus between the Fuglen and the Hekkingen Formations is here called the E0 unconformity.

Above 74.93 m in the Hekkingen Formation reliable biostratigraphic datums are sparse. The latest occurrence of the dinoflagellate *Pareodinia cappilosa* might indicate a minimum age of 140 Ma at 52.74 m (i.e. the DPc 140 event). At 48.49 m a maximum age of 140 Ma is suggested by the earliest appearance of the foraminifera *Evolutinella emeljanzevi*. If these datums are true, it will imply a marked change in the slope of the sedimentation rate curve above the AA 145Lo event (reduced rate of sedimentation). This interpretation is shown by the dashed line on the depth vs. time curve in Appendix II.

There is an estimated overlap of ~51.5 m within the Hekkingen Formation between core 7018/05-U-02 and 7018/05-U-01. Considering the overlap, the earliest appearance of *Evolutinella emeljanzevi* (the FEc 140 event) occurs at approximately the same stratigraphic level in both cores. However, using the biostratigraphic datums recognized in the overlapping strata in core 7018/05-U-01, it is possible to introduce a Pseudo-DOp 144 event at approximately 50 m in core 7018/05-U-02. This would suggest an age of 144 Ma at this level. A sedimentation rate curve (drawn through the Pseudo-DOp 144 event) with a slope comparable to that interpreted for the lowermost (overlapping) Hekkingen Formation in core 7018/05-U-01 is illustrated by the upper right line on the depth vs. time plot in Appendix II. We believe this to be more reliable than the dashed line.

The biostratigraphic evidences discussed above indicate that the Hekkingen Formation cored at site 7018/05-U-02 was deposited during Late Oxfordian - Kimmeridgian (?earliest Volgian) time.

#### Core 7018/05-U-01:

Comparable to what was found in core 7018/05-U-02 the lowermost dark shales of the Hekkingen Formation in core 7018/05-U-01 (i.e. the Alge Member) show very high gamma ray values and a high content of organic carbon. The presence of the ammonite *Amboceras* (?*Prionodoceras*) sp. indet at 270.96 m (i.e. the AA?(P) 146 event) and the occurrence of *Rasenia* ? sp. indet at 264.50 m (the AR? 145 event) suggest a Late Oxfordian (to earliest Kimmeridgian) age for the Alge Member. The earliest appearance of the dinoflagellate *Oligosphaeridium patulum* at 256.38 m (the DOp 144 event) is indicative of a maximum age of 144 Ma for the lowermost Krill Member in this core. The earliest appearance of the foraminifera *Evolutinella emeljanzevi* at 243.63 m is marked as the FEc 140 event on the depth vs. time plot in Appendix III.



Comparable to what was shown on the depth vs. time plot for core 7018/05-U-02 in Appendix II, this event seems to fall to the left of the interpreted depth vs. time line, meaning that probably a somewhat too young age has been assigned to this event.

No reliable biostratigraphic events has been identified between ~243 m and ~150 m. The uppermost record of Dorsoplanitinae ammonites at 149.65 m suggests a minimum age of 136 Ma at this level (the ADo 136 event in Appendix III). The uppermost occurrence of *Laugeites* cf. *groenlandicus* at 102.11 m suggests a minimum age of 134 Ma (ALg 134 event). At 118.13 m the earliest appearance of the foraminifera *Trochammina septentrionalis* is plotted as the FTs 133 event). An age of 130 Ma has been assigned to the three uppermost biostratigraphic events shown in the depth vs. time plot in Appendix III. These are the ABo 130 event at 84.03 m (defined by the presence of the ammonite *Borealites* sp.), the BBo 130 event at 83.03 m (defined by the presence of the bivalve *Buchia okensis*) and the BBo/u/130 event at 61.33 m (defined by the latest occurrence of bivalves of the *Buchia okensis* - *B. unschensis* group).

The biostratigraphic events listed above, are evidences that the Hekkingen Formation at site 7018/05-U-01 was deposited during Late Oxfordian to Boreal Berriasian time.

With a sharp boundary the Hekkingen Formation is overlain by a 1.25 m thick, condensed unit of green and grey bioturbated claystone (i.e. Unit B of Weiss et al. 1991). There is a 10 cm thick brownish to yellow nodular, fossiliferous limestone in the upper part of this thin unit. The biostratigraphic events recognized in this Unit B range in age from 121 Ma to 127 Ma (see depth vs. time plot in Appendix III), indicating that there is a time break of minimum 3 Ma between the top of the Hekkingen Formation and this condensed unit. This hiatus is here tentatively termed the EV unconformity.

## 4. JURASSIC SEQUENCES

### 4.1 Terminology

The term depositional sequences was initially defined and described by P.R. Vail and his co-workers at Exxon as "stratigraphic units composed of a relatively conformable succession of genetically related strata and bounded at their top and base by unconformities or their correlative conformities" (Vail et al. 1977). According to Embry (1990) a depositional sequence is thus a genetic stratigraphic unit which depends upon the recognition of its boundaries for its delineation rather than upon specific lithologies as is done for lithostratigraphic units (e.g. formations).

Three important stratigraphic surfaces are generated in a stratigraphic column during a single cycle of relative sea level change (Figure 6). As described in Embry (1990), these are:

1. **Subaerial Unconformity and Correlative Conformity** - This surface is used as the sequence boundary by Vail et al. (1987) and is coincident with the maximum rate of sea level fall (inflection point on the sinusoidal curve). The subaerial unconformity develops over a considerable time span as relative sea level falls and the unconformity migrates seaward. The correlative conformity represents the depositional surface which is equivalent to the unconformity at its maximum seaward extent (i.e. at the time of maximum rate of relative fall).
2. **Transgressive Surface or Surface of Maximum Regression** - This surface occurs within a sequence and is coincident with the point on the relative sea level curve when the rate of relative rise exceeds the rate of the sedimentation. The surface can have a number of manifestations, varying from a conformity over much of the basin to a shoreface unconformity (ravinement) or subaerial unconformity on the basin margins (Embry & Podraski 1988). The transgressive surface marks the change from regressive sedimentation to transgressive sedimentation.
3. **Maximum Flooding Surface or Downlap Surface** - This surface also occurs within a depositional sequence and is coincident with the position on the relative sea level curve when the rate of sediment supply begins to exceed the rate of relative sea level rise (Figure 6). The surface

commonly occurs within a condensed section and can be represented by a hard ground which may have submarine erosion associated with it (Embry & Podruski 1988). This surface represents the change from transgressive sedimentation to regressive sedimentation.

In the Exxon model subaerial unconformities and its correlative conformities have been chosen as the bounding surfaces of a depositional sequence. Thus a sequence develops from one time of maximum sea level fall to the next during a cycle of relative sea level change (millions of years for a third order cycle).

As pointed out by Embry (1990), it is important to realize that the Exxon depositional sequence model, which has been widely quoted, is only one of many possible models. Various models can be generated depending upon the magnitudes and the variation in time of those magnitudes of both the rates of relative sea level change and sediment supply. The great value of the Vail model is that it demonstrates the existence of the three main stratigraphic surfaces (sequence boundary, transgressive surface and maximum flooding surface) and the three main separate systems tracts (see Figure 6). These features are common to all sequence models. The difference between the various sequence models which are generated by different input curves, are in the thickness, extent and facies composition of each of the three system tracts (Embry 1990).

Two other currently defined and used stratigraphic units are the T-R cycle (author unknown) and the depositional complex (Frazier 1974, Galloway 1989). The definition of these other two genetic stratigraphic units and their relationships to each other and to depositional sequences is illustrated in Figure 6. Three main stratigraphic surfaces are generated from the interplay of relative sea level change and sedimentation. Each of the three genetic stratigraphic units uses one of the three surfaces for its

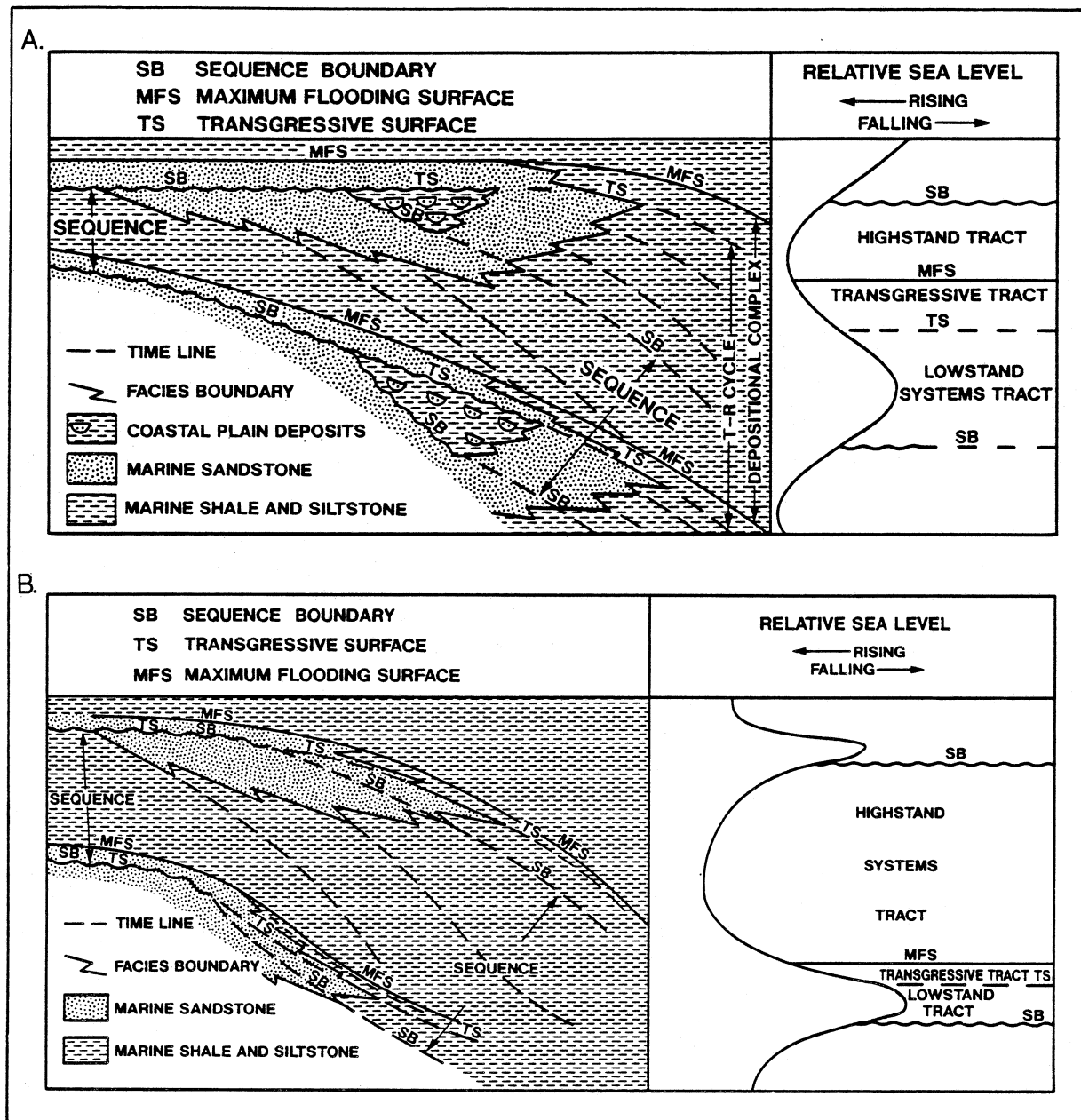


Figure 6 Depositional sequence models generated by a sinusoidal relative sea level curve (A) and cusped relative sea level curve (B). Note the three main stratigraphic surfaces which occur within the succession: Sequence Boundary (SB: subaerial unconformity and correlative conformity), Transgressive Surface (TS), and Maximum Flooding Surface (MFS). Note that in model B the lowstand system tract is much thinner and lacks the characteristic onlapping wedge of non-marine strata. (From Embry 1990).

boundaries, depositional sequences use the subaerial unconformity and its correlative conformity; T-R cycles use the transgressive surface; and depositional complexes use the maximum flooding surface.

In the present report the assignment of four main sequences is based on the recognition of the transgressive surfaces and unconformities associated with these, i.e. the LT/A, LB, E0 and EV unconformities. Regardless the validity of the LB unconformity (see discussion on p. 18), the transgressive surface interpreted at the boundary of the Stø and Fuglen Formations delineates the boundary between sequences II and III. Following the definition in Embry (1990) the sequences described in this report should be termed T-R cycles, and not described as depositional sequences.

According to Embry (1990) there exists considerable confusion as to the relationship of T-R cycles to depositional sequences. For example, some authors (e.g. Johannessen and Embry, 1989; Harris and Ericksson, 1990) claim they are using sequence analysis whereas they are really using T-R analysis. In these cases the authors interpret the transgressive surface to be the correlative conformity (Johannessen and Embry, p. 156) which theoretically is incorrect in most instances. Such confusion is not surprising given the coincidence of the transgressive surface and the unconformable sequence boundary on the basin margins and the lack of adequate discussion and illustration of the correlative conformity in the literature (Embry 1990).

#### 4.2 Sequences of the cored Jurassic succession

The four unconformities which here are described in the Jurassic strata of the Troms III area, subdivide the cored succession into four main sequences. These are tentatively named sequences I to IV (see Appendix I-III).

Sequence I comprises the oldest deposits. Only a few metres of these sequences were cored during the Shallow Drilling 1990 project, and consequently the lower boundary of this sequence is not defined. The upper boundary is delineated by the LT/A unconformity, and the transgressive surface between the lagoonal siltstone unit and the overlying lower shoreface/offshore transition zone deposits in core 7018/05-U-06. The cored part of the sequence comprises the 4 m thick dark grey clayey siltstone in base of core 7018/05-U-06.



Sequence II corresponds to the Stø Formation above 241.10 m in core 7018/05-U-06. This sequence represent nearshore (lower shoreface-foreshore) well sorted sandstones deposited during a fairly short time interval (~170-172 Ma) in Late Aalenian to Early Bajocian time.

The sequence II sandstone unit comprises several sub-environments within the nearshore-inner shelf setting, and can be subdivided into three separate intervals as discussed more detailed in Weiss et al. (1991). The recognition and descriptions of "parasequences" within sequence II is not further discussed here.

As proposed in Weiss et al. (1991), the mudstone rich zone in this lower shoreface/offshore transition deposits in the lowermost part of the cored Stø sandstone (i.e. between 241.10 m and 232.00 m) probably reflects the maximum transgression within this sequence, while the cleaning toward the top represents shallowing and regression.

This interpretation implies a thin transgressive system tract, and a relatively thicker regressive system tract. It should be noted that this interpretation fit rather well with a sequence model generated by a cusplate relative sea level curve (Embry 1990), rather than the model generated by a sinusoidal relative sea level curve as shown in the "Exxon model" (Figure 6).

The LB boundary between sequence II and the overlying sequence III coincides with the boundary between the Stø Formation and the Fuglen Formation in core 7018/05-U-06. As described previously (p.18), the validity of the proposed LB unconformity may appear rather speculative, however. If we reject this unconformity, one could assign both the Stø Formation and the Fuglen Formation to the same depositional sequence using the "Exxon model". "Sequence (II/III)" bounded by the LT/A unconformity and the E0 unconformity will range from Late Aalenian to Early Oxfordian in age. This interpretation following the "Exxon model" would imply that the transgressive surface of this depositional sequence corresponds to the transition between the Stø Formation and the Fuglen Formation. The upper boundary of this "sequence (II/III)" would be equivalent with the upper boundary sequence III as shown in Appendix III.

However, using the transgressive surface as the sequence boundary, the boundary between sequence II and IV would be placed at the Stø/Fuglen Formation boundary regardless the presence or not of a LB unconformity at

this level.

The upper boundary of sequence III was covered at site 7018/05-U-02 where this sequence boundary corresponds to the E0 unconformity (and the boundary between the Fuglen and Hekkingen Formations). Provided that the LB unconformity is valid and that the straight line on the depth vs. time diagram in Appendix I represents the correct "sedimentation curve" for the lowermost Fuglen Formation, sequence III was deposited during Late Bathonian to Early Oxfordian time (~160-150 Ma).

As described in Weiss et al. (1991) the highest gamma-readings at ~80 m in core 7018/05-U-06 may demonstrate maximum deepening or flooding. This corresponds also to the level where the oldest ammonite assemblages are found in sequence III. The same deepening or flooding event is also recognized in core 7018/05-U-02, where high gamma-readings and the incoming of ammonites are seen at around 260 m. A small peak in the diversity and abundance of dinoflagellates is noted just above this level, i.e. at 251.76 m. However, considering both core 7018/05-U-06 and 7018/05-U-02 an alternative candidate for the maximum flooding surface in sequence III could be around 146-140 m in core 7018/05-U-02. At this level the peak in the relative abundance of palynomaceral 4, is accompanied by a distinct peak in dinoflagellate diversity. Highest dinoflagellate abundance and diversity is recorded at 140.33 m.

The overlying sequence IV corresponds to the Hekkingen Formation in cores 7018/05-U-02 and 7018/05-U-01. This sequence represents dark to very dark grey laminated claystones deposited in a deep anoxic to dysoxic shelf environment. The transgressive surface which delineates the lower boundary of this sequence, corresponds to the E0 unconformity and was penetrated at 105.68 m in core 7018/05-U-02 (Appendix II). All logs show a clear break across this boundary.

The upper boundary of sequence IV corresponds to the boundary between the Hekkingen Formation and the condensed early Cretaceous Unit B of Weiss et al. (1991). This boundary is recognized at 46.67 m in core 7018/05-U-01 (Appendix III). Considering the depth vs. time diagrams in Appendix II and III, sequence IV was deposited during the Late Oxfordian to early Boreal Berriasian time (i.e. ~146-130 Ma).

The maximum flooding surface in sequence IV possibly coincides with the highest gamma readings at ~85 m. At this level there is also a peak in the

relative abundance of amorphous organic matter. In this interpretation the transgressive surface and maximum flooding surface are separated by a short time interval which results in a very thin transgressive system tract. This also implies a relatively thick regressive system tract represented by the major part of the Hekkingen Formation.

Note that in the following discussions in Chapters 5, 6 and 7 the proposed LB unconformity is treated as a "true sequence boundary", and consequently sequences II and III are treated separately. Using the transgressive surface as the sequence boundary, this subdivision into four sequences (i.e. TR-cycles) is considered valid, regardless whether the interpretation of the LB unconformity is correct or not.

## 5. PALYNOFACIES

### 5.1 Methods

Extensive descriptions of palynodebris (i.e. total acid-resistant organic residue) found in palynological slides have been published by Hancock and Fisher (1981), Parry et al. (1981), Whitaker (1984), Boulter and Riddick (1986) and Van der Zwan (1989, 1990). Different approaches have been applied in the description and classification of the particulate sedimentary organic matter, and a number of synonyms are used for the palynodebris categories. In the present study we have adopted the nomenclature proposed by Whitaker (1984) in his study of the Troll Field. The same approach was also used by Van der Zwan (1990) in the reconstruction of the upper Jurassic to lowermost Cretaceous succession of the Draugen Field. The classification proposed by Whitaker (1984) is preferred because:

- it is largely based the sedimentary properties of the organic matter (i.e. buoyancy, sensitivity to degradation processes), and thus the palynodebris categories provide useful means in the recognition of various marine and non-marine sub-environments
- it contains a well defined number of autochthonous and allochthonous categories which can be related to their approximate coal maceral equivalents, and thus can be used in organic geochemistry assessments (see Figure 7)
- it has proven applicable and very useful in determination of both reservoir units and source rock deposits. (Whitaker 1984, van der Zwan 1989, 1990).

#### Palynodebris categories

A throughout description of the main palynodebris categories used in the present study is given in Whitaker (1984). The following brief summary of Whitaker's descriptions is taken from Van der Zwan (1990): The organic content of a palynological slide can be subdivided into an allochthonous or in situ fraction. The first fraction contains elements which are sorted according to their buoyancy characteristics and can be subdivided into the following categories:

- 1) Palynomaceral-1 consists of orange-brown or dark brown structured or structureless material, irregular in shape, variable in preservation and of dense appearance. It may include "structured" plant debris, humic gel-like and resinous substances and algal detritus.
- 2) Palynomaceral-2 consists of brown-orange structured material of irregular shape. It may include structured plant material, algal detritus and to a less extent, humic gels and resinous substances. Its buoyancy is considered to be higher than palynomaceral-1.
- 3) Palynomaceral-3 consists of pale, relatively thin-irregular shaped, usually structured material. It includes structured plant material, mainly of cuticular origin and degraded aqueous plant material. It is considered the most buoyant of palynomacerals 1-3.
- 4) Palynomaceral-4 consists of black or almost black equidimensional or bladeshaped material, which is usually uniformly opaque and structureless. It includes compressed humic gels, charcoal and geothermally fusulinized material. Bladeshaped palynomaceral-4 is extremely buoyant and can be transported over long distances. Equidimensional palynomaceral-4 is intermediate in character to palynomacerals 1 and 2 and thus has a lower buoyancy.
- 5) The allochthonous fraction also includes terrestrial palynomorphs such as bisaccate and non-saccate pollen, spores, freshwater algae and fungal spores.

The autochthonous fraction is governed largely by ecological factors, and includes dinocysts, acritarchs, marine green algae and microforam test linings. Also included in this category is SOM or structureless organic matter (=sapropel), which is the bacterial mass resulting from the conversion of organic matter.

In addition, the palynodebris composition is also affected by preservational processes. They include rounding, bleaching, darkening or degradation.

Different preparation techniques and in particular oxidation, will effect the composition of the palynofacies assemblages. The more consistent percentages of the palynomacerals are estimated on unoxidized preparations,

although this leads to an (uncontrollable) decrease in the percentage of SOM. Often, these additional characteristics, together with ecological factors and debris size, are more important for the detailed environmental interpretation than the composition of the assemblage.

In addition to this distinction based on biological origin, the degree of organic matter biodegradation provides another clue to the depositional environment, because it is a direct function of organic matter residence time in the surficial, i.e. aerobic, environment, where fungi, bacteria and burrowing animals are the main degradation factors (Pratt 1984, Hart 1986, Tyson 1987, Hue 1988). Consequently, organic matter biodegradation is directly related to sedimentation rate and oxygen content of the depositional environment. Mechanical degradation of the most resistant continental organic fragments (e.g. inertinite, see below) is another indicator of depositional conditions. Finally, observation of the same organic residues in UV-fluorescence is an extra help in classifying the nature of unoxidized, thermally immature to early mature organic matter (Hart 1986, Tyson 1987, McPhilemy 1988).



| MAIN PALYNODEBRIS CATEGORIES                                |                                                                                     |                                             |                  |                           | APPROX. COAL MACERAL EQUIVALENT                    |            |
|-------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------|------------------|---------------------------|----------------------------------------------------|------------|
| MODIFIED AFTER WHITAKER, 1984                               |                                                                                     |                                             |                  | BOULTER AND RIDDICK, 1986 |                                                    |            |
| DECREASING BUOYANCY OF (LARGER) ALLOCHTHONOUS FRACTION<br>↓ |    | DARK STRUCTURELESS ORGANIC MATTER (SOM)     |                  |                           | COMMINUTED DEBRIS<br>DEGRADED DEBRIS<br>BROWN WOOD | VITRINITE  |
|                                                             |    | PALYNOMACERAL 1                             |                  |                           |                                                    |            |
|                                                             |    | PALYNOMACERAL 2                             |                  |                           |                                                    |            |
|                                                             |    | PALYNOMACERAL 3                             |                  |                           | WELL PRESERVED WOOD, PARENCHYMA                    | CUTINITE   |
|                                                             |    | EQUI-DIMENSIONAL                            | PALYNO-MACERAL 4 |                           |                                                    |            |
|                                                             |    | BLADES                                      |                  |                           |                                                    |            |
|                                                             |    | SPORES                                      |                  |                           | BLACK DEBRIS                                       | INERTINITE |
|                                                             |    | FUNGAL SPORES                               |                  |                           | BISACCATES AND SPORES (PRO PARTE)                  | SPORINITE  |
|                                                             |    | FRESHWATER ALGAE (BOTRYOCOCCUS)             |                  |                           | FUNGI                                              | LIPTINITE  |
|                                                             |    | BISACCATES                                  |                  |                           | ALGAE (PRO PARTE)                                  |            |
| RELATIVELY AUTOCHTHONOUS                                    |    | DINOFLAGELLATE CYSTS                        |                  |                           | BISACCATES AND SPORES (PRO PARTE)                  | LIPTINITE  |
|                                                             |   | ACRITARCHS                                  |                  |                           | DINOFLAGELLATE CYSTS                               |            |
|                                                             |  | MARINE ALGAE (TASMANITES)                   |                  |                           | ALGAE (PRO PARTE)                                  |            |
|                                                             |  | STRUCTURELESS ORGANIC MATTER (SOM=SAPROPEL) |                  |                           | AMORPHOUS MATTER, SPECKS                           |            |
|                                                             |  | MICROFORAM TEST LININGS                     |                  |                           |                                                    |            |

Figure 7 Comparison of main palynodebris categories (From van der Zwan 1990).

## 5.2 Palynofacies of the Jurassic succession

A total of 142 samples from the cored Jurassic succession were analysed in order to determine the palynofacies. Given a composite core-length of 732 m the average sample spacing is 5.2 m. This appears sufficient to give a reliable picture of the palynofacies in the late middle and upper Jurassic sequences III and IV. A more detailed breakdown and interpretation of the various "para-sequences" found in sequence II would, however, would have required a far more comprehensive analytical program and has not been the scope of this project.

The relative proportion of the main palynodebris categories found in each sample is presented in Tables IV-VI. The data given in these tables are visualized as palynofacies plots in Appendix I to III. In the following the palynofacies distribution is described, while a discussion of the significance of the palynofacies related to the different sequences is given in Chapter 7.

### Sequence I

The two samples at 245.13 m and 241.62 m from the lowermost siltstone unit of core 7018/05-U-06 are relatively uniform in palynofacies composition (Table IV). They contain dominantly terrestrially derived palynodebris, both woody fragments, palynomaceral 3 and palynomorphs. Freshwater algae (*Botryococcus*) are also present. Blade shaped palynomaceral 4 comprises 20% and 15% in these two samples, respectively. Amorphous organic matter comprises around 10% of the total sedimentary organic matter in each sample. Dinoflagellates are fairly common. In the sample at 241.62 m an acme of *Nannoceratopsis* is observed, and the dinoflagellate accounts for about 10% of the palynodebris (Appendix I).

### Sequence II

The deposits in the lowermost part of sequence II are characterized by abundant opaque black/dark brown palynomaceral 4, which comprises between 30% (sample 240.87 m) and 50% of the sedimentary organic matter. The sample at 240.88 m differs from those above by having a relatively higher proportion of structured woody particles and dark structureless organic matter (probably mostly degraded wood). Cuticular sheets assigned to palynomaceral 3 generally comprise 10% through this interval. Freshwater algae, spores, pollen and dinoflagellate cysts comprise each around 5% in the examined samples.

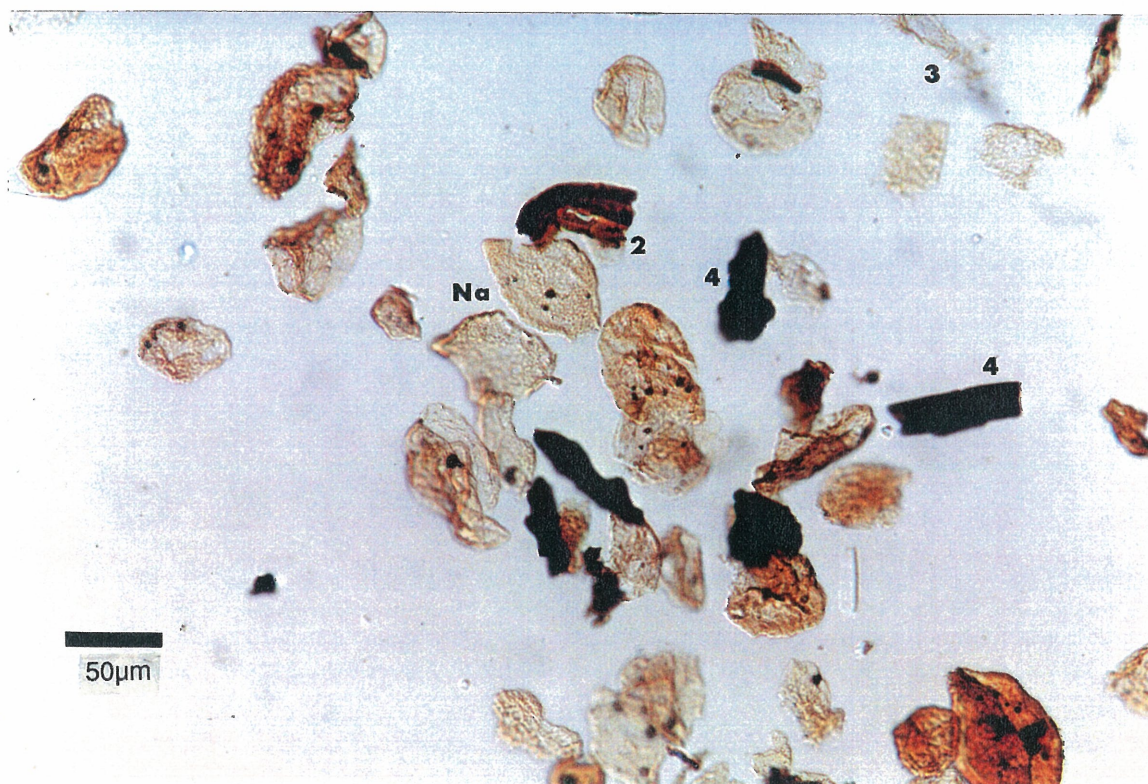


Figure 8 Palynofacies of the lagoonal deposits of sequence I. (Sample at 241.62 m in core 7018/05-U-06). 2=palynomaceral 2, 3=palynomaceral 3, 4=palynomaceral 4, Na=Nannoceratopsis (dinoflagellate).

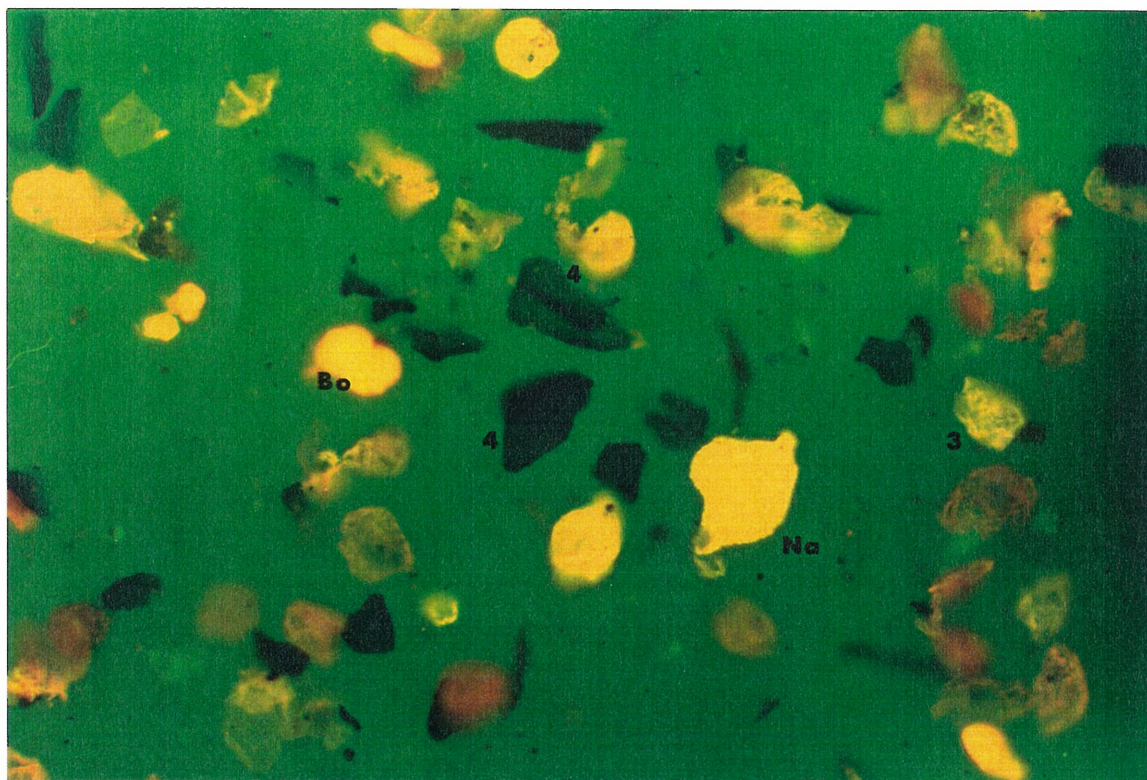


Figure 9 Palynofacies of the lagoonal deposits of sequence I. (Sample at 241.10 m in core 7018/05-U-06). Fluorescence light. Legend to palynodebris as above. (Bo=Botryococcus).



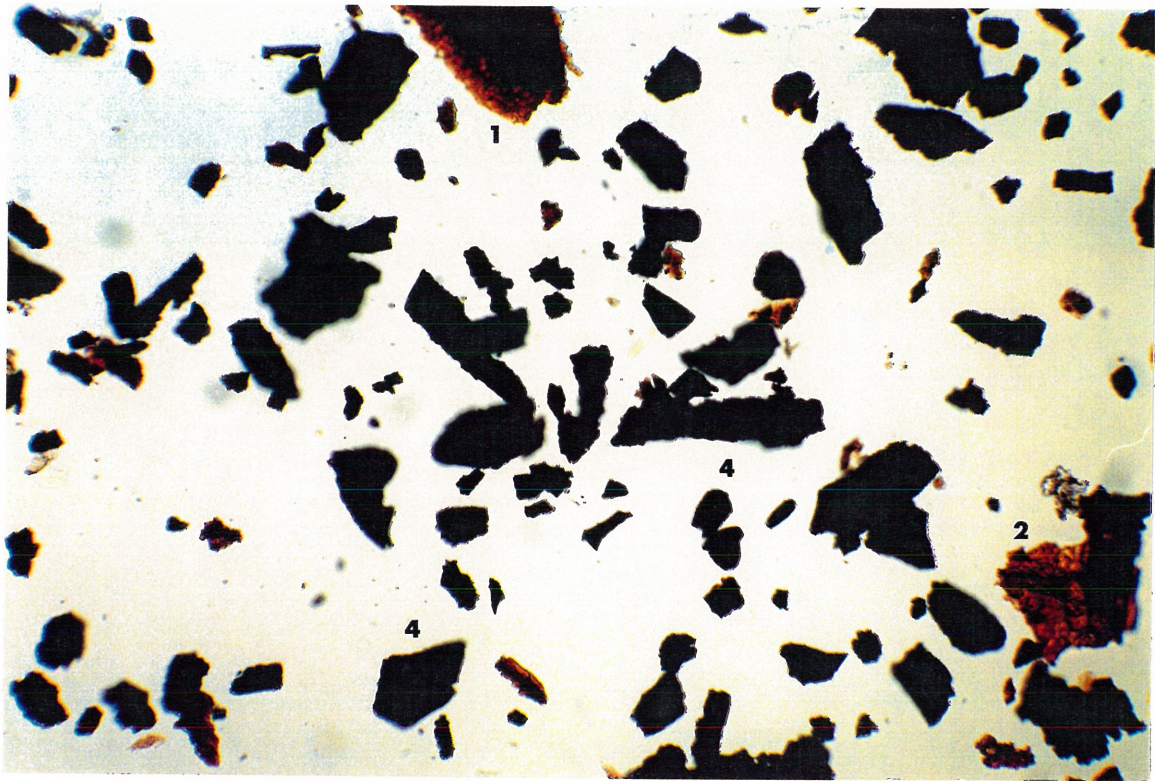


Figure 10 Palynofacies of the Stø sandstone assigned to sequence II (Sample at 165.80 m in core 7018/05-U-06). 1=palynomaceral 1, 2=palynomaceral 2, 4=palynomaceral 4.

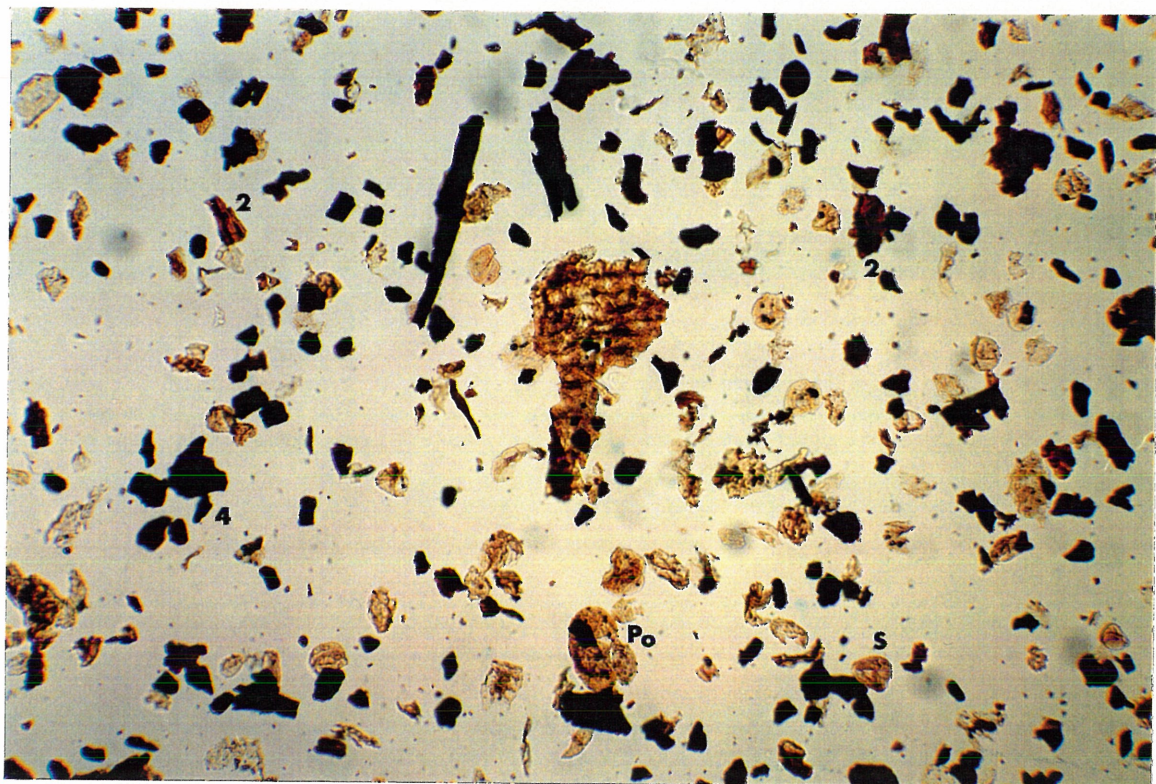


Figure 11 Palynodebris of the Stø sandstone assigned to sequence II (Sample at 159.58 m in core 7018/05-U-06). 2=palynomaceral 2, 4=palynomaceral 4, Po=pollen, S=spores.

The nearshore (lower shoreface - foreshore) deposits found upwards in sequence II show a more heterogenous palynofacies development. Generally, palynomaceral 4 is the most prominent constituent of these deposits. In the samples 229.55 m, 200.75 and 191.60 m palynomaceral 4 comprises as much 85% of the sedimentary organic matter. Palynomaceral 1 comprises from 5% to 10% in the examined samples. The relative proportion of structural woody material (palynomaceral 2) varies from about 5% (samples 229.55, 203.71, 200.75, 191.60 m) to about 35% (samples 225.00 and 218.75 m). Palynomaceral 3 generally represents 5-10% of the palynodebris, except for in sample 159.58 where the liptinitic material comprise as much as 20%.

Freshwater algae are found sporadically through the sequence. Terrestrial palynomorphs are generally present. Exceptions are the clean sandstone samples at 200.75 m and 191.60 m which contain no palynomorphs. Dinoflagellates are found in about half of the examined samples. When present, they comprise 5% or less of the palynodebris. Amorphous organic matter generally comprises 5-10%. A small peak of 15% amorphogen is found at 142.71 m in the uppermost part of the sequence. Most of this amorphous matter probably represents degraded woody material.

### Sequence III

The palynofacies of the offshore transition zone in the lowermost part of the Fuglen Formation deposits in core 7018/05-U-06 show a pattern comparable to that seen in the upper part of sequence II. Palynomaceral 4 is the most prominent constituent from the lower sequence boundary up to about 120 m.

Woody fragments assigned to palynomaceral 2 comprise between 20-25%, except in sample 134.94 m when this category comprises 10%. Spores and bisaccates represents each 5% through these deposits. Freshwater algae occur sporadically. Dinoflagellates are found in minor amount (~5%) in all samples except at 134.94 m. The relative proportion of amorphogen varies between 5% and 10% through the interval (Appendix III).

Within sequence III a distinct change in the palynofacies is observed at 115.71 m. This sample has a fairly high proportion of amorphous organic matter (40%), while the palynomaceral 4 is less abundant than in the underlying part of the sequence. Pollen and spores are fairly common at this level (each group comprising 10% of the palynodebris). In core 7018/05-U-06 the palynofacies from 109.91 m and upwards to the top of the



core show a rather heterogeneous development. Amorphous organic matter comprises 20-25% of the palynodebris. Palynomaceral 1 accounts for 5% to 10%, whereas palynomaceral 2 and 3 each comprise 10% to 15% of the sedimentary organic matter. The relative proportion of palynomaceral 4 is between 15-20%. Bisaccate pollen grains are fairly common and comprise 10% of the palynodebris in most samples. Spores also occur regularly (varying between 5-10%). Dinoflagellates are also found regularly throughout the sequence, but are generally subordinate compared to the pollen and spores.

As previously noted there is an overlap of 103 m in the Fuglen Formation between core 7010/05-U-06 and 7018/05-U-02. Consequently, the uniform palynofacies pattern seen in the upper part of core 7018/05-U-06 is also recognized in the lower part of core 7018/05-U-02. The uppermost examined sample at 17.76 m in core 7018/05-U-06 a relatively higher proportion of amorphous debris (i.e. 35%) compared to the samples below. A distinct peak in abundance of amorphogen is also recorded at 202.99 m in core 7018/05-U-02. Considering the estimated overlap (and the biostratigraphic evidences) these peaks in amorphogen distribution are correlative. Above this level up to about 122 m in core 7018/05-U-02 the palynofacies show a heterogeneous development similar to that is found comparable to below this "amorphogen event". At 146.45 m a characteristic decrease in the proportion of amorphous matter (down to 15%) and a relative increase in the proportion of palynomaceral 4 is observed. A significant break in the slope of the "sedimentation rate" curve is also recognized around this level (see depth vs. time diagram in Appendix II).

At 119.65 m a distinct peak (i.e. 50%) in the relative abundance of amorphous organic matter is noted. This peak is also accompanied by a relative decrease in the proportion of palynomaceral 4. At this level the dinoflagellate diversity is relatively high. Above 119.65 m there is a marked decrease in the relative abundance of amorphous matter.

Palynomaceral becomes slightly more common than in the sediments immediately below. The relative proportions of palynomaceral 2 and 3 are approximately of the same magnitude as in the middle part of the this sequence. As observed elsewhere in sequence pollen and spores also occur regularly in the uppermost part of sequence III. Freshwater algae are recorded at 111.47 m, 108.51 m and 107.84 m. Dinoflagellates comprise 5-10% of the palynodebris through the uppermost part of sequence III.

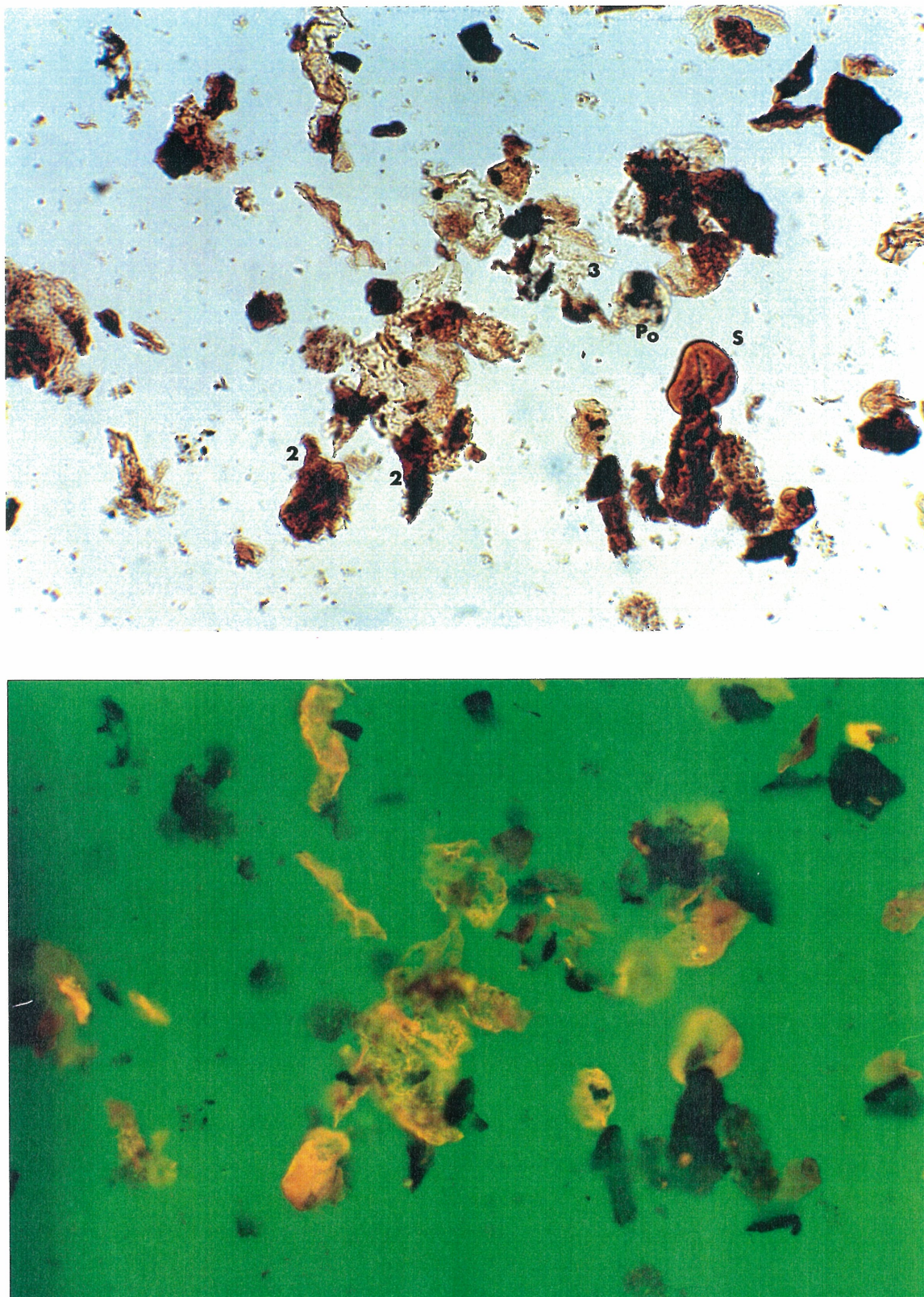


Figure 12 Palynofacies of the offshore/shelf deposits of sequence III (Sample at 220.36 m in core 7018/05-U-02). Note the heavy degradation of the organic debris. 2=palynomaceral 2, 3=palynomaceral 3, 4=palynomaceral 4, Po=pollen, S=spores.  
A: transmitted light, B: Fluorescence light.



#### Sequence IV

The palynofacies of sequence IV (i.e. the Hekkingen Formation) is typically characterized by abundant amorphous organic matter. This palynodebris generally comprises between 40% and 60% of the total sedimentary organic matter. In the lowermost part of the sequence, corresponding to the Alge Member, the amorphogen reaches up to 75-80% at some levels (i.e. 270.13 m and 267.70 m in core 7018/05-U-01). Peaks in the relative proportion of amorphous organic matter is also found at some levels in the upper part of the sequence, i.e. at 98.49 m and 62.00 m in core 7018/05-U-01.

Palynomacerals 1 and 2 occur regularly in subordinate amounts through the sequence, mostly accounting for 5% of the palynodebris. (Exception is one sample at 45.32 m in core 7018/05-U-02 where palynomaceral 1 comprises ~15%). Palynomaceral 3 is only found sporadically and in minor amounts (5% or less). The relative abundance of phytoclasts assigned to palynomaceral 4 varies generally between 10% and 15% through sequence III. (Exception being the sample at 45.32 m in core 7018/05-U-02 in which this category comprises 25%). Bisaccates occur regularly throughout the sequence and are fairly common at some levels (i.e. comprising around 10%). A small peak (15%) in the relative distribution of bisaccate pollen grains is found in the middle part of the sequence at 158.27 m in core 7018/05-U-01. Spores are generally less common and subordinate compared to bisaccates. Freshwater algae (*Botryococcus*) are found in some intervals in core 7018/05-U-02 (99.45 - 64.25 m and 59.28 - 20.12 m) and in most samples up to 73.02 m in core 7018/05-U-01. When present, these algae account for 5% or less of the palynodebris; exception being one sample at 99.45 m in core 7018/05-U-02 where the relative amount reaches 10%. Dinoflagellate cysts are not common, but in some parts of the sequence they occur sporadically. A peak in the dinoflagellate distribution reaching 10% of the palynodebris is noted at 58.00 m in core 7018/05-U-01 (i.e. in the uppermost part of sequence IV). Tasmanitids (marine prasinophycean algae) account for 5% of the total palynodebris at some levels in sequence IV.

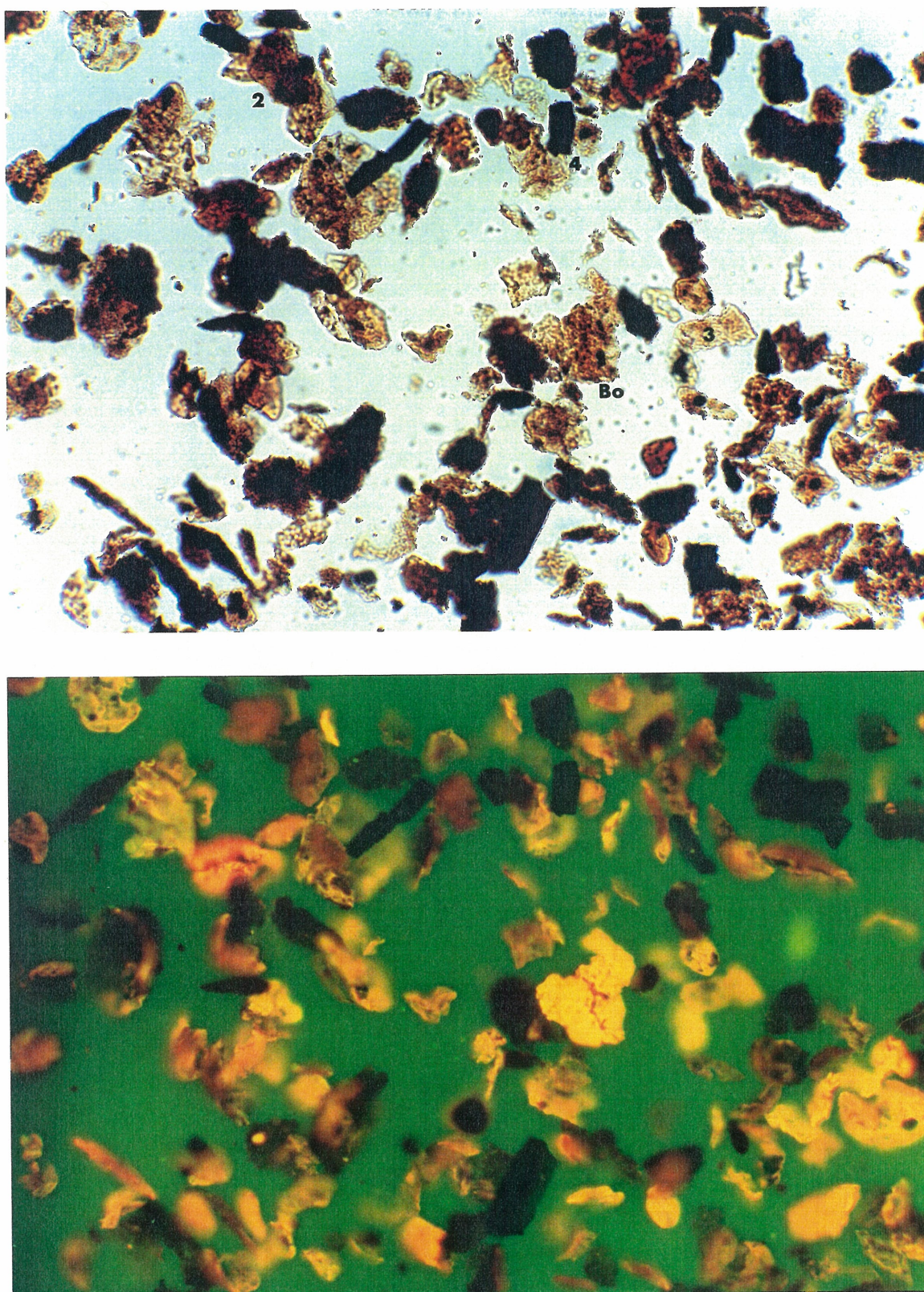


Figure 13 Palynofacies of the Alge Member (Hekkingen Formation) of sequence IV (Sample at 99.45 m in core 7018/05-U-02). Note the abundance of algal and liptinitic material.  
2=palynomaceral 2, 3=palynomaceral 3, 4=palynomaceral 4, Bo=Botryococcus (freshwater algae).  
A: transmitted light, B: Fluorescence light.



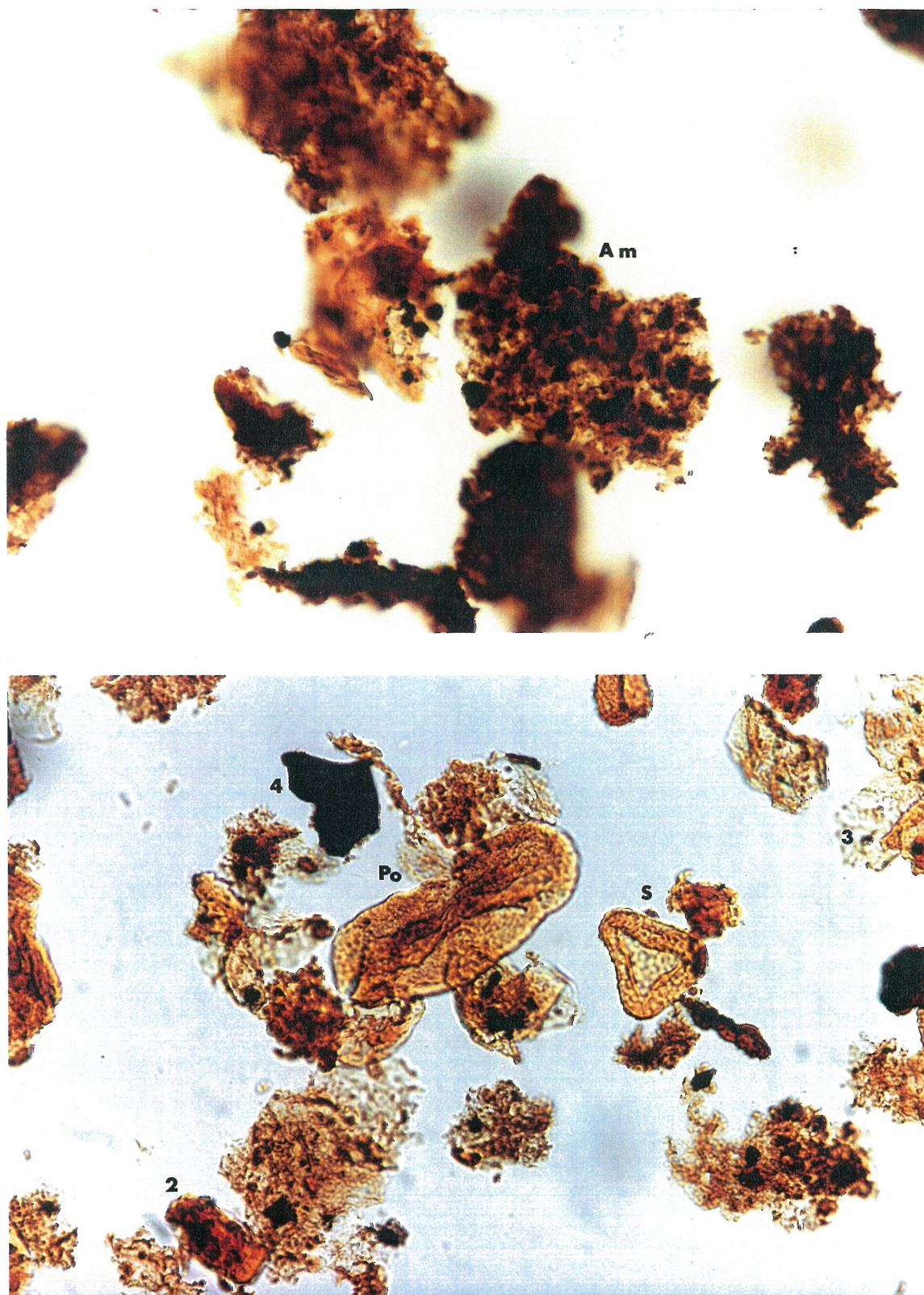
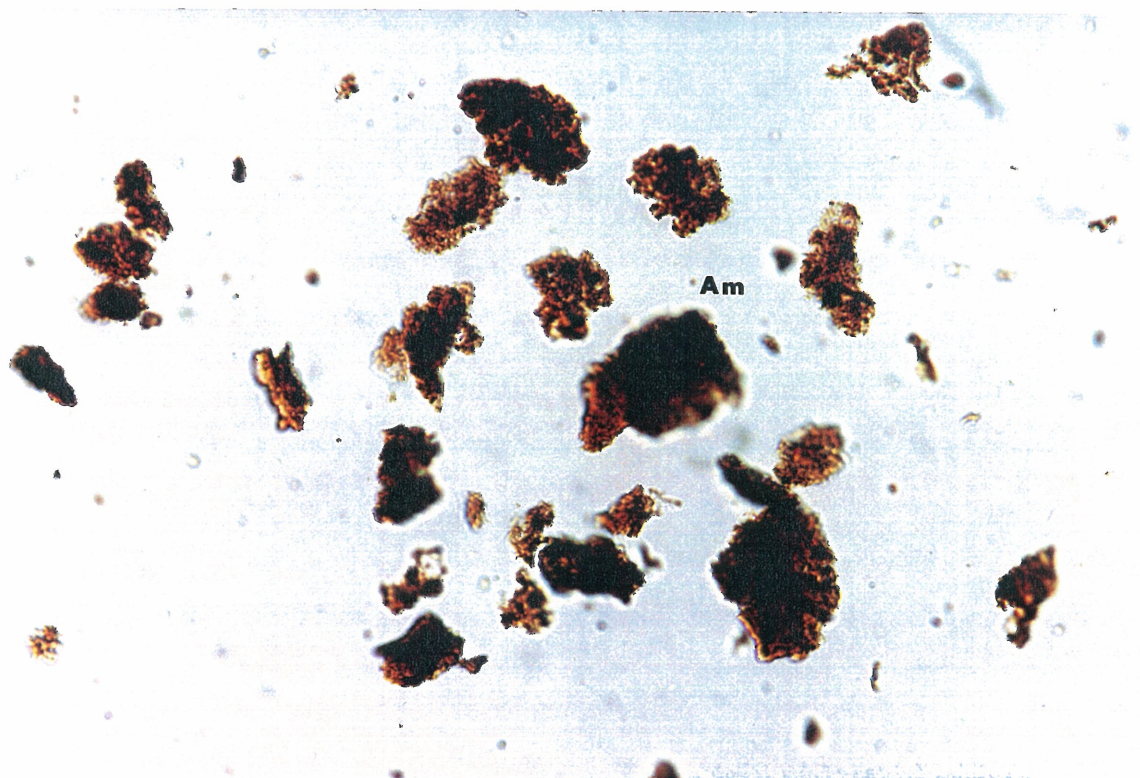
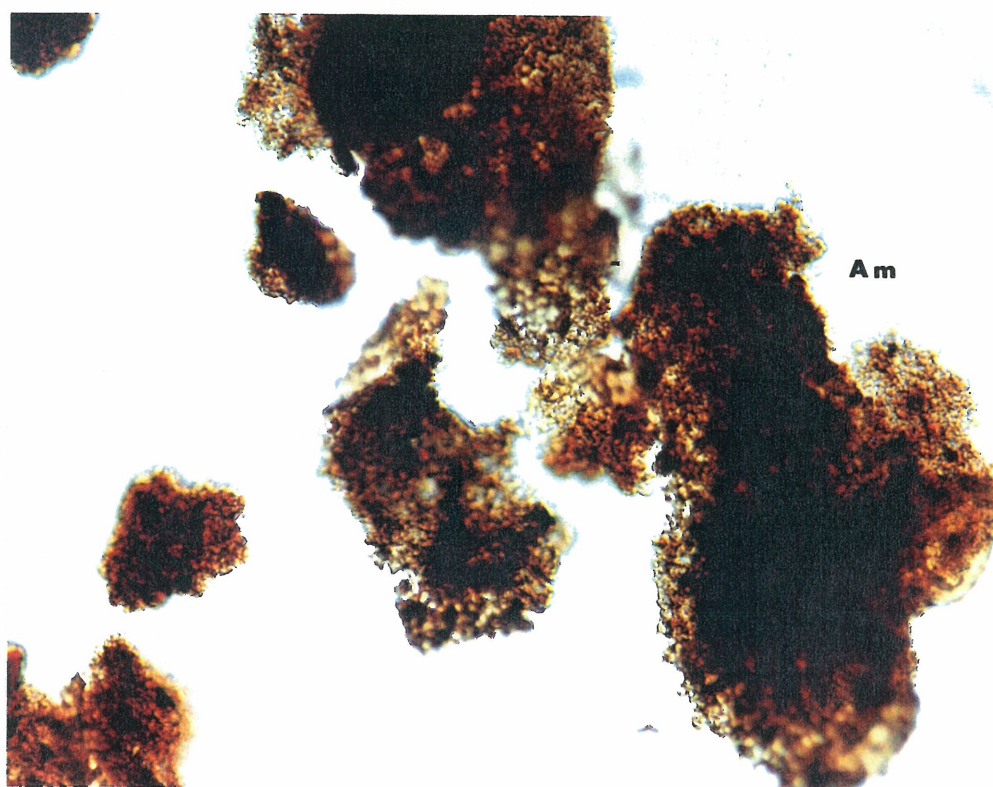


Figure 14 Palynofacies of the Krill Member (Hekkingen Formation) of sequence IV. Am=amorphous debris, 2=palynomaceral 2, 3=palynomaceral 3, 4=palynomaceral 4, Po=pollen, s=spores, (A: Sample at 73.02 m in core 7018/05-U-01, B: Sample at 20.12 m in core 7018/05-U-02).





**Figure 15**    *A: Palynofacies of the Krill Member in core 7018/05-U-01 (Sample 73.02 m). Degraded amorphous palynodebris.*

*B: Palynofacies of the lowermost Alge Member in core 7018/05-U-02 (Sample at 105.54 m). Note the small size of the amorphous palynodebris.*

## 6. ORGANIC FACIES

### 6.1 Terminology

In the literature the term organic facies is used in a number of relations concerning descriptions and classifications of source rocks. Mostly organic facies is specifically related to organic geochemical parameters such as pyrolysis compositions, but sometimes the term is used more or less synonymous with palynofacies (i.e. Combaz 1980, Gorin & Steffen 1991).

In this present study organic facies is defined as an assemblage of macerals/bulk pyrolysis compositions/molecular species which is characteristic of specific depositional environments.

### 6.2 Organic facies of the Jurassic sequences

In this Section and in the following discussion (7.1), organic facies is limited to the TOC and Rock-Eval pyrolysis character of the Jurassic sequences. More detailed information on the organic geochemistry of the Jurassic succession in the Troms III area is presented in Weiss et al. (1991) and in Appendix Volume 2 of the Shallow Drilling Troms III 1990 report.

#### Sequence I

From the lowermost siltstone unit in core 7018/05-U-06 four samples were analysed for total organic carbon (TOC) content and Rock-Eval pyrolysis character in order to evaluate the organic richness of the rocks and the type of the organic matter present. The samples were rich in organic matter (1.7 - 2.2 wt% TOC), but had relatively low Rock-Eval hydrogen index values of between 90 mg/g TOC and 107 mg/g TOC. The Rock-Eval data suggest that the kerogen is relatively poor in hydrogen (type III) with only very minor hydrocarbon generation potential (Appendix I).

Tmax values varied between 434°C and 440°C (average = 436°C), which suggests that the organic material has not yet reached thermal maturity. The production index (Rock-Eval  $S_1/(S_1+S_2)$ ) was less than 0.05, suggesting that non-indigenous hydrocarbons are absent in this sequence.



## Sequence II

TOC and Rock-Eval pyrolysis determination was carried out on twenty-one samples from this sandstone sequence. These rocks were generally organic-poor, with TOC contents of less than 0.3 wt%. Only a few samples, e.g. at 166.35 m, 141.35 m and 138.35 m, contained fair TOC concentrations of up to 1.5 wt% (Appendix I).

The scattered and rather unreliable hydrogen index values reflect the organic leanness of these samples. Samples with TOC contents exceeding 0.3 wt% had hydrogen index values of between 43 and 144 mg/g TOC, which suggests a hydrogen-poor, type-III or type-IV organic matter. Values exceeding 200 mg/g TOC are considered as artifacts, caused by the poor TOC content.

## Sequence III

From core 7018/05-U-06, fifty-seven samples from this unit were analysed for TOC content and pyrolysed using the Rock-Eval analyser. The samples typically contained between 0.8 and 2.5 wt% TOC, most values falling in between 1 and 2 wt%. Highest values (2.3 - 2.5 wt%) occurred at 120 - 110 m and at 103 m. A thin (few cm) band of a carbonaceous siltstone, containing 20.5 wt% TOC, was present at 135.35 m (Appendix I).

The hydrogen index varied between 29 and 176 mg/g TOC, increasing gradually with decreasing depth. These values suggest that the organic matter is relatively hydrogen-lean (type III or type IV), with no or only limited hydrocarbon generation potential. A few elevated hydrogen index values were recorded at depths between 136 m and 103 m. Some of these were associated with relatively well-developed  $S_1$  peaks. The hydrogen index values from these samples may therefore have been influenced by (non-indigenous) bitumen, giving an overly optimistic indication of the hydrocarbon potential of these kerogens.

The maximum Tmax values varied between 421°C and 440°C, with an average value of 433°C (SD =  $\pm 4^\circ\text{C}$ ). This is in accordance with the values for sequence I and suggests that the organic matter in these rocks is thermally immature to early mature (Weiss et al. 1991).

From sequence III in core 7018/05-U-02 total organic carbon analysis and Rock-Eval pyrolysis were performed on 123 samples taken at intervals of one

to two metres. Most samples had fair to good organic richness (0.8 - 2 wt% TOC), except for some obviously oil-stained samples close to the boundary with the overlying Hekkingen Formation (126 - 106 m). These contained up to 7 wt% TOC, but after solvent extraction, the TOC content decreased by 1 - 2 wt%. These samples were also characterized by high  $S_1$  peaks, as might be expected from oil-stained samples (Weiss et al. 1991).

The Rock-Eval hydrogen index values varied between 38 and 421 mg/g TOC, increasing from an average of around 50 - 100 mg/g TOC at the bottom of the core to approximately 100 - 200 mg/g TOC at the top of the Fuglen Formation. These rather low values suggest that the organic matter in these rocks is relatively hydrogen-lean, type-III and type-IV kerogen with no or only limited hydrocarbon generation potential. This would be consistent with the intense bioturbation of these sediments.

#### Sequence IV

From sequence IV in core 7018/05-U-02 Rock-Eval pyrolysis and TOC analysis are performed on 110 samples from the Hekkingen Formation taken at intervals of approximately 1 m (Appendix II). The organic richness of the samples closely followed the spectral gamma ray intensity for uranium and reached a maximum in the black claystones of the Alge Member. These claystones contained between 6.0 and 16.3 wt% TOC (average 10.2 wt%, SD = 2.4 wt%). In contrast, TOC contents dropped to values between 2.2 and 5.8 wt% (average 3.7 wt%, SD = 1.1) in the overlying Krill Member.

The Rock-Eval hydrogen index ranged between 136 mg/g TOC and 321 mg/g TOC for both members, most values falling between 200 mg/g TOC and 300 mg/g TOC (average 222 mg/g TOC). No correlation between hydrogen index and gamma ray intensity for uranium could be observed, although values above 200 mg/g TOC were slightly more frequent in the Alge Member than in the Krill Member. Considering the low thermal maturity of the organic matter in this core, the hydrogen index values indicate that the organic matter can be classified as a type- II/III and type-III kerogen with a moderate hydrocarbon generation potential (Weiss et al. 1991).

From core 7018/05-U-01 a total of 310 core chip samples, taken at 0.5 - 1 m intervals, was analysed for total organic carbon content and bulk pyrolysis character (Appendix III). The TOC content went parallel to the spectral gamma ray activity of uranium. The excellently rich, black claystones of the highly radioactive Alge Member contained on average 10 wt% TOC (6.5 -

12.4 wt%) while the dark grey claystones of the Krill Member had a considerably lower average TOC content of 4 wt% (0.8 - 7.0 wt%). Somewhat increased TOC contents in the intervals 260 - 230 m and 102 - 50 m coincided with increased production indices in these intervals and may reflect the presence of non-indigenous hydrocarbons in these rocks. This was verified by extraction of a sample at 84.0 m in which the TOC content dropped from 6.5 to 5.1 wt% after extraction.

Despite the difference in organic richness, the two members had quite similar Rock-Eval hydrogen index values (Weiss et al. 1991). These varied between 192 and 306 mg/g TOC (average  $\pm$  SD =  $247 \pm 26$  mg/g TOC) for the Alge Member, and between 115 and 399 mg/g TOC (average  $\pm$  SD =  $263 \pm 46$  mg/g TOC) for the Krill Member. Given the low thermal maturity of the rocks, these data suggest that the organic matter may be classified as type II/III kerogen. Only a few samples appear to contain type-III kerogen.

## 7. DISCUSSION

### 7.1 Jurassic sequences, palynofacies and organic facies relations

Accumulation and preservation of organic matter in sediments result from the complex interaction of factors associated with production of biomass, degradation and transport processes (Huc 1988). It has not been the objective of this study to go into details on all factors controlling the distribution and presentation of the overall organic content of the depositional sequences recognized in the cored Jurassic succession, but in the following some factors are discussed. These include rate of sediment accumulation, rate of allochthonous organic matter supply and bottom water oxygenation.

#### Sequence I

Core 7018/05-U-06 penetrated only the upper 4 m of sequence I and the lower boundary of the sequence is not defined. The limited biostratigraphic data available do not provide any means for calculations of sediment accumulation rates. The slightly bioturbated dark gray clayey siltstone assigned to this sequence is fairly rich in organic matter (1.7-2.2 wt% TOC), but have relatively low Rock-Eval hydrogen index values (i.e. 90-107 mg/g TOC). The sediments contain dominantly terrestrially derived palynodebris, and the high percentage of allochthonous organic matter (and palynomaceral 4) explains the hydrogen poor (type III) kerogen quality of these deposits.

The ichnofaunas and the palynomorph assemblages, together with abundant pyrite suggest a marine depositional environment for this cored sequence. However, the distinct reduction of trace fossil density and diversity upward, probably reflect increasing restriction of the environment and may indicate of a lagoonal setting (Weiss et al. 1991). The dominance of the dinoflagellate *Nannoceratopsis* is suggestive of a milieu of fluctuating salinity. The presence of the freshwater algae *Botryococcus*, and the relatively common and well preserved cuticle sheets (Appendix I), indicate proximally to land areas and apparently support the interpretation of a lagoonal depositional environment.



## Sequence II

As shown in Appendix I the biostratigraphic evidences suggest a fairly rapid deposition of this sandstone sequences in core 7018/05-U-06. Calculated post compaction sedimentation rate is ~15m/Myr. Most organic particles are hydrodynamically equivalent to clay and silt grade clastics (Trask 1939, Stanley 1969, Wall et al. 1977), and naturally this sequence is poor in organic matter. Generally, the TOC values are less than 0.3 wt%.

As thoroughly described in Weiss et al. (1990), the sandstone unit assigned to sequence II comprises several sub-environments within a nearshore-inner shelf setting, and it can be subdivided into three main units: 241.10-232.0 m, 232.0-166.50 m and 166.50-136.50 m.

The transgressive system tract deposits found in the lowermost part of the sequences contain mostly opaque black/dark brown phytoclasts (palynomaceral 4). This reflects the highly oxidizing depositional regime of these fine-grained lower shoreface/offshore transition zone sediments. The overlying nearshore (lower shoreface-foreshore) deposits assigned to the units comprising the regressive system tract show a comparable picture. Palynomaceral 4 dominates the sedimentary organic matter, and in some samples comprise as much as 85%. In these oxidizing sandstone regimes organic matter is degraded with great efficiency and recycled inertinitic fragments accumulates. The good porosity and permeability of the well sorted sandstone probably also assisted in the oxidation of the organic matter deposited. Although present, marine organic matter is totally subordinate to the allochthonous input. The relative proportion of woody fragments varies between 5% and 85% in the sequence, while terrestrial palynomorphs and cuticle sheets are less frequent. The relative enrichment in woody fragments is attributed to hydrodynamic (sorting) and preservational conditions.

The boundary between the lower and middle unit of sequence II is made by a sharp erosional contact at 232.0 m. The sample at 229.55 m near the base of middle unit shows a marked peak in the abundance of palynomaceral 4 (85%) reflecting the high energetic nature of these deposits.

As previously mentioned, a detailed subdivision of the palynofacies found in the various "para-sequences" has not been carried out. One should, however, note that the upper unit (166.50-136.50 m), which generally contains a higher content of mud compared to the units below, shows a more

heterogeneous palynofacies than the middle unit. This upper unit consists of three gradually cleaning-upward sequences, with bases at 166.50 m, 151.45 m and 142.70 m. As shown in Appendix I, the palynofacies of the upper sedimentary unit can also be subdivided into three different units, separated by levels of high relative input of palynomaceral 4.

The palynofacies units do not correspond exactly to the three "para-sequences", but more detailed analyses would provide the mean for a better matching of the sedimentary and the palynofacies subunits.

### Sequence III

Sequence III corresponds to the Fuglen Formation penetrated in cores 7018/05-U-06 and 7018/05-U-02. The biostratigraphic evidence suggests a fairly high average depositional rate of ~21 m/Myr. A rapid deposition is also suggested by the common presence of *Thalassinoides* and the lack of suspension feeder ichnofossils. Sediment accumulation rates have a significant effect on the TOC content of marine sediments. Calculations by Müller & Suess (1979) indicate that where all other factors remain constant, the organic content of a sediment deposited in oxygenated conditions apparently doubles with every ten-fold increase in the rate of sediment accumulation. Müller & Suess interpreted this relationship in general terms of the residence time of organic matter in the region of the sediment/water interface. Heath et al. (1977) have laid particular emphasis on the effect of sedimentation rate on the efficiency with which the benthos utilizes the available sedimented organic matter. The extensive bioturbation and the abundant pelagic fossils found in these muddy siltstones, show that well oxidizing conditions prevailed in the sea water as well in the seabed during deposition.

The sequence typically shows a fair to good organic richness (0.8-2.5 wt% TOC). Rock-Eval hydrogen index values vary between 29 and 421 mg/g TOC. Highest average HI-values are found in the upper part of the Fuglen Formation (see Appendix II). If one accepts that the maximum flooding surface is situated around 140 m in core 7018/05-U-02, the increased HI-values fall within the regressive system tract deposits in sequence III.

The rather low Rock-Eval hydrogen index values found in this sequence suggests that the organic matter is relatively hydrogen-lean, mostly type III and type IV kerogen, with no or only limited hydrocarbon generation potential.

The palynofacies of sequence III support the interpretation of oxic shelf depositional environment for these sediments. The high relative proportion of allochthonous organic debris reflect the relative distal position of these settings. The high degradation of the organic matter is characteristic of oxic bottom conditions, with well bioturbated sediments.

The common presence of marine microplankton, combined with the fairly high input of liptinitic material (palynomaceral 3, pollen and spores), suggest that the original input of hydrogen-rich organic matter could originally have been relatively high. However, the lack of fluorescence of the amorphogen and the low HI-values, suggests that oxidation processes have altered the original composition of the organic matter.

The sediment/water interface appears to be the main site of organic matter degradation (Tyson 1987), and the higher TOC values tend to be exhibited by sediments deposited under conditions of oxygen deficiency which are sufficient to exclude or seriously inhibit macrobenthic activity. According to Flint & Kamykowski (1984) macrobenthos is observed to play a major part in the rate of benthic nutrient regeneration. In sequence III the extensive bioturbation (especially in the transgressive system tract deposits) caused a strong degradation of the sedimentary organic matter (see Figure 12). Bioturbation prolongs the residence time of organic matter in the chemically 'open' pore water/bottom water system between the sediment/water interface and the redox potential discontinuity (Tyson 1987). It is also probable that bioturbation actively stimulates bacterial metabolism by maintaining a constant supply of organic substrates and oxidants (Yingst & Rhoads 1980). The net effect is probably that the benthos catalyse are much more efficient in remineralization and recycling of organic matter and consequently results in lowered TOC and HI-values.

In the upper part of the sequence individual trace fossils are not as easily distinguishable as further down, and at 113.00 m incomplete bioturbation mainly by very small, scattered *Chondrites*, may indicate dysaerobic conditions. From above ~127 the TOC and HI-values show an increased trend compared to the succession below. Using the solide line on the depth vs. time diagram in Appendix II, one can calculate an average depositional rate of ~7 m/Myr for these uppermost sediments of sequence III. This is significantly lower than the average of 21 m/Myr calculated for the whole sequence. This difference is not mirrored in the overall composition of the palynofacies, which suggest (with some exceptions

discussed in Chapter 5.2) relative comparable compositions of allochthonous and autochthonous organic matter through the entire sequence (i.e. a situation perhaps suggesting that the dashed line on the depth/time diagram in Appendix II represents a more correct interpretation).

#### Sequence IV

This sequence corresponds to the Hekkingen Formation in cores 7018/05-U-02 and 7018/05-U-01. The lower 50 m comprise very dark shales and show very high gamma ray values due to high content of uranium. This is accompanied by a high content of organic carbon (mostly between 8 and 15% TOC), and this part of the formation is referred to the Alge Member. The upper 210 m, which also consist of dark grey laminated organic rich shale, are referred to the Krill Member.

The present sequence stratigraphic interpretation suggests that the maximum flooding surface is found in the middle part of the Alge Member, corresponding to the level of the highest gamma readings.

From the depth vs. time diagram in Appendix II and III one can calculate an average depositional rate of ~17 m/Myr for the entire sequence. The average depositional rate (post compaction) for the Alge Member in core 7018/05-U-02 is around 22 m/Myr. Looking at the deposits assigned to the transgressive system tract, a comparable average accumulation rate of ~20 m/Myr is suggested.

Sequence IV contains fair to high concentrations of organic matter. The claystones of the Alge Member typically show TOC values of 6-16 wt%. The Krill Member shows decreased TOC values generally around 2-7 wt%. As discussed in the previous chapter sedimentation rates is proposed to have an important effect on the TOC content of marine deposits. However, while the organic content of a sediment deposited in oxygenated conditions according to Müller & Suess (1979) doubles with every ten-fold increase in the rate of sediment accumulation, the increased sedimentation rate may have had a much more profound effect in the anoxic to dysoxic deposits in sequence IV (i.e. comparing the values of 7 m/Myr for the uppermost sequence III and the values of around 20 m/Myr for the Alge Member).

However, both sediment accumulation rates and the effects of low oxygen levels on the macrobenthos act in a similar way to reduce the extent of preburial organic matter degradation which occurs between the sediment

water interface and the redox potential discontinuity. Tyson (1987) suggests that given the normally occurring range of sediment accumulation rates encountered in the marine environment, and the rates and depths to which sediments can be bioturbated, it is apparent that the level of oxygenation is probably a far more efficient way of achieving the aim than increasing the sedimentation rate. The lack of bioturbation and the overall lack of evidence of any current activity show that sequence IV was deposited under conditions favourable for preservation of organic matter. In this environment where oxygen levels are sufficiently low to exclude effective bioturbation, the relationship described by Müller & Suess (1979), possibly do not hold true. Under such circumstances one would anticipate that sediment accumulation rates would become merely a dilution factor. The small difference between the calculated accumulation rates of the Alge and Krill Members may support this interpretation, although the present evidences make this rather speculative.

Sequence IV represents deep shelf depositional environments and in overall composition palynofacies of sequence IV appear rather homogeneous. The high abundance of amorphous organic matter seen through sequence IV is typical for such environments. Increase in bisaccate pollen relative abundance is sometimes used as indicator of a more distal position, due too the higher buoyancy of bisaccates compared to other terrestrial palynomorphs. However, the small peak in the relative distribution of bisaccates at the middle part of sequence IV (158.27 m in core 7018/05-U-01), may just as well express changes in the continental runoff by climatic variations, rather than being an indication of more distal conditions at this level.

Because inertinite is the most stable maceral of the allochthonous organic fraction, it is often preserved from total degradation in distal marine sediments and can be spread over large areas of the shelf. Peaks in the relative abundance of blade-shaped palynomaceral 4 (in an otherwise amorphous dominated palynofacies) may be used as a parameter to indicate proximal-distal trends. Because of their elongated shape, their settling to the seafloor is delayed in the same way as mica flakes, and consequently they have a better buoyancy than equidimensional fragments. The somewhat increased proportion of such particles at 45.32 m in core 7018/05-U-02 may thus be suggestive of a "deepening event" within sequence IV (although this interpretation is rather speculative).

Viewed in transmitted light, the palynofacies of this sequence appear rather uniform (The few variations are described in details in Section



5.2). It is noteworthy that despite the difference in organic richness, the two members of the Hekkingen Formation have quite similar Rock-Eval hydrogen index values. These vary between 192 and 306 mg/g TOC (average  $\pm$  SD =  $247 \pm 26$  mg/g TOC) for the Alge Member, and between 115 and 399 mg/g TOC (average  $\pm$  SD =  $263 \pm 46$  mg/g TOC) for the Krill Member. Given the low thermal maturity of the rocks, these data suggest that the organic matter may be classified as type II/III kerogen. The palynofacies show that the sequence contain dominantly terrestrially derived phytoclasts. In UV-light it is seen that most of the abundant amorphous organic matter exhibit no fluorescence, indicating that most of this represent degraded land plant material. The fairly regular occurrence of freshwater algae through the sequence also supporte a location near land areas with dominantly terrestrially derived organic matter sourcing the palynofacies.

Although, the HI-values indicate only small differences between types of organic matter in the Alge and Krill Members, a marked difference is seen examining the palynodebris in UV-light. As shown in Figures 13 and 14, the Alge Member contains a much higher proportion of fluorescent organic particles. The abundant fluorescent debris in the Alge Member is mostly palynomorphs and cutinise, besides freshwater algae.

A number of authors (e.g. Jenkyns 1980), have suggested that the transgressive maxima resulted in an increase in shelf productivity which in turn promoted oxygen deficiency and improved preservation potential of the organic matter. Although parts of the Alge Member coincide with a transgressive maximum, this explanation is not valid to differences between the Alge and Krill Members, which as described contain dominantly allochthonous palynodebris. It is, however, probable that the differences attribute to small scale differences in the bottom water/sediment surface oxygenation and the extent of bacterial degradation under these 'anoxic' and 'dysoxic' conditions.

An increase in oxygen content of the depositional environment will affect the preservation of the hydrogen-rich organic particles (algal, palynomorphs, cuctinites) and reduce their fluorescence. Abundant H-rich amorphous organic matter may characterize stagnant oxygen-depleted depositional environments (Van der Zwan 1990). The (more or less) lack of fluorescent amorphous palynodebris in the Krill Member may therefore not only be attributed to the high input of land plant material, but may also indicate somewhat less stagnant conditions during the deposition of this unit compared to the Alge Member. The role of sulphate reducing and

methanogenic bacteria in metabolism of lipids is under anoxic-dysoxic conditions discussed in details by Tyson (1987) and is not further treated here. On a large scale the differences between the Alge and Krill Members probably can be related to the formation and breakdown of local basinal barriers, suggesting less restricted bottom water conditions during the deposition of the Krill Member compared to the Alge Member.

## 7.2 Jurassic sequence correlation of the western Barents Sea area

Detailed sequence stratigraphic correlation of the Mesozoic succession of the Barents Sea area is to be included in the forthcoming IKU Arctic Correlation Program. In the following only brief comparisons and correlations with the sequences recognized in the Troms III area are presented.

Descriptions and correlations of Jurassic sequences of the western Barents Sea region, following "modern" principles of sequence stratigraphy were first published in recent papers by Embry (1989) and Johannessen & Embry (1989). In his paper on correlation of upper Paleozoic and Mesozoic sequences between Svalbard, Canadian Arctic Archipelago and Alaska, Embry (1989) recognized three main correlatable sequences within the Jurassic successions. Throughout the Barents Sea Region, major sequence boundaries occur at the base of the Jurassic, at the base of the Bajocian, at the base of the Oxfordian and the base of the Valanginian.

A more detailed sequence correlation of the upper Triassic to lower Jurassic succession of Arctic Canada and the western Barents Sea area was given by Johannessen & Embry (1989). Their approach differs from the frequently used depositional sequence model of Vail et al. (1987) in the sense that they are using T-R cycles as the genetic stratigraphic unit. In recent review of the Jurassic stratigraphy of the western Barents Sea I included a brief discussion of recognized depositional sequences (Smelror, in press). The following paragraphs are based on this review.

In the Hammerfest Basin the early Pliensbachian - early Toarcian sequence is succeeded by a unit comprising very fine/fine-grained sandstone, followed by a strongly cyclic alternation between offshore mudstones and lower/upper shoreface sandstones. The sequence represents maximum transgression in the area. The upper boundary of this sequence is of late Toarcian/?Aalenian age and corresponds to the transition between units II

and I of the Stø Formation in the Hammerfest Basins (LT/A on Figure 15), and the LT/A unconformity in the Troms III area (Appendix I)..

During the late Bajocian - Bathonian the Svalbard area became emerged, and Spitsbergen strata of Hettangian - Aalenian age occur mainly as thin erosional remnants of shelf shales and sandstones (Steel & Worsley 1984). This, combined with rather poor biostratigraphic control of some units, make it difficult to relate the deposits to their correlation sequences in the Barents Shelf. In eastern Svalbard, i.e. east of the Billefjorden lineament, a more complete lower Jurassic succession is developed, and tentatively it appears that the early Pliensbachian - early Toarcian and the early Toarcian - ?Aalenian sequences in the Hammerfest Basin can be correlative to the Passet Member of the Wilhelmøya Formation on Kong Karls Land.

The following ?Aalenian to Bajocian shallow marine sandstone sequence (sequence II) in the Troms III area can be related to a contemporaneous sequence in the Hammerfest Basin, comprising the Stø Formation Unit I. This sequence has not been recognized on Svalbard, which is mentioned above, was emerged during this time. The unconformity surface of this upper sequence boundary (LB on Figure 16) was transgressed from Bajocian to Bathonian in the Hammerfest and Tromsø Basins and from late Bathonian on Svalbard, and much of the Bajocian and Bathonian is represented by very thin condensed deposits, i.e. the Brendskardhaugen Bed on Svalbard and Stø I unit in the eastern Hammerfest Basin, which contains several erosional surfaces or hiatuses.

On Spitsbergen the overlying upper Bathonian - lower Oxfordian succession comprises generally a fining upwards sequence, starting with the basal Brendskardhaugen conglomerate followed by shales of the lower Agardhfjellet Formation. Eastwards on Kong Karls Land the basal conglomeratic unit is not recorded, but the lowermost siltstones of the Retziusfjellet Member contain common reworked ?Toarcian palynomorphs comparable to those found elsewhere in the Brendskardhaugen Beds. The upper boundary of this upper Bathonian - lower Oxfordian sequence is at the Hårfagrehaugen section on Kong Karls Land marked by the abrupt transition to the overlying sandstones of lower Cretaceous Helvetiafjellet Formation (Smelror 1988). Elsewhere in the Svalbard area there appears to be no profound depositional break within the lower Oxfordian, although the transition between the zones ("sequences") 1 and 2 defined by Dypvik (1985) in the Agardhfjellet Formation, may correspond to this lower Oxfordian sequence boundary (EO on Figure 15).

In the deep wells drilled in Hammerfest and Tromsø Basins the lower boundary of the upper Bathonian - lower Oxfordian sequence is recognized by sharp increases in gamma ray and density respons and by an accompanying decrease in interval transit time (Worsley et al. 1988). The sequence boundary corresponds to the transition between the Stø and the overlying Fuglen Formation, and in this area the hole sequence can be assigned to the Fuglen Formation. This lower boundary corresponds to the LB unconformity in the Troms III area, where the upper Bathonian - lower Oxfordian sequence III is assigned to the same formation.

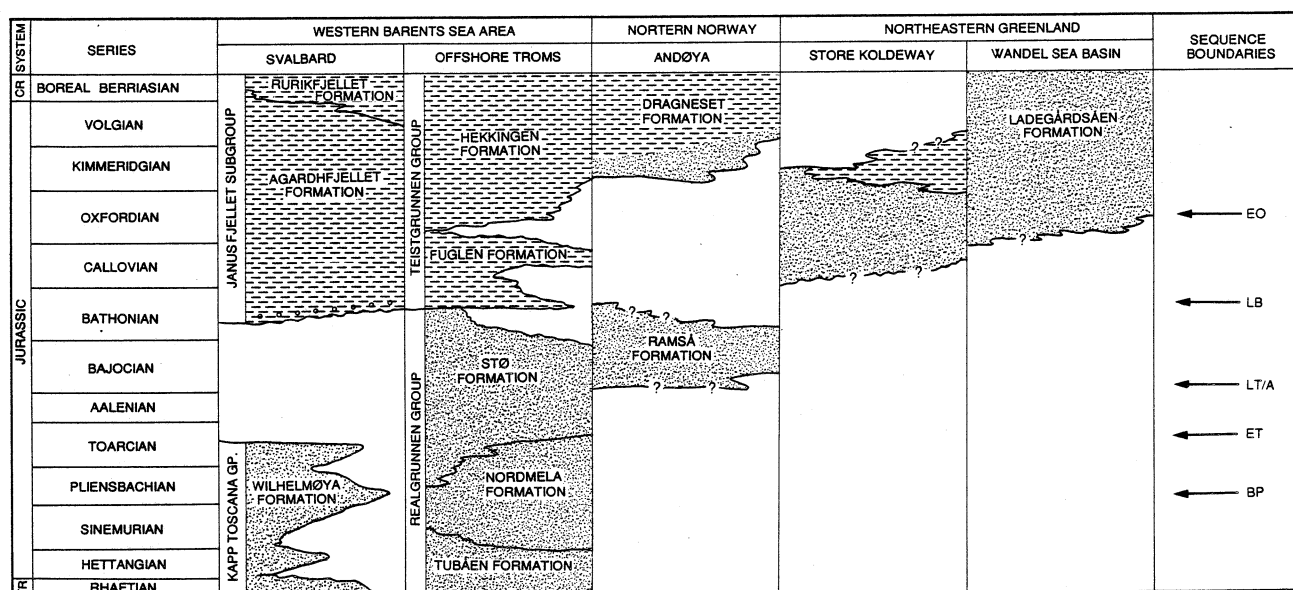


Figure 16 Lithostratigraphic correlation of the western Barents Sea area, northern Norway and northeastern Greenland. Sequence boundaries shown to the right are: BP-base Pliensbachian, ET-early Toarcian, LT/A-late Toarcian/?Aalenian, LB-late Bathonian, EO-early Oxfordian.

In the Hammerfest Basin the upper boundary of the upper Bathonian - lower Oxfordian sequence is defined by the transition from carbonate cemented and pyritic mudstones to poorly consolidated shales, producing a sudden increase in interval transit time and an abrupt decrease in bulk density values (Worsley et al. 1988). In the Troms III area this upper sequence is recognized as the Eo unconformity, corresponding to the transition between the Fuglen and Hekkingen Formations. At IKU corehole 7230/05-U-02 in the Nordkapp Basin the correlative sequence boundary is marked by an erosional surface and hiatus spanning the ?Early/Middle Callovian to Late Oxfordian.

The last sequence boundary considered here is the base Valanginian, which represents a major regional sequence boundary in the Arctic region (Embry 1989). In the Barents Sea area regression started about middle Volgian time, when there were often minor stratigraphic breaks in the successions (Kelly 1988). On Svalbard this regressive episode is expressed by the transition between the Agardhfjellet Formation and the Rurikfjellet Formation, where locally the Rurikfjellet Formation is unconformable on the Agardhfjellet Formation and older strata, and on intruded dolerites (Parker 1967). In the Hammerfest and Tromsø Basins the Middle Oxfordian - Boreal Berriasian sequence corresponds to the Hekkingen Formation, which locally shows breaks in the deposition at the base and top, probably most developed near the basin axis. In the Bjørnøya Basin upper Jurassic dark shale sequence are overlain by condensed dolomitic limestone of Valanginian and Hauterivian age (Århus et al. 1990). This corresponds to what is observed on Kong Karls Land, where a thin sandy bioclastic limestone of Valanginian age assigned to the Tordenskjold Member overlies the upper Jurassic shales of the Retziusfjellet Member (Smith et al. 1976).

The "base Valanginian" sequence boundary is also recognized in the Troms III area, where it corresponds to the boundary between the Hekkingen Formation and the overlying Unit B at 49.67 m in core 7018/05-U-01 (see Appendix III).



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**TABLES IV - VI**

*Table IV: Frequency distribution of the main palynofacies categories in core 7018/05-U-06.*

[illegible]



Table IV: cont.

[illegible]

Table IV: cont.

[illegible]

Table IV: cont.

[illegible]

*Table V: Frequency distribution of the main palynofacies categories in core 7018/05-U-02.*

[illegible]

Table V: cont.

[illegible]



Table V: cont.

[illegible]

Table V: cont.

[illegible]

Table VI: Frequency distribution of the main palynofacies categories in core 7018/05-U-01.

[illegible]

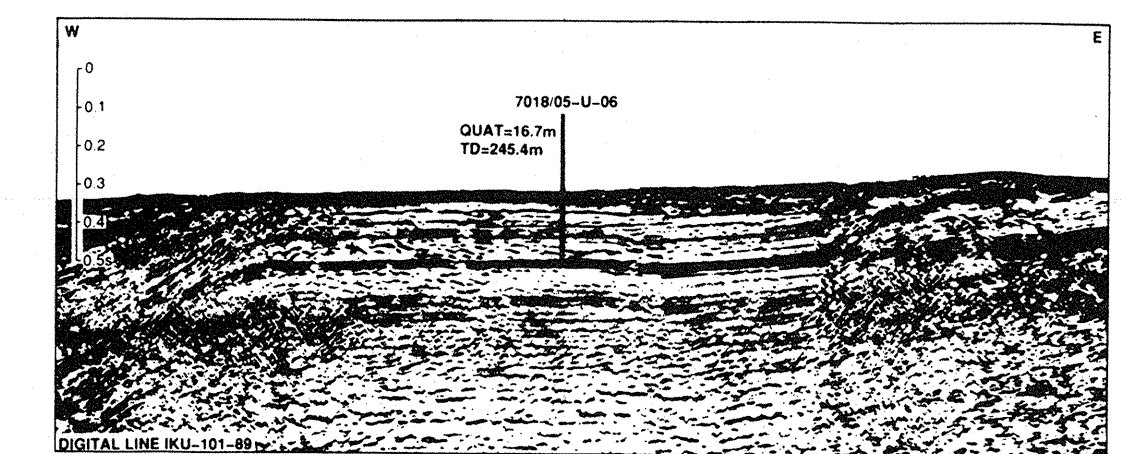
Table VI: cont.

[illegible]

Table VI: cont.

[illegible]





| LEGEND TO PALYNOFACIES, TROMS III |                                                                                       |                      | Approx. coal/macerals equivalent |
|-----------------------------------|---------------------------------------------------------------------------------------|----------------------|----------------------------------|
| Main palynodebris categories      |                                                                                       |                      |                                  |
| ALLOCTHONOUS FRACTION             |  | Dark SOM             | Degraded debris                  |
|                                   |  | Palynomaceral 1      | Degraded – brown wood            |
|                                   |  | Palynomaceral 2      | Well preserved wood, parenchyma  |
|                                   |  | Palynomaceral 3      | Unstructured cuticle and debris  |
|                                   |  | Palynomaceral 4      | Black debris                     |
|                                   |  | Spores               |                                  |
|                                   |  | Bisaccates           |                                  |
| AUTOCTHONOUS                      |  | Acritarchs and algae |                                  |
|                                   |  | Dinoflagellate cysts |                                  |
|                                   |  | Amorphous matter     |                                  |
|                                   |                                                                                       |                      | Structureless organic matter     |
|                                   |                                                                                       |                      | VITRINITE                        |
|                                   |                                                                                       |                      | CUTINITE                         |
|                                   |                                                                                       |                      | INERTINITE                       |
|                                   |                                                                                       |                      | SPORINITE                        |
|                                   |                                                                                       |                      | LIPNITE                          |



AGE SEDIMENTOLOGICAL LITHOLOGY

DEPOSITIONAL ENVIRONMENT

SELECTED BIOSTRATIGRAPHIC DATUMS (first/last occurrences)

GAMMA LOG

DEPTH VS TIME DIAGRAM OF BIOSTRATIGRAPHIC EVENTS

PALYNOFACIES

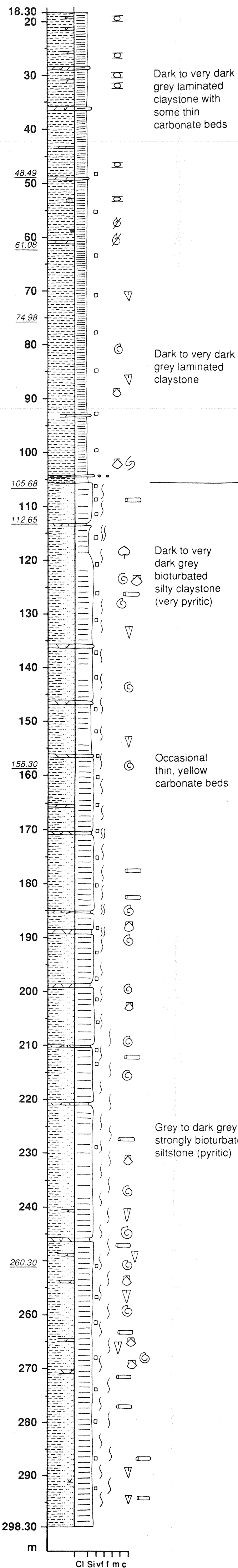
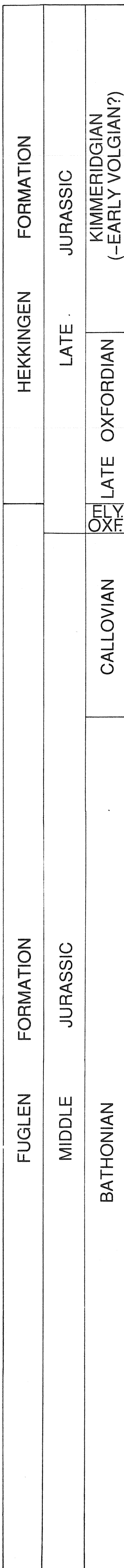
TOTAL ORGANIC CONTENT (TOC)



APPENDIX II SUMMARY SHEET

23.1620.00/01/91

Core 7018/05-U-02 Vertical logscale 1 : 500



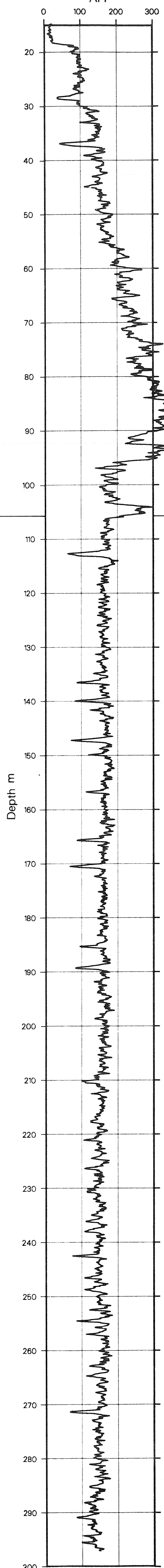
Deep shelf Anoxic to dysoxic

Deep shelf Anoxic

Shelf Oxic

Shelf Oxic

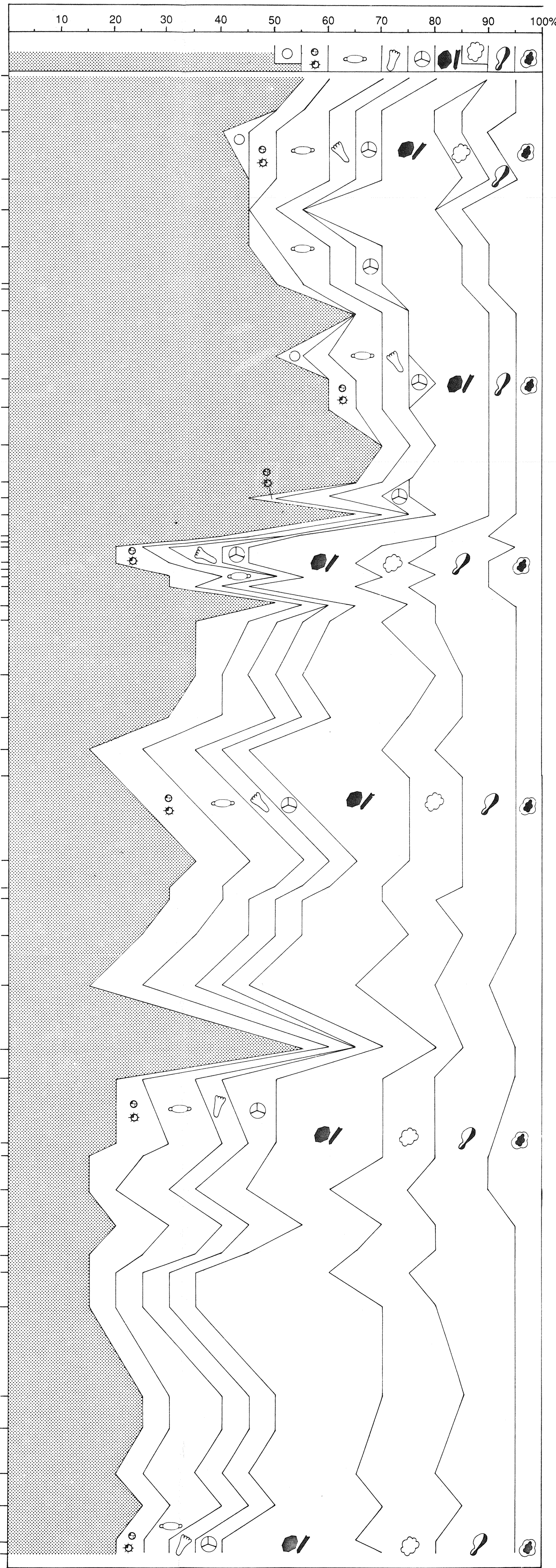
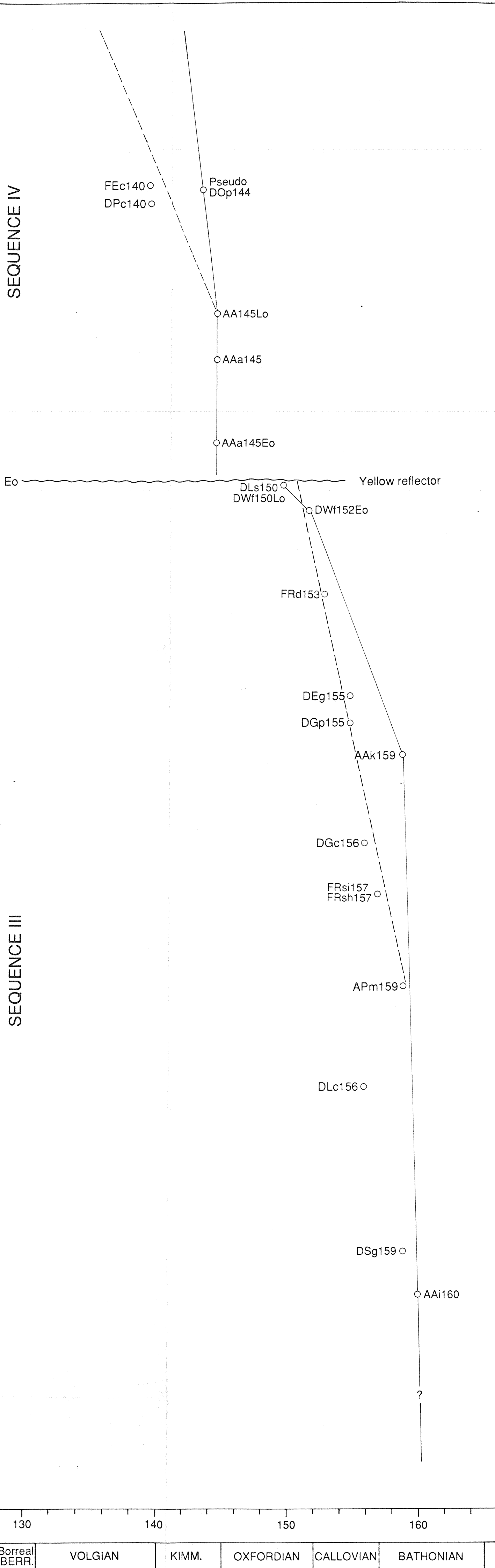
- Evolutinella emeljanzevi
- Pareodinia capillosa
- common Cribroperidinium gigas
- Gonyaulacysta jurassica
- Amoeboceras (A.) ex gr. alternans
- Amoeboceras (A.) ex gr. alternans
- Buchia concentrica
- common Rhynchodiniopsis cladophora
- Liesbergia scarburghensis
- Recurvoides disputabilis
- Liesbergia scarburghensis
- Wanaea fimbriata
- Recurvoides disputabilis
- Gonyaulacysta pectinigera
- Arcticoceras sp. (cf. krylowi)
- Riyadheila sibirica
- Riyadheila shapkinaensis
- Pseudocadoceras sp. (cf. mundum)
- acme Dichadogonyaulax sellwoodii
- Sirmiodinium grossii
- Arcticoceras sp. (ex gr. ischmae)



SEQUENCE IV

SEQUENCE III

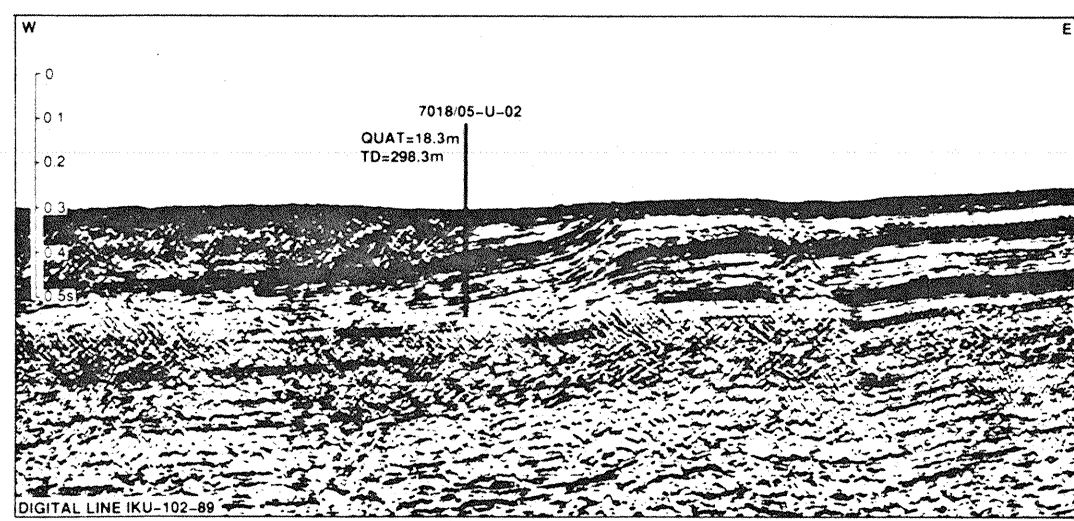
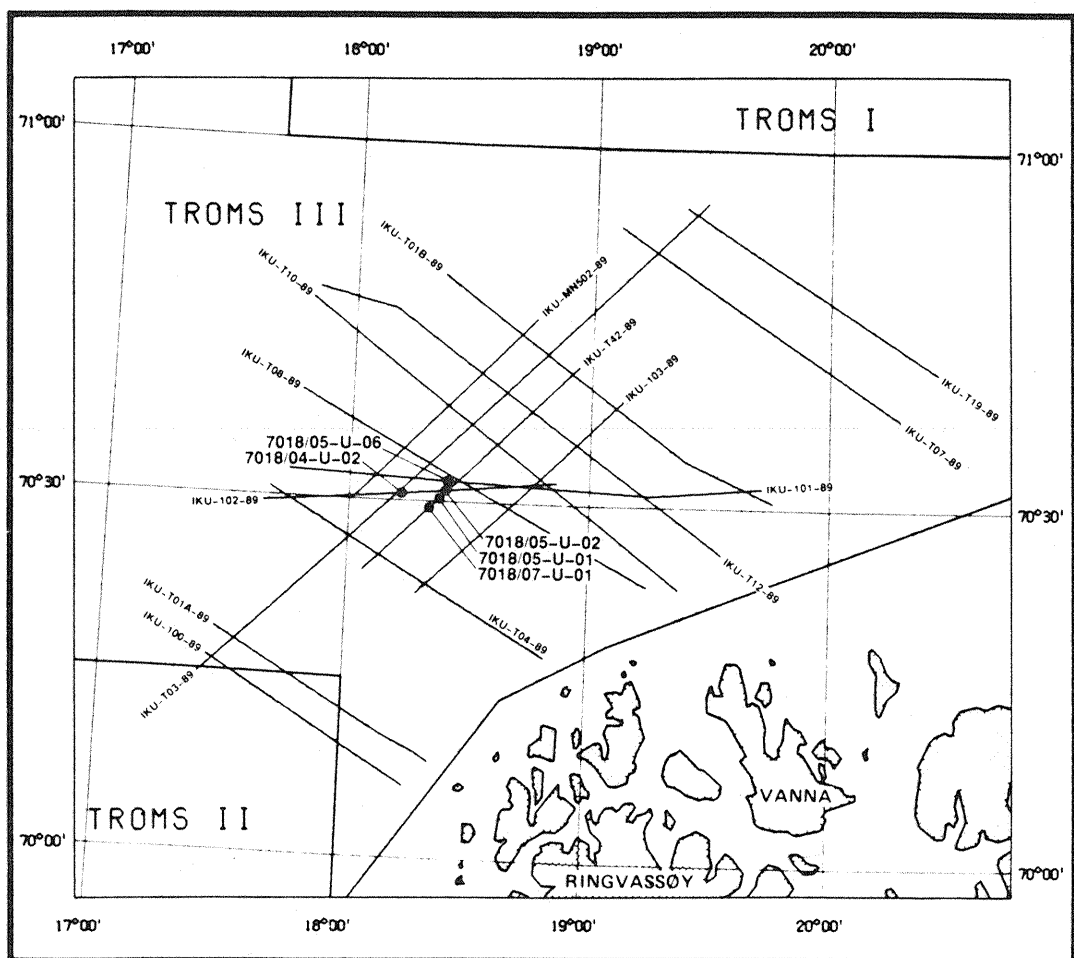
Boreal BERR. VOLGIAN KIMM. OXFORDIAN CALLOVIAN BATHONIAN



Hydrogen index locally increased due to hydrocarbon staining. Plotted data relate to unextracted rock.

Depth m

LEGEND :  
● Hydrocarbon staining observed  
○ Hydrocarbon staining suggested by geochemical data



| LEGEND TO PALYNOFACIES, TROMS III |                                 |            |
|-----------------------------------|---------------------------------|------------|
| Main palynodebris categories      |                                 |            |
| ALLOCTONOUS FRACTION              |                                 |            |
| Dark SOM                          | Degraded debris                 |            |
| Palynomaceral 1                   | Degraded - brown wood           | VITRINITE  |
| Palynomaceral 2                   | Well preserved wood, parenchyma |            |
| Palynomaceral 3                   | Unstructured cuticle and debris | CUTINITE   |
| Palynomaceral 4                   | Black debris                    | INERTINITE |
| Spores                            |                                 | SPORINITE  |
| Bisaccates                        |                                 |            |
| AUTOCTONOUS                       |                                 |            |
| Acrinarchs and algae              |                                 |            |
| Dinoflagellate cysts              |                                 |            |
| Amorphous matter                  | Structureless organic matter    | LIPTINITE  |

LEGEND TO KEROGEN TYPE

Type I (HI > 600 mg/g TOC)

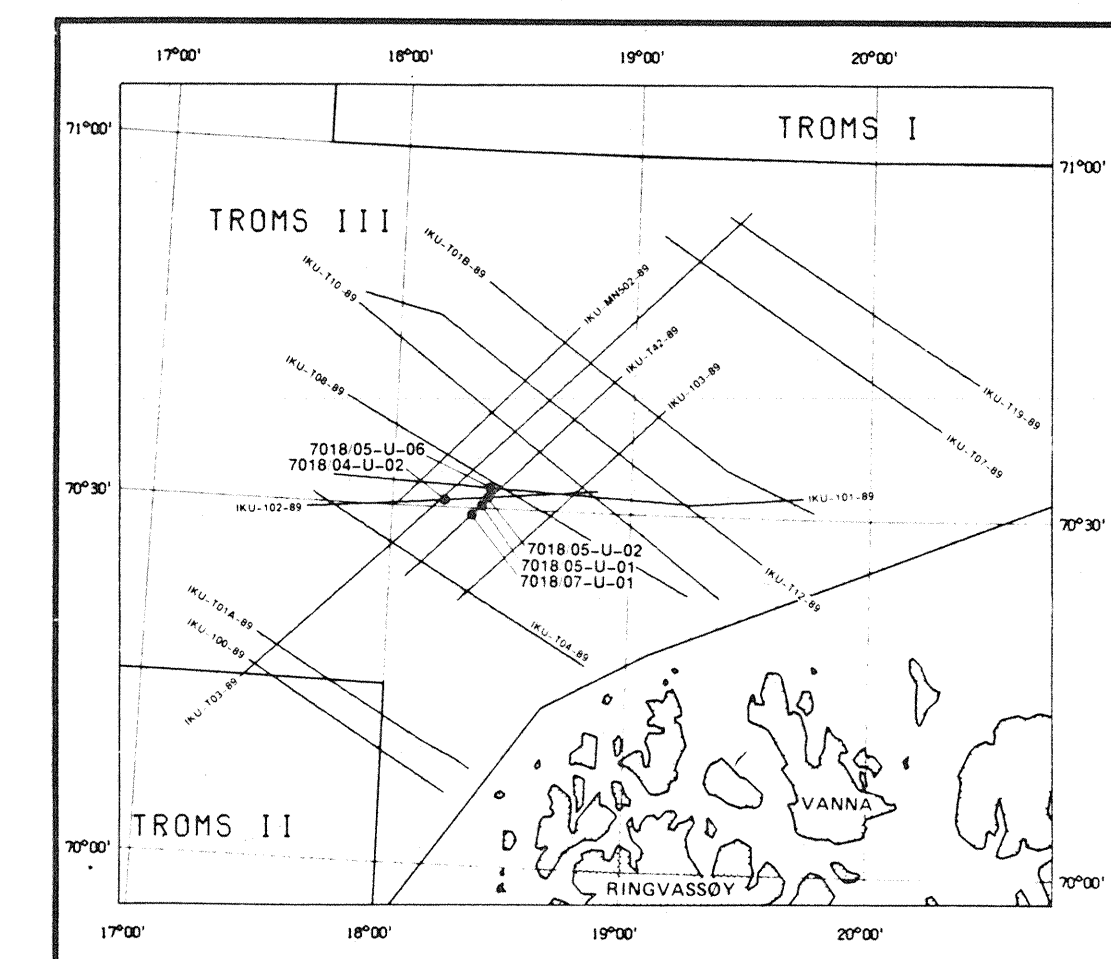
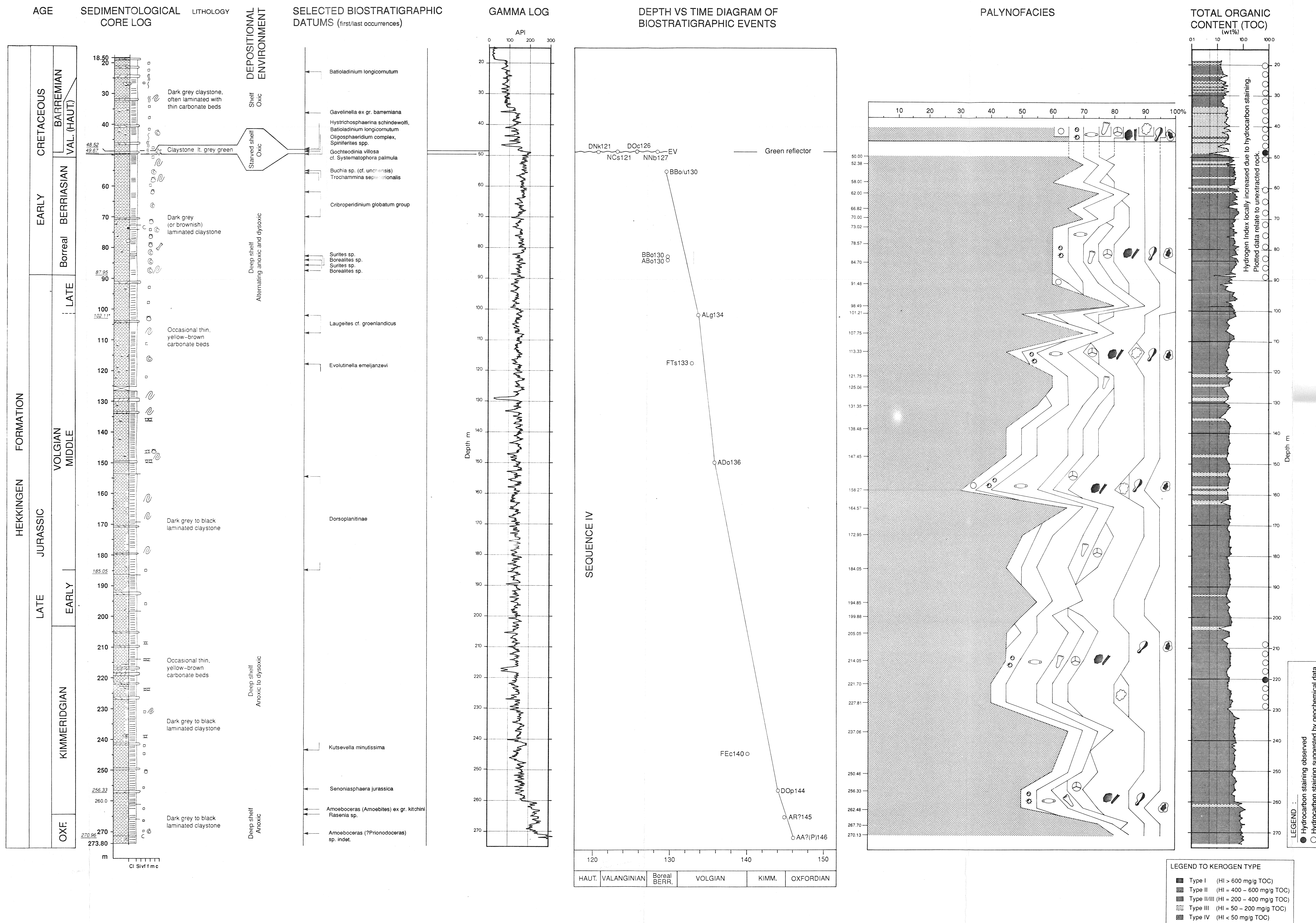
Type II (HI = 400 - 600 mg/g TOC)

Type II/III (HI = 200 - 400 mg/g TOC)

Type III (HI = 50 - 200 mg/g TOC)

Type IV (HI < 50 mg/g TOC)







23.1620.00/01/91

Jurassic depositional sequences, palyrnofacies  
and organic facies of the Troms II Area

