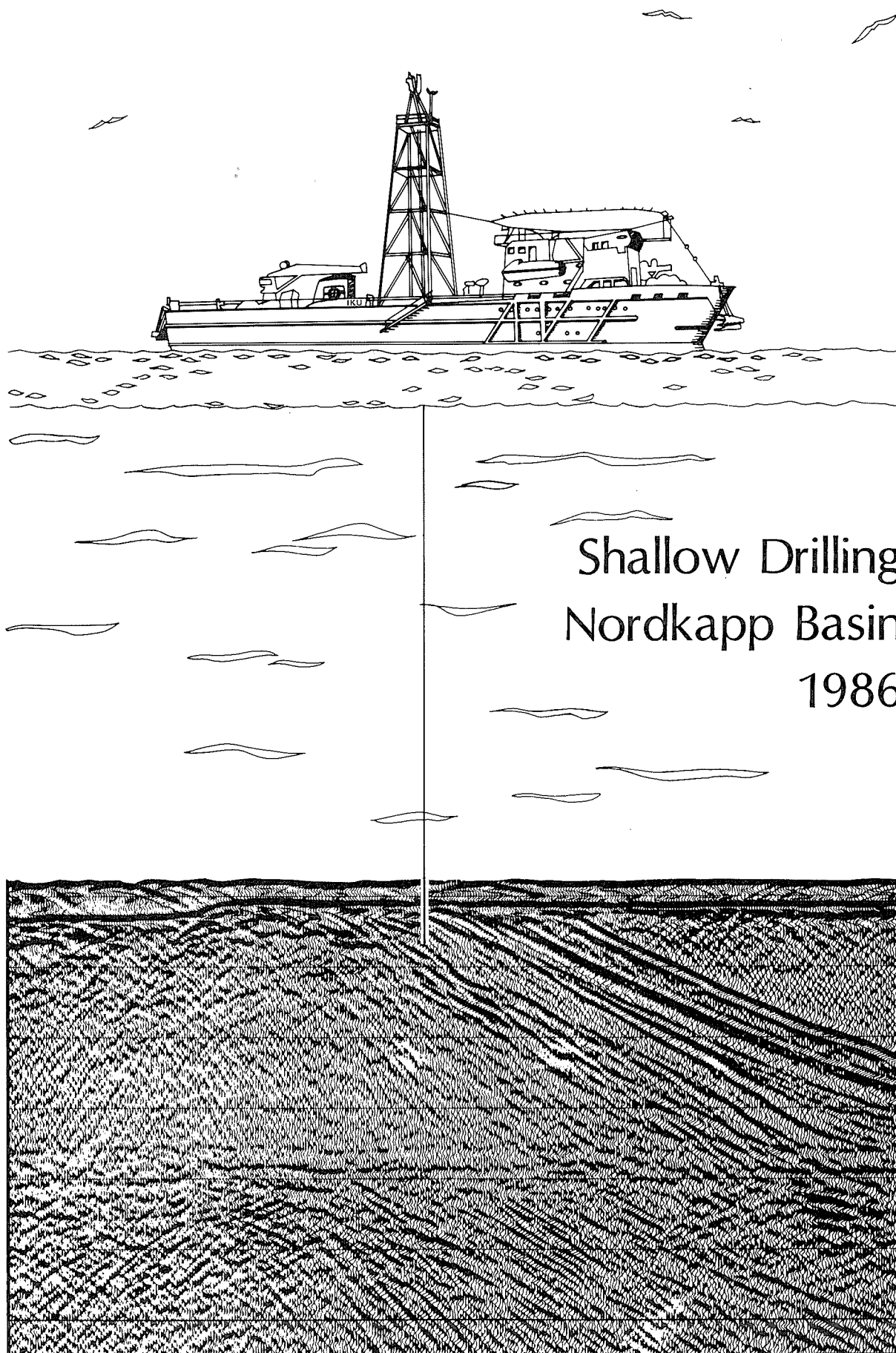




REPORT

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SHALLOW DRILLING NORDKAPP BASIN 1986

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SUMMARY:

This report is part of the project "Nordkapp Basin shallow seismic, shallow drilling and heat flow measurements 1986". A total of 880 km of shallow seismic data has been collected (500 km analog data and 380 km multichannel, 2.5 sec data). The heat flow data are reported separately (IKU report 21.3419.00/03/87). All data on Quaternary samples are included in that report.

The present report gives data on sedimentology, palaeontology and organic geochemistry integrated with seismic interpretation of the Nordkapp Basin and adjacent areas.

A total of 120 m of bedrock cores were obtained from four sites in the Middle Triassic-Lower Cretaceous succession. Three of the locations are within a distance of 400 m along the same seismic line. Core recovery was 96%. Several significant seismic reflectors were penetrated.

KEY WORDS:	
Barents Sea	Sedimentology
Nordkapp Basin	Palaeontology
Shallow Drilling	Organic geochemistry

PREFACE

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Elf Aquitaine Norge a/s
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The field work was co-ordinated by Joar Sættem and the laboratory work by Nils Aarhus (stratigraphy and sedimentology) and Hermann Weiss (organic geochemistry). The report is based on contributions from the following persons:

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CONTENTS

	PAGE
Preface	2
1. INTRODUCTION	6
2. SUMMARY	7
3. DATA PRESENTATION	10
3.1 7228/3-U-1	10
3.1.1 Summary	10
3.1.2 Seismic interpretation	12
3.1.3 Core description	13
3.1.4 X-ray diffraction analysis	17
3.1.5 Petrophysics	18
3.1.6 Palaeontology	20
3.1.7 Organic geochemistry	22
3.1.8 Depositional environment	31
3.2 7227/8-U-1	33
3.2.1 Summary	33
3.2.2 Seismic interpretation	35
3.2.3 Core description	36
3.2.4 X-ray diffraction analysis	42
3.2.5 Petrophysics	43
3.2.6 Palaeontology	45
3.2.7 Organic geochemistry	48
3.2.8 Depositional environment	57
3.3 7227/8-U-3	61
3.3.1 Summary	61
3.3.2 Seismic interpretation	62
3.3.3 Core description	63
3.3.4 X-ray diffraction analysis	64
3.3.5 Petrophysics	65
3.3.6 Palaeontology	67
3.3.7 Organic geochemistry	72
3.3.8 Depositional environment	81

	PAGE
3.4 7227/8-U-2	82
3.4.1 Summary	82
3.4.2 Seismic interpretation	82
3.4.3 Core description	84
3.4.4 X-ray diffraction analysis	86
3.4.5 Petrophysics	87
3.4.6 Palaeontology	88
3.4.7 Organic geochemistry	92
3.4.8 Depositional environment	100
4. SEISMIC INTERPRETATION OF THE NORDKAPP BASIN AND ADJACENT AREAS	101
4.1 Seismic interpretation of adjacent areas	101
4.2 Seismic interpretation of the Nordkapp Basin	103
5. DISCUSSION	109
5.1 Correlation of cores and seismic data Block 7227/8	109
5.2 Tentative models for local sediment sources	110
6. REFERENCES	115
APPENDICES	
A.1 Drilling operation - Field statistics	117
A.2 Navigation - Final positions	126
A.3 Analytical methods	127
A.4 Summary sheet	
A.5 Core logs M 1:100	
APPENDIX VOLUME	
Organic geochemistry data	

1. INTRODUCTION

The present report gives the results from bedrock drilling at four sites in the Nordkapp Basin.

Two data reports have previously been submitted, presenting preliminary results on heat flow, datings and organic geochemistry. The final heat flow results are reported separately.

In the present report we give a core by core description in Chapter 3, starting with a short summary of each core and followed by a discussion of the local tie between the core and the seismic data, core description, datings and organic geochemistry results. All organic geochemistry laboratory results with plots and tables are presented in a separate appendix volume.

In Chapter 4 we present a seismic interpretation of the Nordkapp Basin and adjacent areas. The first part presents a preliminary subcrop map of bedrock geology in adjacent areas, i.e., the southeastern area of the Norwegian part of the Barents Sea, and the second concentrates on the Nordkapp Basin and gives a brief geological description, mainly based on the data collected in this project. The term seismic sequence boundary is used in the context of Vail et al. (1977). For time-depth conversion for the seismic data we have applied a mean value of 1800 m/s in the Pleistocene and 2500 m/s in bedrock.

Chapter 5 presents a discussion of the core data and the seismic data, and tentative models of the palaeogeographic settings and potential sediment source areas are described.

Description of the field work and drilling procedures, final positions, analytical methods and detailed core logs are found in the appendix of this volume. A separate Appendix volume contains raw data from the organic geochemistry analyses and the results of hydrous pyrolysis on core 7227/8-U-3.

2. SUMMARY

The project "Nordkapp Basin shallow seismic, shallow drilling and heat flow measurements 1986" comprised a shallow seismic survey in May 1986 and shallow drilling combined with heat flow measurements in July/August (for location, see Figure 2.1).

The shallow seismic survey was designed to find adequate drill sites on the flanks of the salt structures in the Nordkapp Basin, and a total of 880 km of seismic data was collected. 500 km of this was analog sparker and 380 km multichannel data shot with air-gun and recorded to 2.5 sec. On most of the lines high quality deep towed boomer and side-scan sonar data was obtained simultaneously.

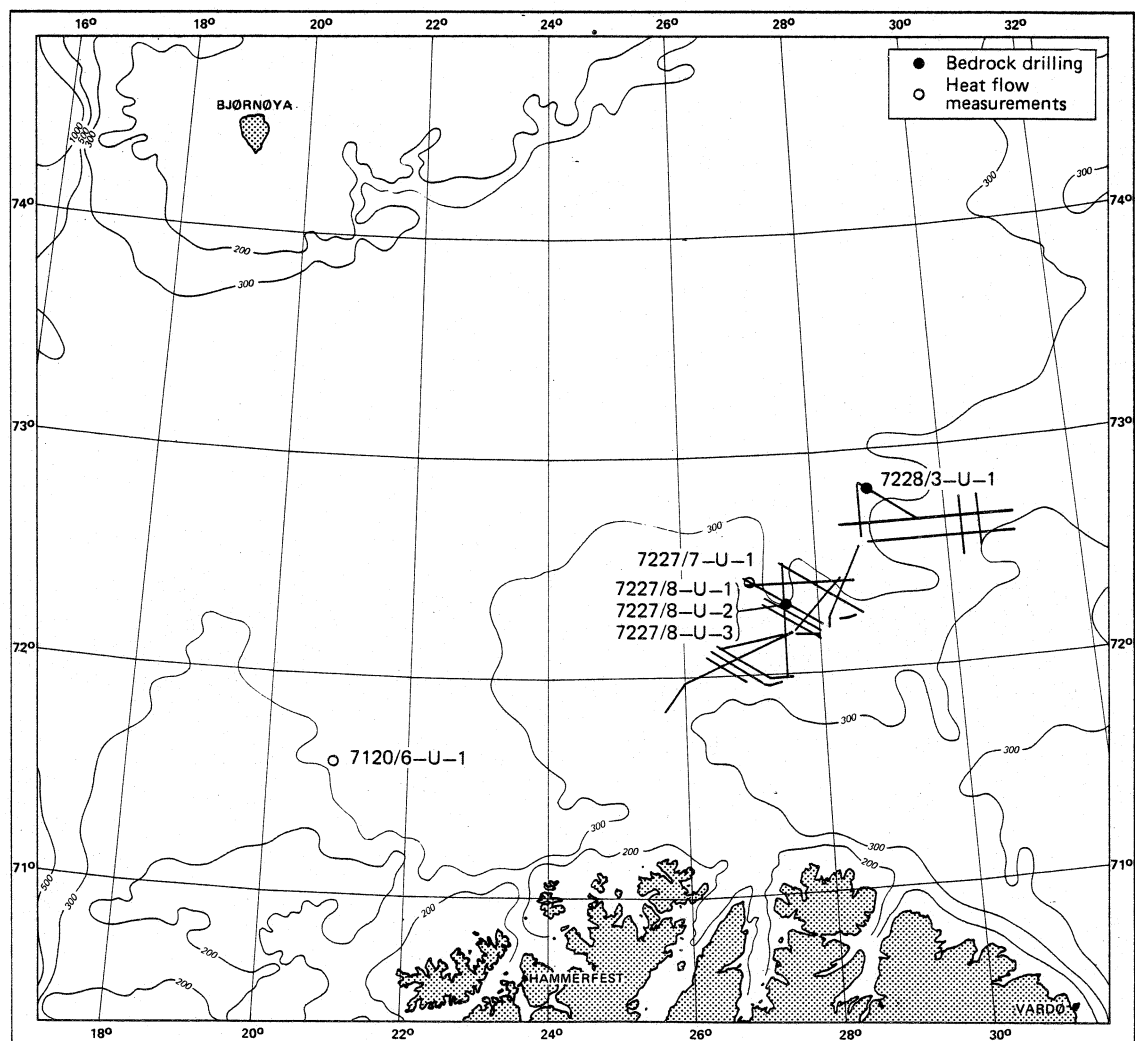


Figure 2.1 Bedrock drilling and heat flow sites.

Four bedrock coreholes were drilled. The oldest core 7228/3-U-1, dated as upper Anisian - lower Ladinian was obtained from the northwestern part of the Nordkapp Basin and is about 46 m long. It may be divided into five coarsening upward units dominated by bioturbated porous silty sandstones deposited in a marginal marine environment. This is in contrast to the more distally deposited finer grained deposits of equivalent age from the Dia-Structure. The drilled core is thermally immature with a vitrinite reflectance of 0.35% Ro.

The three other cores were drilled over a horizontal distance of 400 m along the same seismic line in the southern part of the basin. Core 7227/8-U-1 consists of tentative upper Triassic non-marine coastal plain deposits followed by marine Norian to Lower Rhaetian sandstones. Then there was probably long periods of deposition/erosion and/or non-deposition leading to an undated fluvial unit with sandstones and coarse conglomerates overlain by a marine Toarcian dated sandstone. A significant seismic boundary may be correlated with the base of the fluvial unit.

Core 7227/8-U-3 consists of very dark grey shales which comprise a complete Upper Oxfordian to Kimmeridgian (*sensu gallico*) section indicating very little supply of sediment and no tectonic activity in the area at this time. Geochemical data indicate that this core is rich to excellently rich in kerogen of type II-III and II which has a good hydrocarbon generation potential at optimum thermal maturity. The kerogen is currently immature and shows an average vitrinite reflectance of 0.29 %Ro.

The Middle Albian rocks in core 7227/8-U-2 from immediately below a major regional seismic reflector are in parts strongly bioturbated grey to dark grey clayey siltstones. Three light grey clays are interpreted as bentonitic beds. The solely agglutinated foraminiferal assemblages indicate restrictions in the dissolved oxygen and never optimal conditions for a benthic population on this marine shelf. Most samples from the core contains between 0.5 and 1% TOC, mainly in the form of woody particles (kerogen type IV).

No significant concentrations of non-indigenous hydrocarbons were found in any of the cores. However, it cannot be fully ruled out that the rocks contain trace amounts of hydrocarbons derived from more mature sources. This would help to explain the observed differences between the maturities of kerogens and extracts.

In Chapter 5 we introduce some alternative ideas for sediment source areas in the Nordkapp Basin. Rønnevik and Jacobsen (1984) a.o. suggested a source area for the Triassic sediments to the northeast. These models are based on a few but major land areas from where sediments have been derived. We point at the possibility that local highs including islands may have existed and that these islands were local source areas for Triassic and Jurassic sediments in the Nordkapp Basin. The local highs may have been created by salt tectonism or by extensional faulting along the old graben system in the Nordkapp Basin.

3. DATA PRESENTATION

3.1 7228/3-U-1

3.1.1 Summary

46.26 m of in situ sedimentary rocks were drilled between 42.45 and 88.71 m below sea floor. The core is divided in five units, where the upper four show coarsening upward patterns with bioturbated siltstones and silty sandstones and occasional intraformational conglomerates at the base (Figure 3.1.1). These strata gradually change into more heavily bioturbated poorly sorted sandstone and then into fine- to medium-grained more well-sorted sandstones. Coal occurs on top of Unit D.

Porosities in the mineralogically immature sandstones are high and vertically measured permeabilities low, due to siltstone laminae and growth of authigenic clay minerals, particularly.

The palynological assemblages are facies controlled and dominated by bisaccate pollen and Aratrisporites spp. More age significant taxa point to a Middle Triassic late Anisian-early Ladinian age. Palynological data indicate marine depositional conditions except for the beds around the coal. We interpret the lower part of each unit as an offshore to lower shoreface deposit whereas the upper parts may represent upper shoreface environments. Unit D contains coastal plain deposits in the upper part.

The total organic carbon content is mostly between 0.5 and 1%, but may be locally increased due to coals or coaly plant detritus. The organic matter is poor in hydrogen and belongs to type III, locally to type IV as suggested by Rock-Eval data. The maturity of the kerogen appears to be slightly higher than for the other Triassic core 7227/8-U-1. The rocks are considered to have only a marginal potential for the generation of liquid hydrocarbons. The hydrocarbons extracted from these rocks show a variable composition which may perhaps be attributed to variations in the source material.

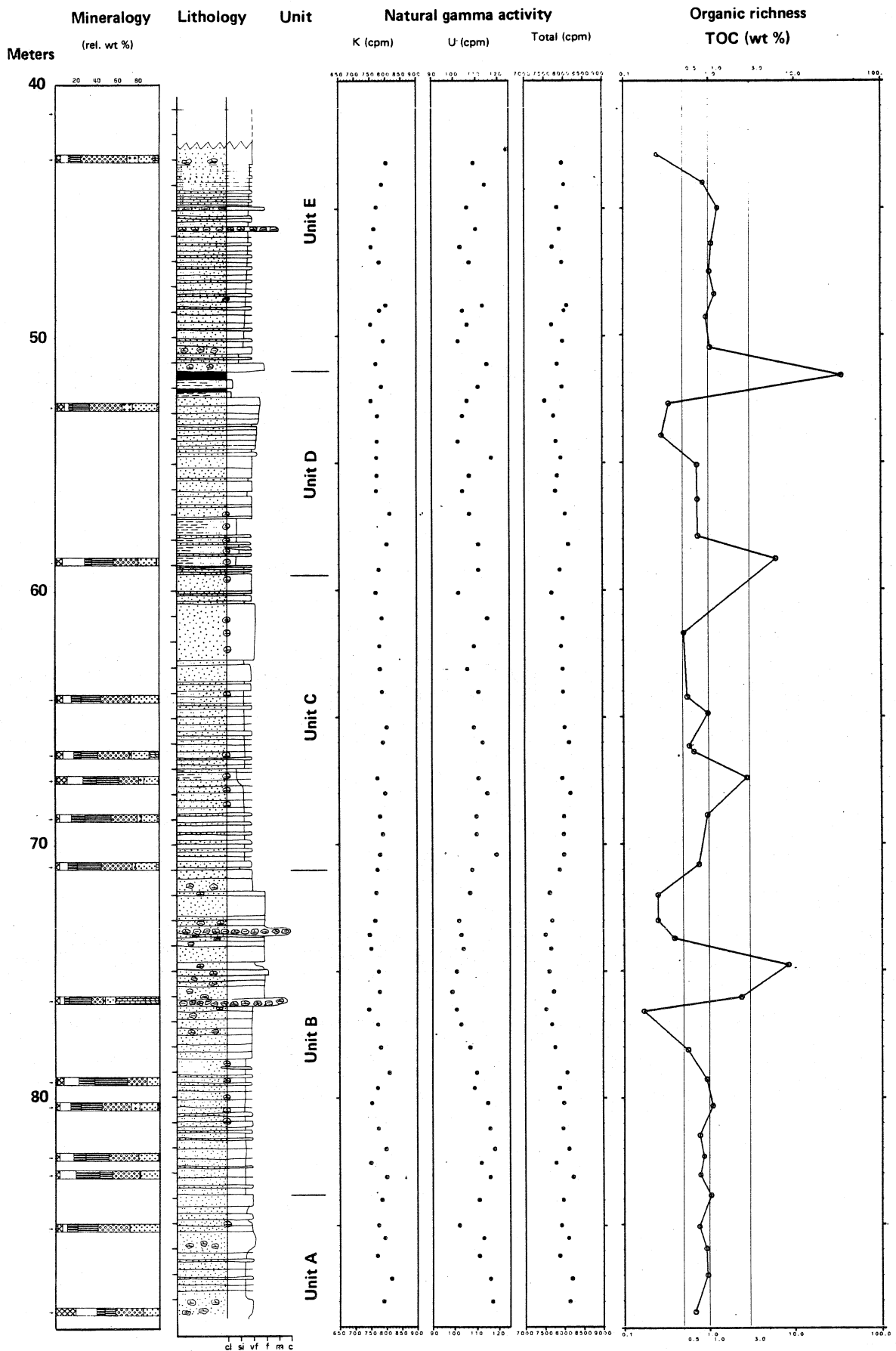


Figure 3.1.1 Summary figure of core 7228/3-U-1.

3.1.2 Seismic interpretation

The drill site is situated on a bedrock terrace 10 m higher than the bedrock surface in the area to the northwest (Figure 3.1.2). The terrace is covered by Pleistocene sediments and the bedrock relief is almost level. The slope surface is a truncational surface. Another major unconformity of possible top Jurassic age cuts this surface about 230 msec below sea bed on line IKU D86-16. Significant hiatus therefore exist between the Middle Triassic sediments obtained in the core and the Cretaceous sediments less than 200 m above.

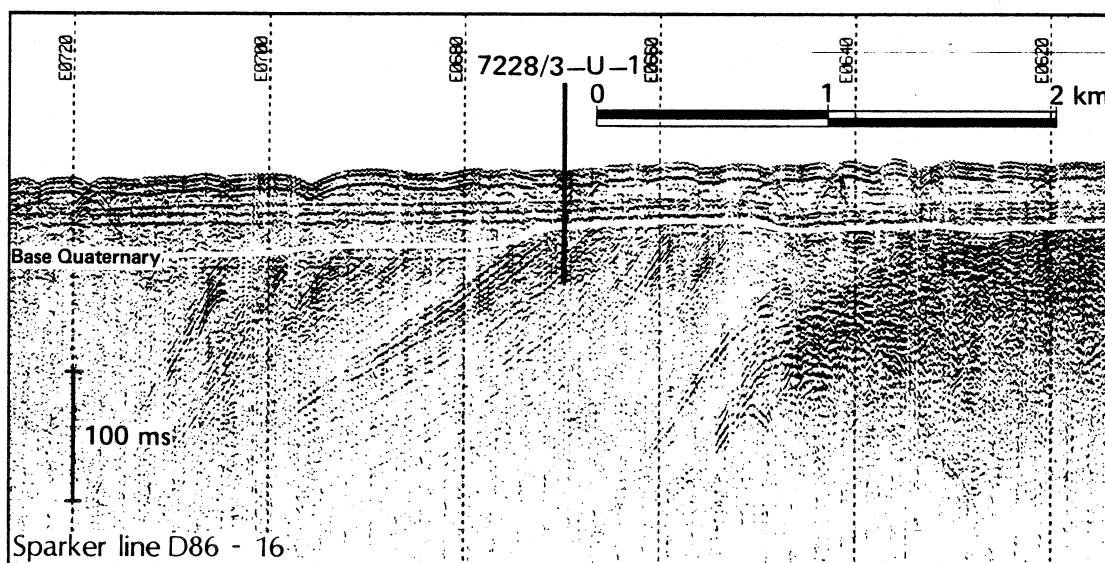


Figure 3.1.2 Sparker line D86-16 at site 7228/3-U-1.

The cored interval lies below the slope related unconformity. One overlapped surface has been penetrated by the core and is probably equivalent to the transgressed surface on top of Unit D. Another seismic reflector recognized about 30 m below base Quaternary may correlate with the boundary between Units B and C. Our data set does not allow us to map the Triassic units into the basins and evaluate the significance of the sedimentary sequences detected in the cores. This would require additional multichannel seismic data.

3.1.3 Core description

46.26 m of sedimentary rocks were drilled between 42.45 m and 88.71 m below sea floor. Additional 1.45 m of sediment affected by Quaternary processes occurs on top of the in situ rocks, below the 41 m thick Quaternary overburden. A lithological column is shown in Figure 3.1.1. The core is divided in five units: Unit A, B, C, D and E with the boundaries between the units at 83.80 m, 70.95 m, 59.40 m and 51.35 m, respectively (Figure 3.1.3). Units B, C, D and E are coarsening upward, while Unit A looks similar to the lower part of the other units. These units are sedimentologically similar and will be described together.

Unit A and the lower part of the other units consist of strongly bioturbated siltstones to silty sandstones with faint remains of laminae and low angle ripples. In the lower part individual graded beds normally are less than 2 cm thick, while they thicken slightly upwards. This part gradually changes into a very strongly bioturbated fine-grained silty sandstone where little of the primary structures are preserved. The probable original bedding is manifested by more or less silty fine-grained sandstone, indicating that the rock consisted of alternations between a few to 20 cm thick sandstones and mudstones. Some horizontal and ripple laminations are seen in this unit. Most burrows are horizontal, but also some vertical burrows up to 2 cm in diameter are seen. Flaser bedded intervals occur in Unit B. Unit A and E contain some intraformational siderite and mudstone pebbles, up to 1 cm in size in strongly bioturbated sandstone.

The bioturbated siltstones to silty sandstones are abruptly overlain by fine-grained sandstone. In the basal part of the sandstone in Units B and E a matrix-supported intraformational conglomerate with brown siderite and greyish mudstone clasts occur, some mm to a few cm in diameter. The burrows are predominantly horizontal, but some vertical burrows, up to 1.5 cm in diameter are observed. In Unit B the conglomerate consists of fine-grained sandstone with some mudstone and siderite pebbles. It also shows larger scale cross-lamination and ripple-lamination. In Unit D it consists of few to 40 cm thick sandstone beds with horizontal lamination and ripples. It is also characterized by vertical burrows up to 2 cm in diameter.

The uppermost part of Unit D contains some vertical structures that either are burrows or root features. The coarsening upward sandstones of Unit D are abruptly overlain by a dark grey coaly silty claystone with two coal beds.

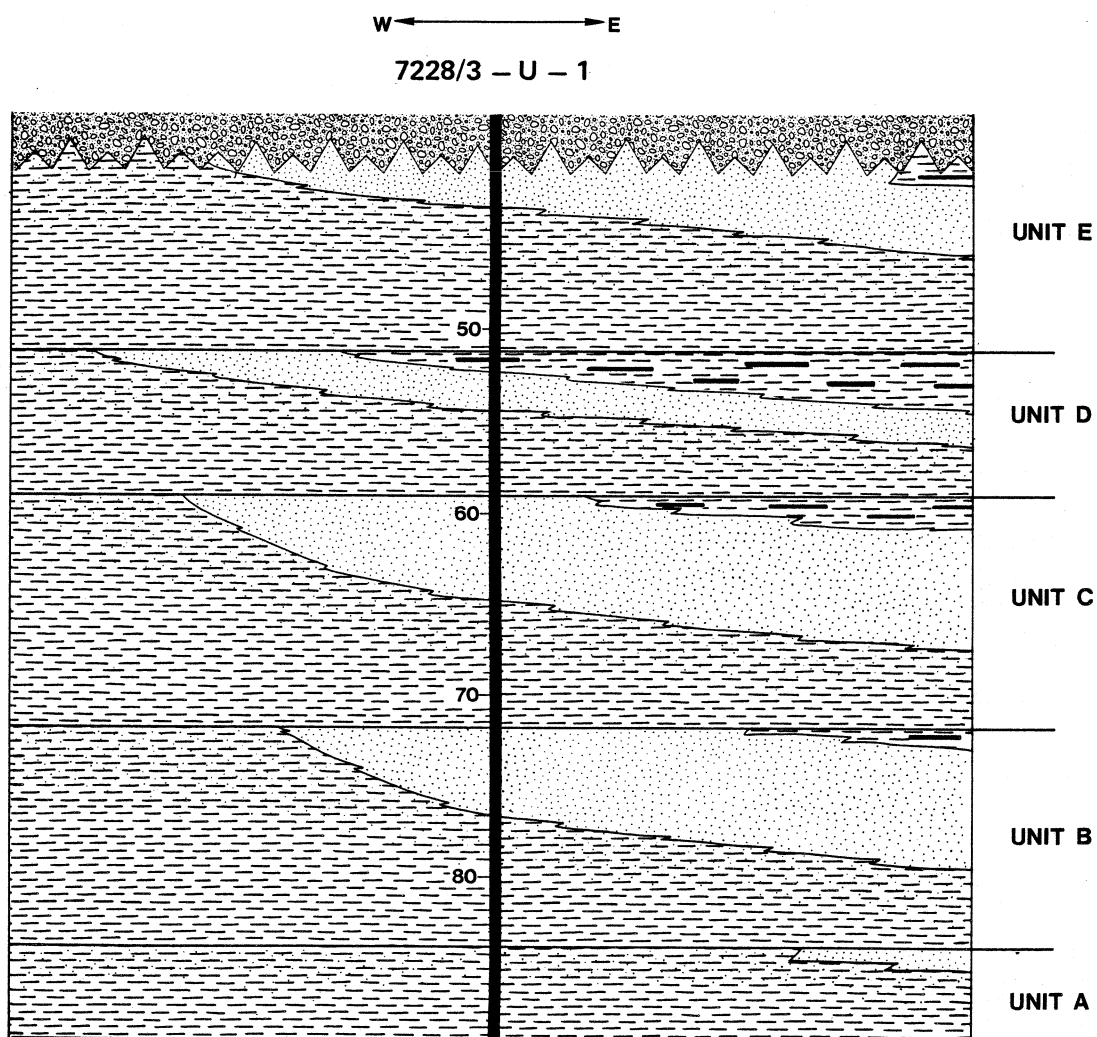


Figure 3.1.3 Diagrammatic chart showing the sedimentological evolution based on the core. Repeated shallow offshore to coastal plain deposits are stacked on each other in a generally regressive environment.

The boundaries between the different units are gradual, except for the boundary between Units D and E. This boundary is developed as an abrupt change from coal to a one meter thick sandstone with intraformational conglomerates (siderite and mudstone clasts). Above the boundary between Unit B and C an about 2 m thick flaser bedded sandstone is developed whereas at the base of Unit D a 35 cm thick bed of alternating sandstones and mudstones occurs.

A few brown, siderite concretions, up to 5 cm x 4 cm, occur particularly in the silty parts. Some siderite occur as filling of the biggest burrows.

Wood and leaf fragments occur very commonly in most of the core. The exceptions are in the upper part of the sandstones where they are more sporadic. A few poorly preserved bivalve fragments are found in each unit. Teeth of reptiles also occur.

Thin section description

The thin sections studied are from high porosity sandstones and one siltstone. Despite the high porosities observed (Table 3.1.1), the vertical permeability is usually low, mainly due to horizontal laminae of silty material rich in sideritic pellets. Another permeability reducing factor is authigenic clay formed by decomposition of feldspar.

The sandstones are grain supported and very fine to fine-grained, usually the grain diameter is 120-200 μm . The major clastic constituents are quartz, rock fragments, feldspars and mica. Unstructured organic material, either opaque or partly transparent reddish brown, is common in most samples.

The quartz occurs both as monocrystalline and polycrystalline grains, the latter showing metamorphic textures as lobate grain boundaries and schistosity.

Table 3.1.1 Porosity and vertical permeability of sandstone samples from core 7228/3-U-1 measured by GECO.

SAMPLE (m)	PERMEABILITY (mD) VERTICAL		POROS HE	GRAIN DENS. G/CC
	KA	KEL		
52.95	26.1	21.1	24.6	2.67
54.75	3.38	2.14	28.6	2.69
59.80	NMP		26.2	2.67
60.70	NMP		26.8	2.71
62.45	0.082	0.041	20.8	2.67
70.10	0.123	0.062	24.7	2.68
71.20	NMP		30.5	2.69
72.10	NMP			
73.00	3.81	2.46	29.1	2.69
73.90	1.20	0.739	27.6	2.70
75.95	48.0	40.6	30.3	2.70
76.90	50.5	42.8	30.0	2.69
78.05	9.72	7.13	29.2	2.70
84.33	0.113	0.059	23.0	2.68
86.23	0.04	0.02	8.9	2.72

Abundant feldspar grains occur. These are usually illitized, showing lots of small illite crystals on cleavage planes and along rims. Where carbonate cementation has taken place, the feldspar is commonly partly replaced by the cement.

Both muscovite and biotite are present. The former is often altered along the rim, forming illite and kaolinite, but commonly the major part of the grain is unaltered. The biotite, however, is commonly partly replaced by micritic siderite. The biotite is often observed as a "ghost" within a cluster of the authigenic siderite.

The porefilling clay minerals illite and kaolinite is mainly formed by decomposition of feldspar and occasionally muscovite. The kaolinite is observed as porefilling booklets and partly pseudomorphosed muscovite, while illite seems to coat clastic grains. Both reduce the macroporosity and the permeability of the sandstones.

The decomposition of feldspar also produce excess silica, and silica cement is seen both as small amounts of overgrowth cement on clastic quartz grains, and as cherty cement.

Carbonate cement is sparry, poikilotopic calcite with a patchy distribution. The patches may be several centimetres across and give the rock a mottled appearance where the more permeable sandstones in between form a three dimensional network. As described above, siderite is also present as pseudomorphs after biotite and as pellets.

The silty and finer grained laminae observed in the thin sections are enriched in mica, organic material and microcrystalline siderite which decrease the vertical permeability.

3.1.4 X-ray diffraction analysis

Fifteen samples were chosen for X-ray diffraction analyses from this core (Table 3.1.2). The core consists of laminated, very fine to fine-grained sandstones and siltstone with variable amounts of clay matrix, which is also indicated by the X-ray diffraction analyses.

Table 3.1.2 Mineralogical composition (relative wt%) of samples from core 7228/3-U-1.

SAMPLE (m)	SMEC	MIX	I/M	CHL	KAO	QTZ	ALK	PLAG	CAL	DOL	SID	APA	PY
42.90	1.0	4.0	7.0	2.0	10.0	45.0	11.0	14.0	2.0	0.0	3.0	0.0	1.0
52.70	3.0	6.0	4.0	4.0	16.0	32.0	10.0	24.0	2.0	0.0	0.0	0.0	0.0
58.79	1.0	6.0	21.0	7.0	21.0	24.0	0.0	17.0	0.0	0.0	1.0	0.0	2.0
64.23	2.0	5.0	8.0	9.0	19.0	29.0	0.0	27.0	tr	0.0	1.0	0.0	tr
66.38	1.0	6.0	10.0	7.0	16.0	30.0	2.0	17.0	tr	tr	9.0	0.0	1.0
67.40	1.0	10.0	15.0	13.0	22.0	19.0	5.0	14.0	0.0	0.0	tr	0.0	1.0
68.86	1.0	3.0	11.0	13.0	25.0	25.0	4.0	15.0	0.0	tr	2.0	0.0	tr
70.81	tr	4.0	8.0	9.0	23.0	30.0	3.0	20.0	0.0	tr	3.0	0.0	tr
71.60	1.0	13.0	27.0	7.0	11.0	34.0	3.0	2.0	tr	tr	tr	0.0	1.0
76.05	tr	4.0	4.0	5.0	21.0	11.0	2.0	10.0	28.0	0.0	13.0	0.0	1.0
79.28	2.0	6.0	14.0	15.0	32.0	19.0	0.0	12.0	0.0	0.0	tr	0.0	tr
80.32	1.0	3.0	10.0	10.0	20.0	28.0	8.0	17.0	0.0	tr	1.0	1.0	tr
82.31	1.0	3.0	13.0	12.0	22.0	29.0	tr	19.0	tr	0.0	1.0	0.0	0.0
83.04	0.0	4.0	15.0	23.0	12.0	26.0	1.0	18.0	0.0	tr	0.0	0.0	tr
85.08	2.0	4.0	4.0	9.0	18.0	28.0	tr	26.0	0.0	0.0	0.0	0.0	0.0

Most samples contain 40 wt% or more clay minerals including clastic micas and less than 60 wt% quartz and feldspars. Exceptions are the medium-grained sandstone samples at 42.90 m and 52.70 m. These also contain abundant alkali feldspars.

Compared to the mineralogy of the other cores described in this report, the most striking difference is the high content of albite, i.e. 10 to about 30 wt% in all the whole rock samples.

Sample 76.05 m is a carbonate concretion cemented by calcite and siderite.

3.1.5 Petrophysics

Natural γ -radiation

The total natural γ -activity from this core only shows small variations as expected from its quite uniform mineralogy (Figure 3.1.1). The highest activities are observed over the intervals 42-49 m, 57-60 m, 65-71 m and 79-88 m, which are due to sand beds, occasionally carbonate cemented, alternating with silty laminated very fine-grained sandstone.

The uranium content is low. The apparent large variations in radiation from uranium are partly effects of the scale of the horizontal axis, but repeated measurements confirm the results.

Sound velocity measurements

The horizontal sound velocity measurements performed on this core give a mean value of 2340 ± 150 m/s (Table 3.1.3). The black coaly claystone at 52.15 m and the strongly carbonate cemented sandstones at 75.00 m and 76.12 m are excluded from the calculation of the mean value. The sound velocity below 60 m is generally higher than above this depth, probably due to a higher degree of cementation.

Table 3.1.3 Horizontal sound velocity (v) in samples from core 7228/3-U-1.

Depth (m)	v (m/s)	Lithology
42.66	2130	Medium-grained sandstone
43.40	2090	Laminated, silty sandstone
44.30	2240	"
45.25	2250	"
46.10	2260	"
48.25	2230	"
49.00	2200	"
50.25	2240	"
51.25	2250	Fine-grained sandstone
52.15	1830	Black claystone
53.20	2300	Fine to medium-grained sandstone
54.20	2350	"
55.15	2310	Fine-grained sandstone
56.10	2120	Very fine-grained sandstone
57.00	2280	"
57.90	2270	Siltstone
59.00	2250	Clayey siltstone
60.00	2360	Fine-grained sandstone
61.00	2540	"
62.00	2560	"
63.00	2390	"
63.90	2410	Sandy siltstone
65.00	2480	"
65.95	2360	Very fine-grained sandstone
66.65	2430	Silty sandstone
68.00	2540	"
69.10	2470	"
70.00	2440	Very fine-grained sandstone
71.15	2380	Fine-grained sandstone
71.90	2410	"
73.05	2210	"
74.08	2160	"
75.00	4040	Fine-grained sandstone, (strongly carbonate cemented)
76.12	3080	"
77.00	2340	Fine-grained sandstone
78.00	2200	"
79.00	2470	Very fine-grained sandstone
80.20	2540	"
81.00	2340	"
82.00	2430	"
83.20	2530	"
84.20	2490	"
85.05	2220	"
86.40	2530	"
87.30	2350	"
88.00	2580	"

3.1.6 PalaeontologyPalynology

42.45-88.71 m: (?middle) Anisian

As a rule for the succession of samples in this well, neighbouring samples tend to differ from each other rather than showing close resemblance. The general impression, however, is of facies controlled assemblages which can be dated to the (?middle) Anisian. We distinguish four regressive marine intervals, two of these separated by an interval of continental deposits.

The dominant palynomorph groups throughout are bisaccates and Aratrisporites spp. The marine intervals contain the richer more varied assemblages including also stratigraphically restricting evidence (Figure 3.1.4).

The richer assemblages include Chordasporites spp., Illinites chitonoides, Staurosaccites quadrifidus, I. trivisicus, Lunatisporites pellucidus, L. noviaulensis, Podosporites amicus, Protodiploxypinus gracilis, P. ornatus, Protohaploxypinus spp., Triadispora aurea, I. obscura as well as a variable proportion of indeterminate bisaccate pollen.

The dominant spores are Aratrisporites spp., A. macrocavatus, A. palettae, A. scabratus, A. tenuispinosus, Cyathidites minor and other laevigate forms. The spores of the marine intervals include Calamospora tener, Conbaculatisporites hopenensis, Nevesisporites fossulatus, N. limulatus, Baculatisporites spp., B. comaumensis, Perotriletes spp., Duplexisporites gyratrus and from 70.89 m Kraeuselisporites sp. A and K. dentatus.

Rare forms with a possible local stratigraphic potential are cf. Dyupetaleum vicentinense, cf. Enzonalasporites spp., cf. Duplicisporites spp., cf. Heliosaccus spp. and Anapiculatisporites spiniger. Verrucosisporites sp. A seems to be important for the local zonation of the Anisian, but is poorly known outside our area.

CORE 7228/3-U-1

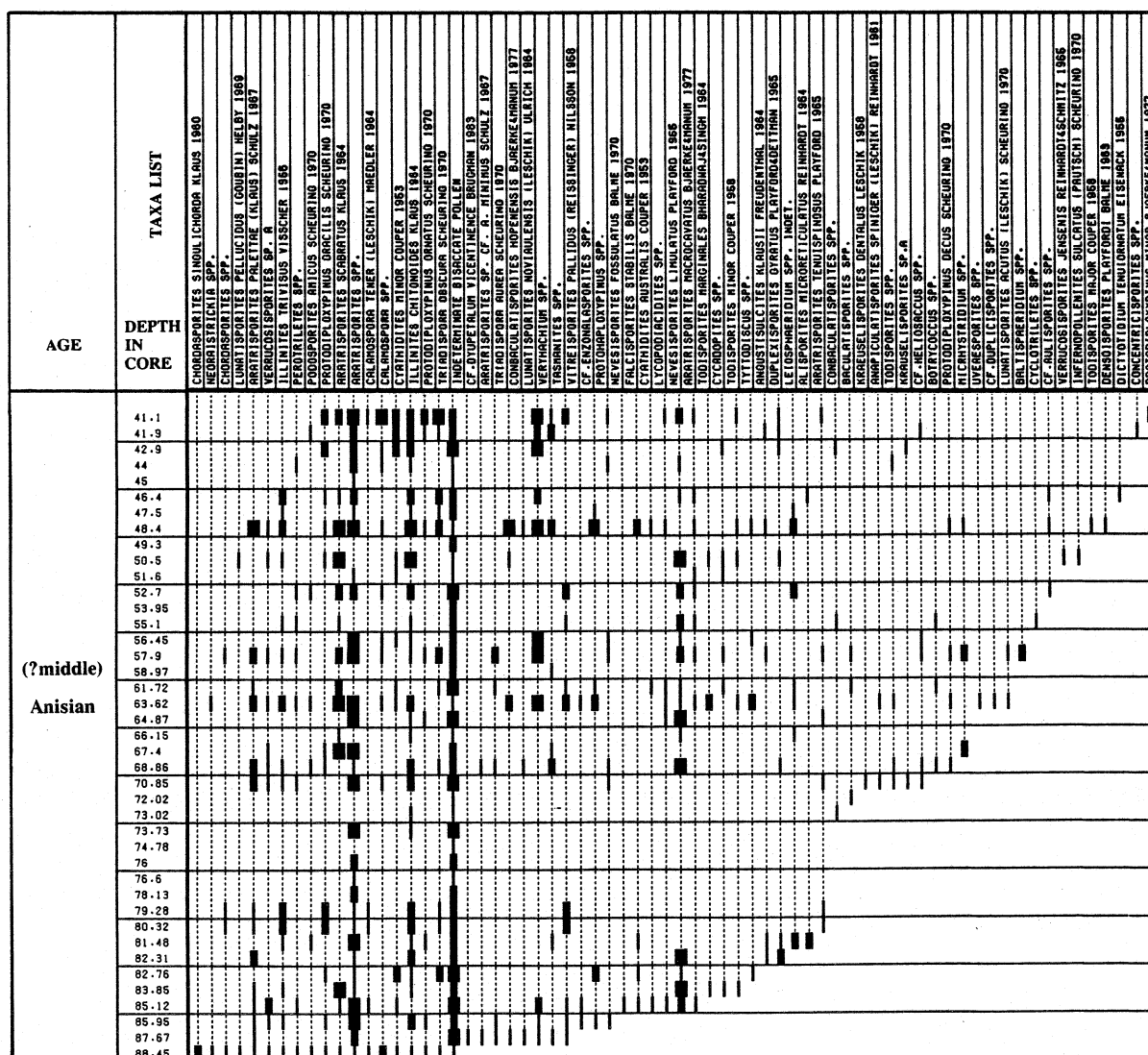


Figure 3.1.4 Revised palynological range chart, core 7228/3-U-1.

According to our local palynofloral evidence in absence of Ovalipollis pseudoalatus we favour an (?middle) Anisian age for the assemblage. This is in agreement with Fisher (1979) who found no pronounced palynofloral break at the Anisian - Ladinian boundary.

The assemblages seem derived from floras growing under humid conditions according to the principles outlined by Visscher & Brugmann (1981).

Visual kerogen

The numerous wood and leaf fragments observed by the naked blue eye in this core are the main constituents also in the organic residues remaining after palynological preparation. Woody tissues as well as their degradational products are preserved, in some samples together with well preserved large cuticles. The productivity of palynomorphs varies relative to the amount of wood in the sample.

In some samples there are biodegradation features ascribed to faunal activity and to prolonged exposure in air. Palynomorphs of such layers have a grey colour. They are often thin-walled, their cavities may have collapsed previous to final deposition, and they have a "crumbled" look.

TAI is 3 to 3.5 on a 1-10 scale equivalent to R_o 0.3-0.4. Pollen grains from the same sample may be variably coloured probably due to their different predepositional history.

Microfauna

Samples at 41.90 m and 87.00 m are barren.

3.1.7 Organic geochemistry

Seven canned samples were analysed for headspace and occluded gas. The hydrocarbon concentrations in the headspace gas were extremely low, because the volume of the samples was relatively small relative to the headspace volume. Therefore, the headspace gas data should be considered as an estimate rather than as exact figures. This applies to all canned samples taken on this cruise.

A low hydrocarbon gas concentration is observed between 44 and 51 m depth, but increases between 51 and 64 m depth by a factor of 1000. (Figure 3.1.5). This is mainly due to an increase in the headspace gas which consists of pure methane. As neither n-butane nor C_{5+} -hydrocarbons were detected in the occluded gas, the wetness for the sum of the gas fractions is quite low. Gas ratios and carbon isotope values of the adsorbed gas nevertheless indicate a thermogenic source at oil-window maturity.

Most of the samples from this predominantly sandy/silty core contain only between 0.5 and 1 % total organic carbon. The occurrence of coal (at 51.60 m), small plant fragments (58.79, 47.78 m), and of mm-thin laminae of carbonaceous matter causes locally stronger variations. (Figure 3.1.6).

The majority of the samples is characterised by a hydrogen index between 50 and 100 mg HC/g TOC and by a relatively high oxygen index (8-168 mg CO₂/g TOC) which indicates a hydrogen-poor kerogen of type III and IV (Figure 3.1.7). The pyrolysis-gas chromatograms show strong peaks of benzene, toluene, lesser amounts of xylenes, but also relatively well developed alkene/alkane doublets which, however, rapidly decrease in intensity with increasing C-number and hardly extend beyond C₁₅. The pyrolysate of the coal at 51.60 m shows doublets up to C₂₉ which may indicate a more hydrogen-rich material although this is not reflected in the hydrogen index (24 mg HC/g TOC). Based on the screening analyses, the rocks are considered to have no potential for generating liquid hydrocarbons. This is consistent with the value for the petroleum potential as expressed by Rock-Eval S1+S2, which rarely exceeds 0.5 mg HC/g rock.

Vitrinite reflectance values of 0.31 and 0.35 %Ro were obtained at 51.60 and 82.31 m, respectively. A sample at 74.78 m gave a fairly reliable value of 0.40 %Ro. This core may therefore be slightly more mature than the Upper Triassic core 7227/8-U-1. A second population of reworked vitrinite showed reflectance values between 0.5 and 0.9 %Ro, which could explain that somewhat high Tmax values were obtained from this core (around 435°C). The value of 475°C at 64.23 m coincides with an unusually high oxygen index and is presumably an artifact caused by the low S2 yield at this depth.

Six samples from this core were extracted (at 51.60, 58.79, 67.40, 74.78, 76.05, and 85.08 m). Except for the coal sample at 51.60 m, all samples yielded low concentrations of EOM due to their low TOC content (Figure 3.1.8). Also the organic matter itself shows a poor extractability which, in connection with the low hydrocarbon content of the EOM (<20%) and the low saturates/aromatics ratio is typical of an immature rock. These data also speak against significant enrichments of migrated hydrocarbons in this core.

The molecular composition of the saturated hydrocarbon fractions vary within wide limits. The proportion of unresolved compounds in the sterane-triterpane region is quite small considering the low maturity of the rock. Most n-alkane distributions are bimodal. High proportions of nC_{21} - nC_{33} alkanes with a pronounced odd-over-even predominance were observed at 51.60, 67.40 and 85.08 m while the nC_{17} - nC_{21} alkanes predominate at 58.79 and 74.78 m depth. The gas chromatogram of the 76.05 m sample, although slightly bimodal, shows a broad n-alkane population ranging from nC_{16} to nC_{31} . These variations in the overall shape of the chromatograms goes along with a variation in the pristane/phytane ratios (0.8 - 5.0) and may therefore reflect differences in the composition of the source material (which is dominated by land plant-derived organic material) as well as in the depositional environment.

The coal-lean samples show pristane/ nC_{17} ratios between 0.9 and 1.7 and CPI values between 1.2 and 1.5 which is not contradictory to the vitrinite reflectance of the samples (Figure 3.1.9). The relatively high pristane/ nC_{17} ratios at 51.60 and 67.40 m are obviously due to the increased abundance of coal in these rocks. The isotope profiles for these two extracts show a good correspondence.

The gas chromatograms of the aromatic fraction show large 'humps' of unresolved heavy aromatics which are often found in immature to early mature extracts. Phenanthrene is the dominating compound among the 2- and 3-ring aromatics, except for the coal extract, which contains a relatively higher amount of di- and trimethylnaphthalenes. The methylphenanthrenes are dominated by the 9- and 1- isomers, which possibly suggests low maturity.

The saturated fractions of two samples at 51.60 (coal) and 76.05 m, respectively, were analysed for biomarkers. Only the coal sample gave reasonable mass chromatograms. The composition of the triterpanes as well as of the steranes suggests that the extract from this coal has a lower maturity than all the other extracts from the four cores. This conflicts with the vitrinite reflectance values, and may be difficult to explain exclusively by a difference in organic facies.

The rocks from this core, although containing a fair amount of organic matter, are considered to have only a marginal potential for the generation of liquid hydrocarbons. In case of high maturity, however, the coal-rich zones could produce some gas. The organic matter of this core appears to be slightly more mature than that from the other Triassic core 7227/8-U-1. The variation in the composition of the extracted hydrocarbons may possibly be attributed to variations in the source material.

C1-C4 HYDROCARBONS C5+ HYDROCARBONS WETNESS (%)

Abundance (ul/kg rock) Abundance (ul/kg rock)

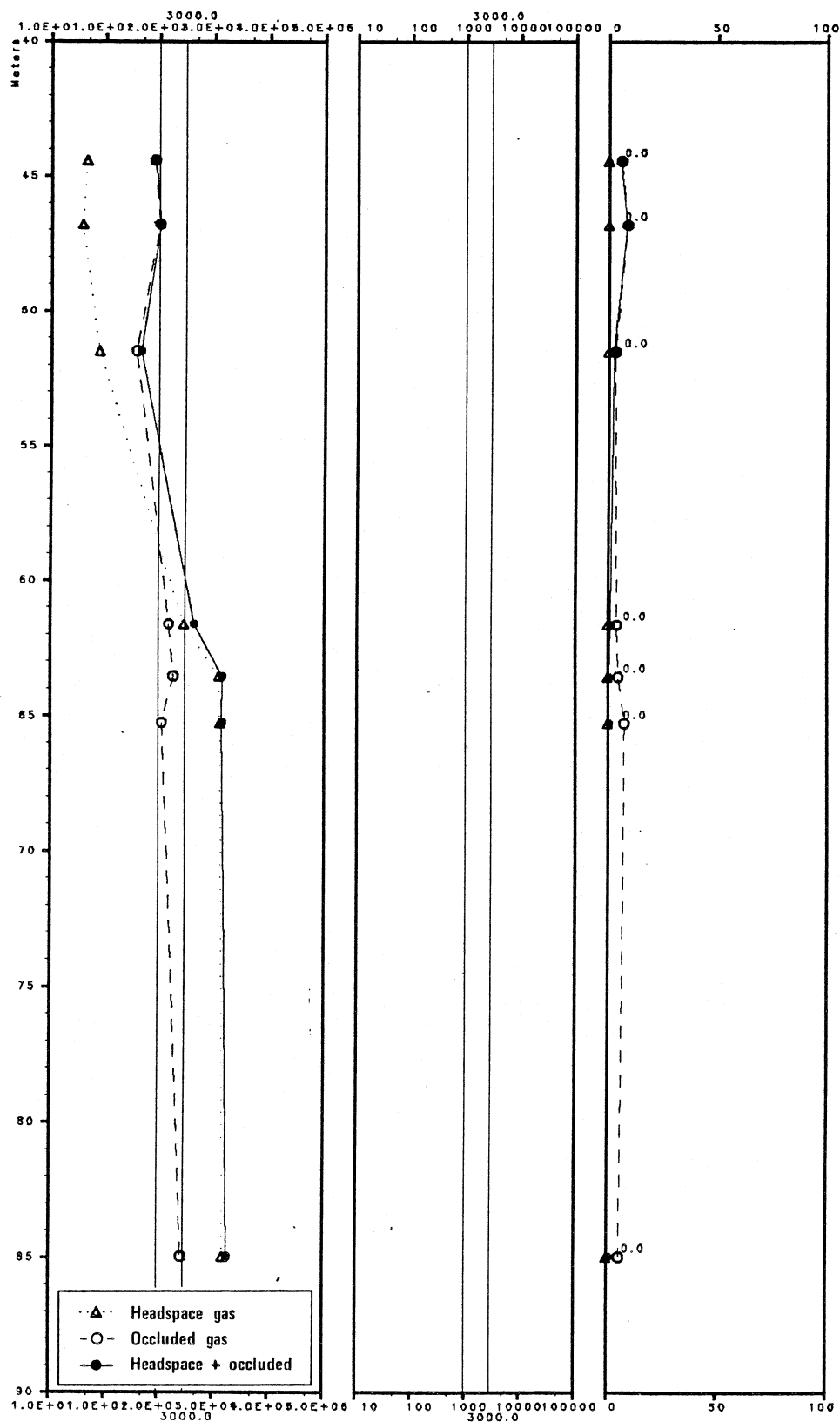


Figure 3.1.5 Yield and composition of headspace/occluded gas of core 7228/3-U-1.

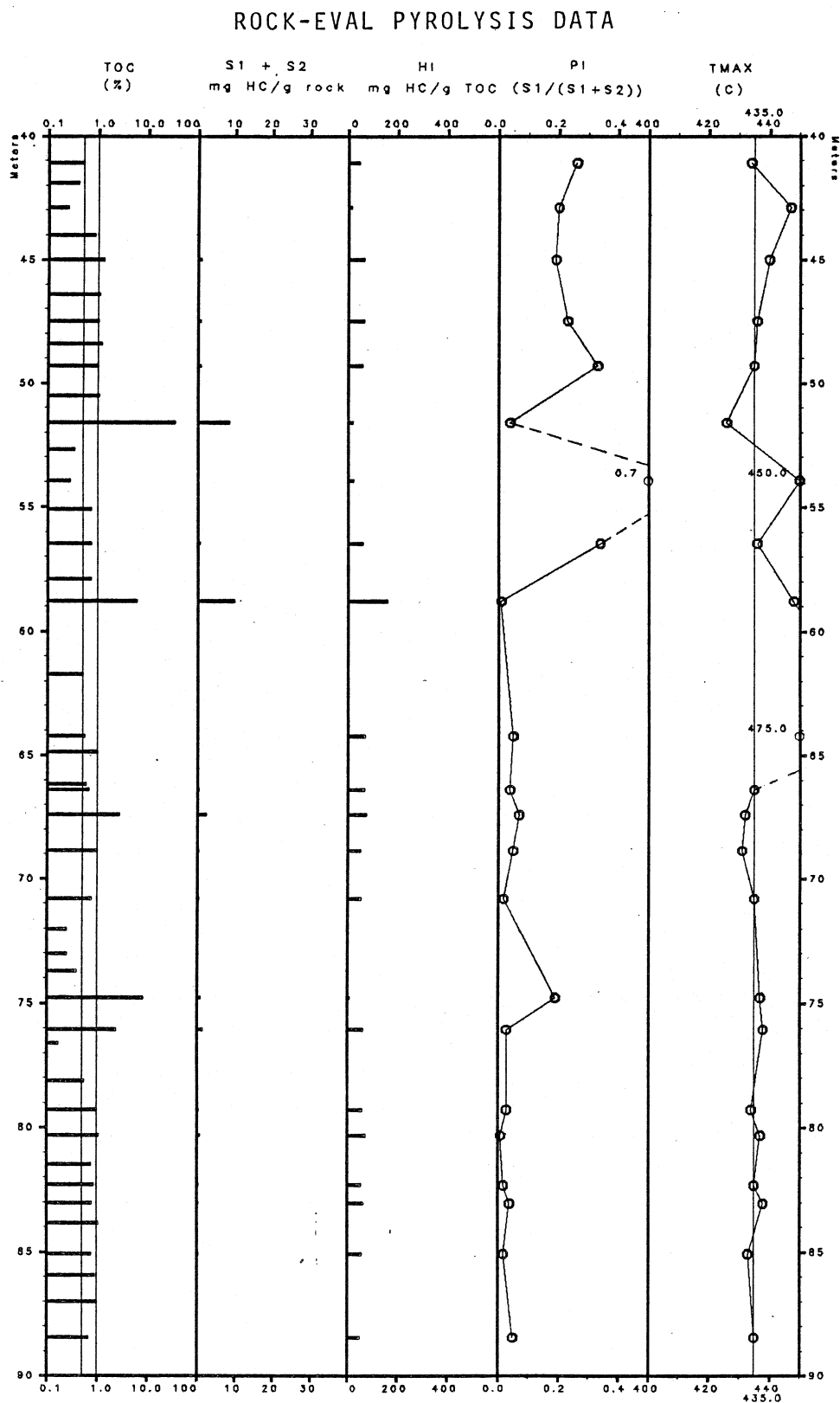


Figure 3.1.6 Total organic carbon content and Rock-Eval data of core 7228/3-U-1.

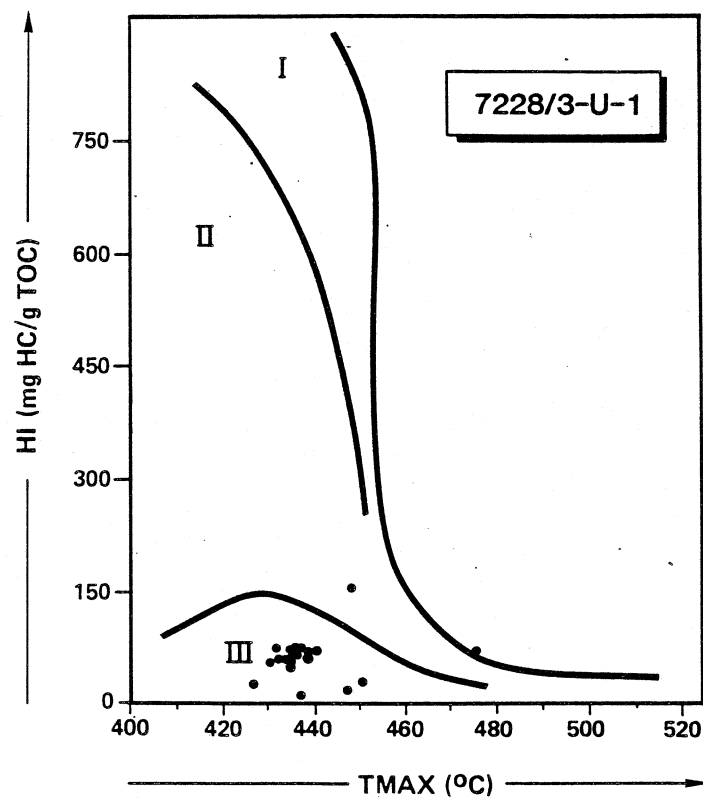
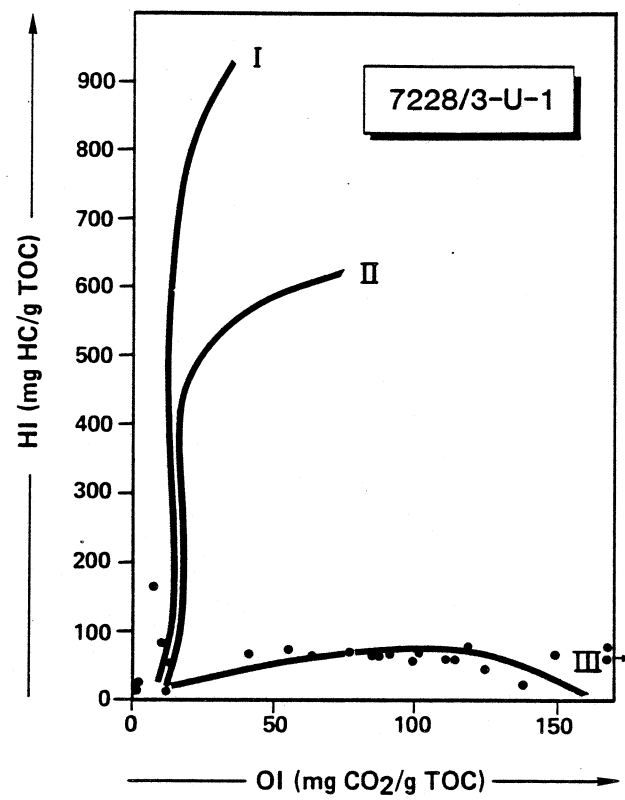


Figure 3.1.7 a Rock-Eval hydrogen index vs. oxygen index for core 7228/3-U-1.
b Hydrogen index vs. Tmax for core 7228/3-U-1.

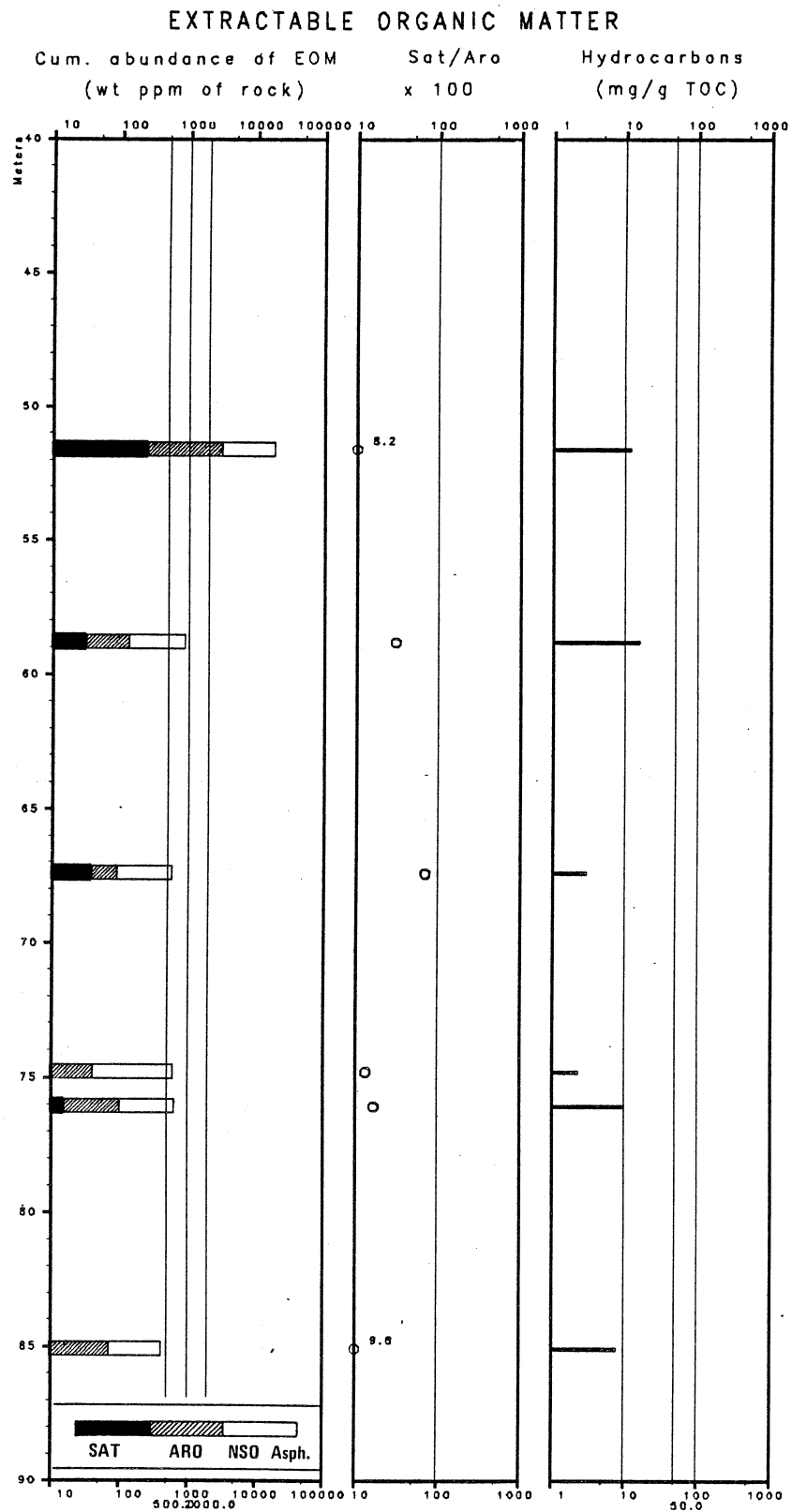


Figure 3.1.8 Extract data for core 7227/3-U-1.

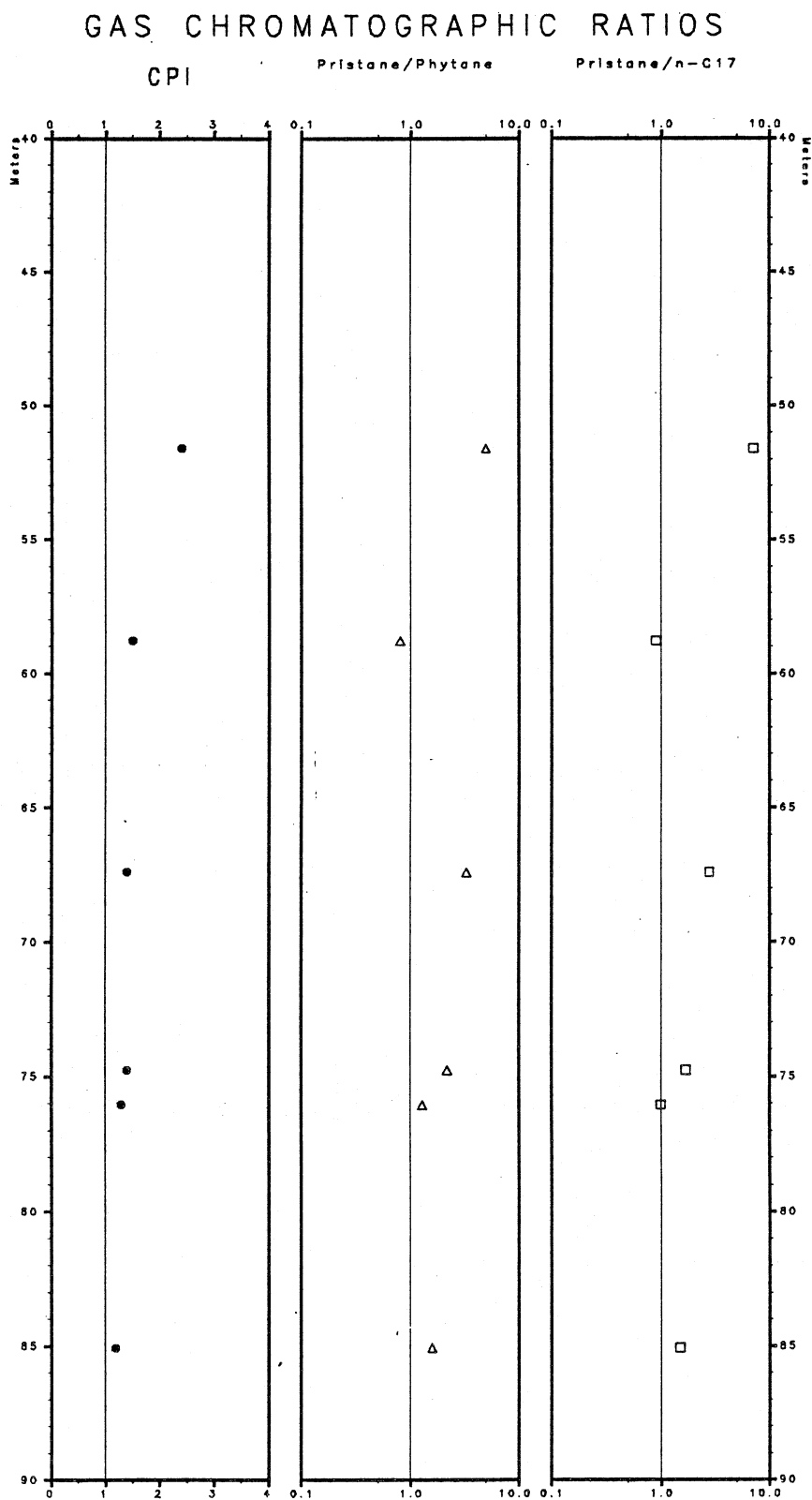


Figure 3.1.9 Compound ratios from gas/chromatograms of saturated hydrocarbon fractions from core 7228/3-U-1.

3.1.8 Depositional environment

The core logs in Appendix A.5 and Figure 3.1.1 sum up the interpretation of the core. These upper Anisian to lower Ladinian rocks are approximate lateral equivalents to the Dia-Structure cores U-7 and/or U-9 (IKU Report 21.3420.00/04/86).

Marine conditions are reflected in most of the core by an assemblage of acritarchs including Veryhachium spp., Tasmanites spp., Dictyotidium tenuiornatum, Micrhystridium spp. and leiospheres. Terrestrial palynomorphs and woody material are far more common than plankton and suggest marginal marine depositional environments.

We apply the model gained from Unit D in the interpretation of the other coarsening upward sequences. This is shown in Figure 3.1.3. Unit D most likely reflects regression from shallow offshore marine to coastal plain environment. The unit shows a transition from bioturbated siltstones with graded sandstone beds to strongly bioturbated silty sandstones. This part probably was deposited during alternating periods of slack water mud accumulation and sand accumulation during storms, in lower shoreface to shallow offshore environments. During periods of slack water, the sediments were almost completely mixed by predominantly sediment-feeding organisms as well as some suspension feeding organisms.

The abruptly overlying fine to mediumgrained sandstones with horizontal and ripple lamination with vertical burrows mainly made by suspension feeding organisms, probably represent upper shoreface deposits. Such deposits accumulate in areas dominated by wave surges during storms and wave-generated currents. The uppermost part of the sandstones may represent foreshore sediments deposited prior to development of a coastal plain environment where accumulation of organic material took place.

Although the general trends are fairly similar in the other units, there are some differences. Neither Unit B nor C have coastal plain deposits on top of the units. The development of the shallow offshore to lower shoreface deposits is thicker in these units indicating deeper

water deposits while upper shoreface deposits are thicker in Unit B and C than in Unit D, and suggests higher energy shore line than in Unit D. Unit A shows no upper shoreface or shallower deposits. All this indicates that they starts their deposition further offshore than Unit D, and that Units A to D represent regressive stacking of repeated episodes of progradation of shoreline, as shown in Figure 3.1.3.

Unit B and E contain some intraformational conglomerates close to the boundary between the lower and upper shoreface deposits. These may be fillings of rip current or tidal channels. The rip current interpretation is favoured.

The regressive sequences in this core can be due to eustatic sea level changes and/or salt tectonic episodes. This is further discussed in Chapter 5 (Figure 5.2 and 5.3). However, we find it hard to believe that salt tectonic episodes have caused the repeated regressive/transgressive events observed in the core. These more likely are due to eustatic sea level changes. But synsedimentary salt movements may also have affected the erosion in the source area.

3.2 7227/8-U-1

3.2.1 Summary

40.9 m of sedimentary rocks were drilled between 30.65 and 71.55 m below sea floor with a core recovery of 36.1 m.

Three significant seismic reflectors were recognized and may correspond to lithological changes at 55, 47.5 and 39.4 m (Figure 3.2.1). The interval below 55 m (Unit A) is a complex lithological unit with reddish mottled mudstones, and siderite pisolites of tidal flat and coastal plain origin. Above the reflector marine strongly bioturbated sandy siltstone units of Norian to lower Rhaetian age occur (Units B and C).

The middle seismic reflector is not easily recognized in the core, but may be represented by the boundary between the sandy siltstone unit and more sandy deposits (Unit B/C boundary). The palynological recovery does not allow us to assign any break in age to take place at this boundary, but there is evidence of a stronger marine influence above 47.75 m.

The next seismic reflector is the strongest one of the three and is represented in the core by a sharp transition into a coarse clastic unit interpreted as a channel fill (Unit D). A 30 cm thick very coarse conglomerate occurs at the base followed by a medium to coarse-grained sandstone with intraformational conglomerates. At 33.75 m a conglomerate with sandstone clasts comprise the transition to a bioturbated fine to medium-grained marine sandstone of Toarcian age. The conglomeratic sandstone unit contains some long-ranging palynomorphs. We interpret the recorded Triassic species as reworked. It is not possible to distinguish the probable channel fill conglomeratic sandstone from the overlying marine Toarcian sandstone in the seismic data.

The rocks from this core are poor in organic matter (TOC content usually below 0.5 %) and contain kerogen of the Rock-Eval types III and IV and only sometimes type II-III. The penetrated sequence is therefore not expected to have any significant hydrocarbon generation potential.

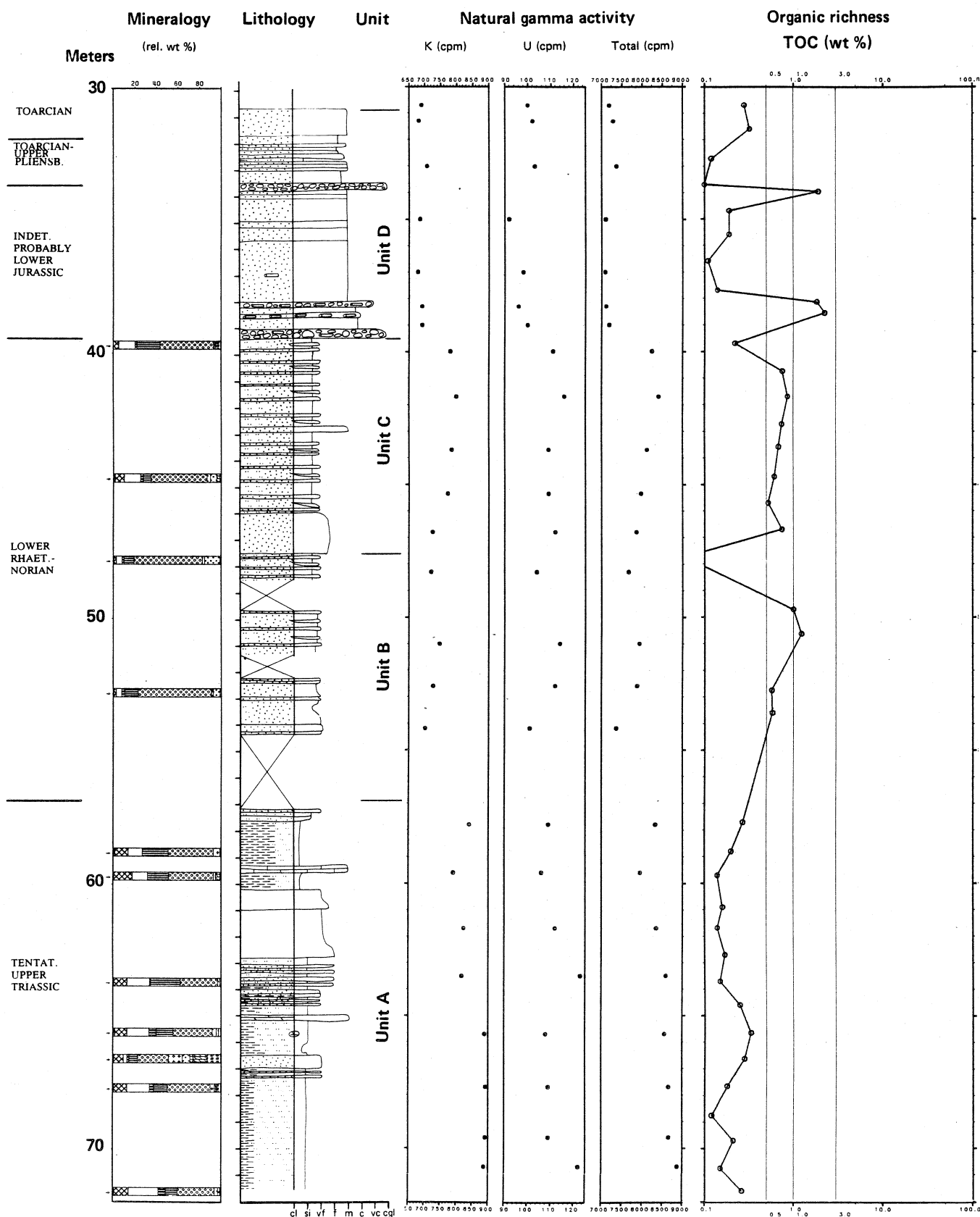


Figure 3.2.1 Summary figure of core 7227/8-U-1.

The rocks are thermally immature (vitrinite reflectance 0.28-0.34 %Ro) and do not contain appreciable amounts of non-indigenous hydrocarbons. The composition of saturated hydrocarbons and biomarkers does, however, not speak against the possibility that small traces of hydrocarbons derived from a more mature source may be present in the rocks.

3.2.2 Seismic interpretation

The Quaternary sediments at this location are 30 m thick. This core covers an uncomplete Norian to Toarcian section, and several significant seismic boundaries have been penetrated (Figure 3.2.2).

The seismic record from the Triassic interval is complex at the drill site. This may relate to syn-depositional salt tectonics in the Triassic and also later faulting. Tracing of the seismic reflectors from the basin to the drill site is not straight forward. Alternatives to the interpretation presented here may therefore exist.

The most significant hiatus in this well is at 40 m below sea bed. Our interpretation relates reflector ϵ to this unconformity. This is both a truncational and onlapped sequence boundary. Erosion of the paleo-surface has exposed older bedrock and a precise dating of the fluvial sequence above the boundary cannot be done in the corehole.

Two other sequence boundaries (reflector ζ and η) have been penetrated. These seismic boundaries have candidates in the core at 47.5 m and at ca. 55 m. The lower sequence boundary, η , is the most significant and corresponds to a major break in the core section, where continental deposits (Unit A) are overlain by marine sediments (Unit B). Reflector ζ probably corresponds to the boundary between Unit B and Unit C at 47.5 m.

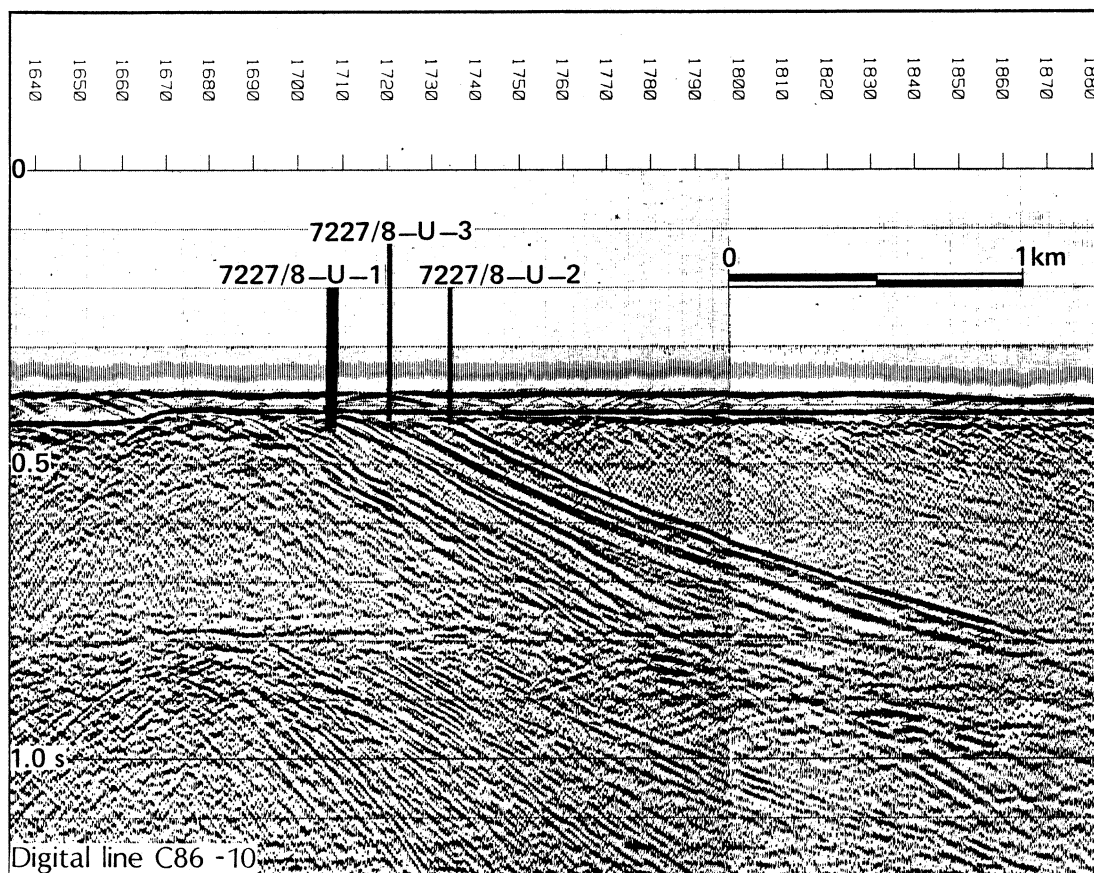


Figure 3.2.2 Digital seismic section from drill site 7227/8-U-1. The reflectors ϵ , ζ and η have been correlated with the core.

3.2.3 Core description

40.9 m of sedimentary rocks were penetrated between 30.65 and 71.55 m below sea floor. The intervals between 57.15 m and 54.35 m, 52.20 m and 51.30 m and 49.65 m and 48.55 m were lost during drilling.

The core is divided in Units A, B, C, D and E as shown in Figure 3.2.1. The boundary between Units A and B is located somewhere in the interval without recovery between 57.15 m and 54.35 m. The boundary between Units B and C is at the base of a medium grey matrix-supported medium-grained sandstone at 47.55 m. The boundary between Units C and D is placed at 39.40 m, at the base of a light grey polymict conglomerate.

Unit A is characterized by a complex alternation between red and greyish green mottled mudstones and sandstones. The lower 5 m consist of a sometimes laminated reddish brown to bluish grey siltstone. Thin section studies show that the reddish colour is caused by disseminated hematite. The rock is also very rich in kaolinite and contains some few mm long fibrous pyrite pseudomorphs of marcasite. One area is cemented by brown siderite. The unit is overlain by a 75 cm thick strongly bioturbated calcite cemented sandstone with up to 1 cm thick graded, laminated to low angle ripple laminated fine-grained sandstone. The bioturbation is dominated by horizontal burrows about 0.5 cm in diameter, but some vertical burrows up to 2 cm in diameter occur. Fibrous pyrite-replacements of marcasite also occur.

The sandstone is gradually overlain by a brownish to greyish green mottled bioturbated mudstone with a 20 cm thick medium-grained siderite bed with some siderite grains in the overlying mudstone. Thin section studies show that the siderite forms up to about 0.4 mm large grains that have grown diagenetic in situ by consuming the mudstone (Figure 3.2.3). The siderite has a dusty appearance caused by clay minerals and clastic grains. The siderite has a submicroscopic fibrous texture with some inclusions of microcrystalline siderite.

The greyish green burrows may be filled either by sandstone or siderite. Some imprints of bivalve shells also occur. Fibrous pyrite replaces marcasite concretions which are up to 1 cm in diameter.

The mudstone is overlain by an alternation between few mm to 15 cm thick either laminated or ripple-bedded fine-grained sandstone with strongly bioturbated predominantly greyish green mudstones, sometimes reddish brown mottled. Some pyrite replacements of marcasite occur.

A 10 cm thick brown siderite bed occurs at 64.25 m. In thin section the siderite proves to consist of in situ crystals up to 0.5 mm in diameter (Figure 3.2.4). They sometimes consist of dusty microcrystalline siderite with common inclusions of clastic grains. Others may show a core surrounded by concentric a few mm to 20 μ m thick rings caused by alternation between clear microcrystalline siderite and dark grey to black zones. They show striking similarities to pisolites. Other grains

may show the fibrous texture described from the siderite at 65 m. Almost every siderite grain has an about 0.05 to 0.15 mm thick zone of radial submicroscopic fibrous siderite. The outermost up to 0.05 mm zone of the siderite consists of clear siderite crystals which show a zoned extinction. This siderite probably has formed by recrystallization of the fibrous siderite. Inclusions of clastic grains occur in all the siderite types.

A 2.5 m thick light grey fining upward fine to very fine-grained ripple laminated sandstone overlies the underlying rocks abruptly. The sandstone is divided in two parts which are separated by a very strongly bioturbated interval. Some mainly vertical burrows about 5 mm wide also occur, particularly in the uppermost 10 cms of the sandstone.

The sandstone is overlain by an about 3 m thick bluish grey silty claystone with a 25 cm thick brown calcite bed at 59.55 m and silt- and sandstones in the uppermost 40 cms. Some brown siderite grains and probable mud cracks occur in the lowest 10 cms of the silty claystone. Such grains also occur just below the calcite beds and the uppermost sandstone beds.

Thin section studies of the brown calcite bed at 59.55 m show that it consists of up to 3 mm large irregular calcite crystals in a mudstone matrix. About 0.1 mm thick branching burrows or root structures are also observed in the mudstone. The burrows are cut by up to 2.5 mm long submicroscopic, clear fibrous calcite crystals that commonly spread out from a diffuse nucleating site. The crystals flower spars (Chafez et al. 1985) may be some inclusions of clastic grains in the calcite.

The fibrous up to 0.3 mm in diameter calcite crystals have inclusions contaminated by micritic calcite inclusions. This calcite is dominant in the lower part of the limestone beds where they probably form a three-dimensional network, while the large fibrous calcite is dominant in the upper part.

Unit B consists of strongly bioturbated silty sandstone with some remains of the original bedding. The up to 3 cm thick very fine-grained sandstone beds may show horizontal lamination and/or low angle ripple-

lamination. In a few cases steeper ripple-laminae occur. Horizontal burrows with a diameter of about 5 mm dominate. However, some commonly pyrite-filled vertical burrows up to 1.5 cm in diameter also occur. Some probable escape burrows are present in the upper part of the unit. No body fossils except some black wood fragments are seen.

Unit C has a 1.5 m thick medium dark grey very strongly bioturbated fine-grained fining upward sandstone in the lower part. The sandstone is overlain by a sandy siltstone with normally less than 2 cm thick laminated to low angle ripple-bedding.

In the lowermost sandstone up to 6 cm x 5 cm large brown siderite concretions are common, while up to 4 cm x 2 cm pyrite concretions occur in the sandy siltstone.

The bioturbation is dominated by nearly horizontal burrows about 5 mm in diameter, but also some vertical burrows occur.

Unit D has a sharp boundary with the underlying sandy siltstone. Its base consists of a 30 cm thick bedded polymict conglomerate. The conglomerate contains sub- to well-rounded predominantly sandstone clasts up to 10 cms in diameter. The clasts are white to light grey fine-grained sandstones, pink sandstones, white coarse-grained sandstone, medium grey siltstone fragment, one mudstone pebble and some black wood fragments. The basal conglomerate is overlain by a speckled calcite-cemented medium- to coarse-grained sandstone with intra-formational conglomerates. It shows horizontal lamination and/or larger scale cross-stratification.

At 33.75 m a conglomerate with sandstone clasts comprises the transition to grey bioturbated bedded medium to fine-grained sandstone with some probable large scale cross-stratification. Horizontal burrows with a diameter of about 5 mm dominate, but some vertical burrows with diameter of up to 2 cm also occur. The bioturbated sandstone contains some poorly preserved bivalve and wood fragments and scattered glauconite grains. Brown siderite concretions occur in the upper part of this sandstone as well.

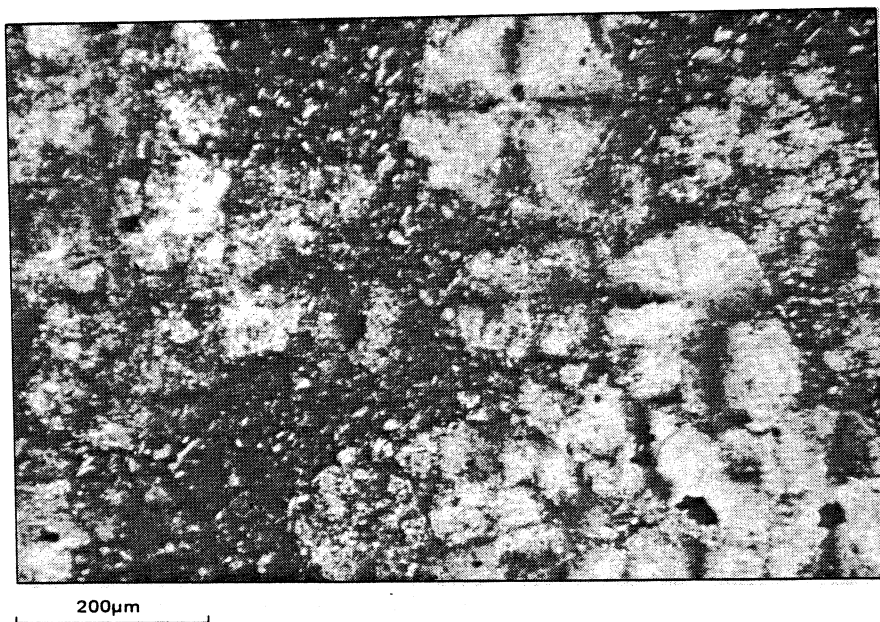


Figure 3.2.3 Radial fibrous to microcrystalline sideritized crystals (?flower spar). 65.10 m.

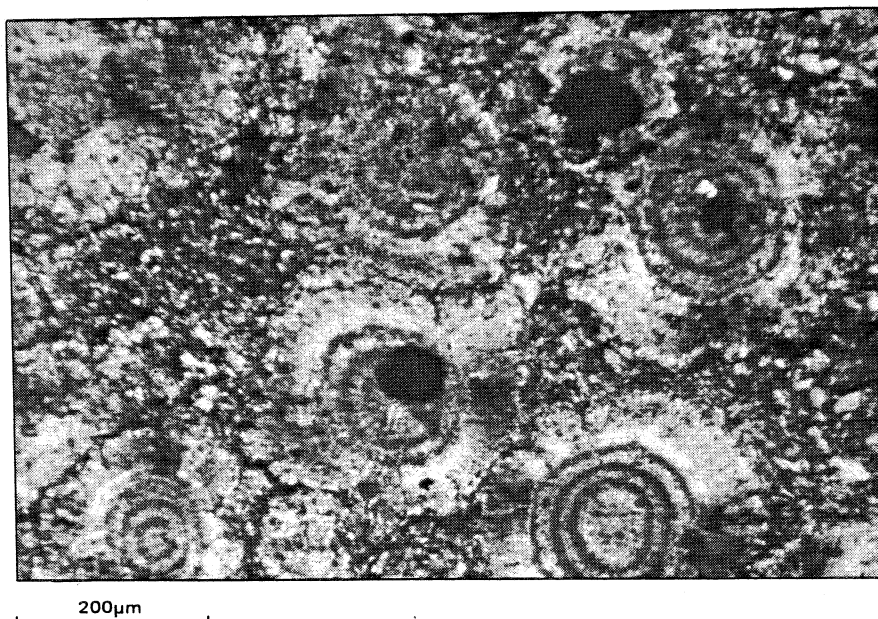


Figure 3.2.4 Sideritized pisolites with inclusion of pyrite (black) and with a radial fibrous cement coat in outermost parts. 64.25 m.

Thin section description

Thirteen samples of sandstones and siltstones from the upper part of this core, i.e. above 58 m, have been studied. In addition, porosity and horizontal permeability have been measured on thirteen samples from 30.70 m - 62.45 m (Table 3.2.1).

The listed porosity and permeability results show large variation. This is mainly due to the sorting and textures of the samples, e.g. reducing factors as pore filling clay matrix and carbonate cement, lamination and bioturbation.

The samples chosen for optical microscopy classify as coarse-grained sandstones to siltstones. The sandstones are mainly moderately sorted, moderately porous and highly permeable with some poorly and very poorly sorted intervals, where finer sand fractions, silt and clay matrix are present as pore filling material, effectively reducing the macro-porosity and the permeability.

The siltstones at 52.50 m and 57.25 m contain well sorted quartz grains and small amounts of clay matrix.

Table 3.2.1 Porosity and permeability in samples from core 7227/8-U-1.

SAMPLE (m)	PERMEABILITY (mD) HORIZONTAL		POROSITY HE	GRAINS DENSITY G/CC
	KA	KEL		
30.70	156	140	19.3	2.69
31.70	86.9	76.0	16.5	2.72
32.70	182	164	14.2	2.69
33.70	<0.04	<0.02	2.0	2.77
34.70	14.4	11.0	6.1	2.68
35.80	1521	1455	13.1	2.68
36.80	82.5	71.9	9.1	2.67
37.65	NMP		15.7	2.67
39.15	<0.04	<0.02	0.7	2.63
46.40	0.04	0.02	2.0	2.85
47.40	NMP		14.1	2.66
60.80	<0.04	<0.02	4.5	2.76
62.45	1.44	0.892	21.5	2.67

The major constituents of the sandstones are quartz, rock fragments and carbonate cement. The rock fragments are quartzitic. The carbonate occurs as patchy, poikilotopic cement (below 32 m) and as scattered rhombohedrons of dolomite (above 32 m). The content of feldspars is low in these samples. The matrix and silt fractions of the sandstones are rich in quartz, mica/illite and kaolinite, whereas mica occurs only in minor amounts in the moderately to well sorted sandstone samples. Glauconite is present above 32 m.

Other constituents observed are small amounts of pyrite, unstructured organic material and trace amounts of zircon, tourmaline and authigenic anatase.

3.2.4 X-ray diffraction analysis

Eleven samples have been analysed by use of X-ray diffraction (Table 3.2.2). They show some variation in mineralogy, mainly reflecting changes in the grain size distribution.

The four uppermost samples are laminated very fine to fine-grained sandstones with high proportions of quartz. The clay mineral content of these samples vary. There is, however, a higher proportion of clastic mica/illite and mixed layered illite-smectite in the two uppermost samples.

The four samples between 58.80 m and 65.64 m are silty claystones with 51 to 63 wt% clay minerals including mica/illite and about 40 to 50 wt% quartz and feldspars; this mineralogy is also observed in the two lowermost samples of clayey siltstones (67.65 m and 71.60 m).

The sandstone at 66.60 m is siderite cemented and also shows a high proportion of pyrite cement.

Table 3.2.2 Mineralogical composition (relative weight %) of samples from core 7227/8-U-1.

SAMPLE (m)	SMEC	MIX	I/M	CHL	KAO	QTZ	ALK	PLAG	CAL	DOL	SID	APA	PY
39.66	tr	5.0	15.0	2.0	21.0	50.0	1.0	1.0	0.0	0.0	tr	0.0	5.0
44.68	2.0	8.0	15.0	3.0	7.0	52.0	3.0	6.0	0.0	0.0	3.0	0.0	1.0
47.75	1.0	2.0	5.0	2.0	9.0	63.0	2.0	14.0	0.0	0.0	1.0	0.0	tr
52.75	1.0	2.0	5.0	3.0	12.0	68.0	2.0	6.0	0.0	0.0	0.0	0.0	1.0
58.80	2.0	12.0	13.0	0.0	24.0	42.0	6.0	tr	0.0	0.0	1.0	0.0	0.0
59.70	1.0	17.0	14.0	0.0	20.0	42.0	2.0	tr	0.0	0.0	4.0	0.0	1.0
63.70	1.0	12.0	21.0	1.0	28.0	35.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0
65.64	2.0	11.0	20.0	7.0	16.0	36.0	4.0	2.0	0.0	tr	tr	0.0	2.0
66.60	1.0	9.0	3.0	2.0	8.0	29.0	13.0	7.0	3.0	tr	13.0	0.0	13.0
67.65	1.0	12.0	21.0	4.0	13.0	40.0	4.0	1.0	0.0	0.0	1.0	0.0	4.0
71.60	1.0	13.0	27.0	7.0	11.0	34.0	3.0	2.0	tr	tr	tr	0.0	1.0

3.2.5 Petrophysics

Natural γ -radiation

The natural γ -radiation from this core closely follows the lithology, i.e. low radioactivity in the coarsest parts and relatively high in the claystones (Figure 3.2.1). The lower part of the core consists of clayey siltstone with relatively high total γ -activity, mainly due to potassium. On top of this a fine-grained sandstone with slightly lower γ -activity rests. The medium to coarse-grained sandstones and conglomerates above 40 m are low in γ -radiation.

Sound velocity

The sound velocity measurements throughout this core are very variable due to the different kinds of lithologies and degree of cementation (Table 3.2.3). The measured values range from about 2000 m/s in the claystones to 2300-3000 m/s in siltstones and sandstones with 4000 m/s or more in the most well-cemented coarse-grained sandstones.

Table 3.2.3 Horizontal sound velocity (v) in samples from core 7227/8-U-1.

Depth (m)	v (m/s)	Lithology
30.85	3140	Coarse-grained sandstone
31.70	3150	"
32.95	2550	" , laminated
33.80	4030	Coarse-medium grained sandstone
34.85	3580	Coarse-grained sandstone
35.80	2760	Coarse-medium grained sandstone
36.65	4590	"
37.48	3610	"
38.40	4830	Coarse-grained sandstone
39.26	4070	Conglomerate
39.85	2340	Very fine-fine grained laminated (graded sandstone)
40.95	2460	"
41.76	2340	"
43.15	2490	"
44.20	2500	"
45.20	2420	"
46.10	3810	Medium-coarse grained sandstone
47.00	2470	"
47.80	2480	Very fine-fine grained laminated sandstone
50.30	2380	"
51.00	2260	"
52.60	2200	Very fine grained sandstone
53.60	2020	"
54.10	2540	Fine-grained sandstone
57.20	2230	Siltstone-very fine-grained sandstone
58.50	1990	Claystone
59.50	4070	Medium grained sandstone, calcite cemented
60.00	1720	Claystone
61.00	2630	Fine-medium grained sandstone
61.75	3380	Fine grained sandstone
61.86	2250	"
62.90	2560	Clayey siltstone
63.40	2700	Sandy siltstone
63.95	2430	Siltstone
64.20	3700	Very fine-grained sandstone
67.85	2460	Siltstone-clayey siltstone
68.80	2370	"
69.85	2760	"
71.25	2040	"

3.2.6 Palaeontology

Palynology

71.60-57.70 m (Unit A): Tentative upper Triassic

The palynomorph productivity in this interval is very low and limited to some few longranging spores and pollen. Samples at 58.8 and 57.7 m contain rare Botryococcus colonies (Figure 3.2.5).

53.6-39.66 m (Units B and C): Norian to lower Rhaetian

Well preserved and rich spore assemblages dominating in this interval allow a correlation with Norian-Rhaetian of Canada and Hopen.

Bisaccate pollen dominate and include particularly forms assigned to Protodiploxypinus gracilis, P. minor, P. ornatus and Ovalipollis pseudoalatus. The spores are dominated by smooth Cyathidites spp. In addition, there are large or heavily sculptured forms of Kyrtomisorites laevigatus, K. speciosus, Conbaculatisporites hopenensis and Duplexisporites gyratrus and monolete cavate spores Aratrisporites spp., A. macrocavatus, A. palettae and A. scabratus.

The bisaccates mentioned and many of the spores extend from the Middle Triassic while Chasmatosporites major/hians, C. apertus, Semiretisporites spp., Zebrasporites interscriptus, Annulispora folliculosa and A. cicatricosa are believed (Fisher 1979) to have a base in the Norian of Canada. The assemblage also has records from Hopen (Bjærke & Manum 1977) in the upper part of the De Geerdalen Formation.

Between 44.7 and 42.73 we note the income of Classopollis classoides, Corollina spp., Quadraeculina anellaeformis and Crybelosporites vectensis. Abundant microplankton Verhachium spp., Michrhystridium spp., Solisphaeridium spp., Cymatiosphaera spp. and Tyttodiscus spp. were recorded from 47.5 m to 39.7 m.

CORE 7227/8-U-1

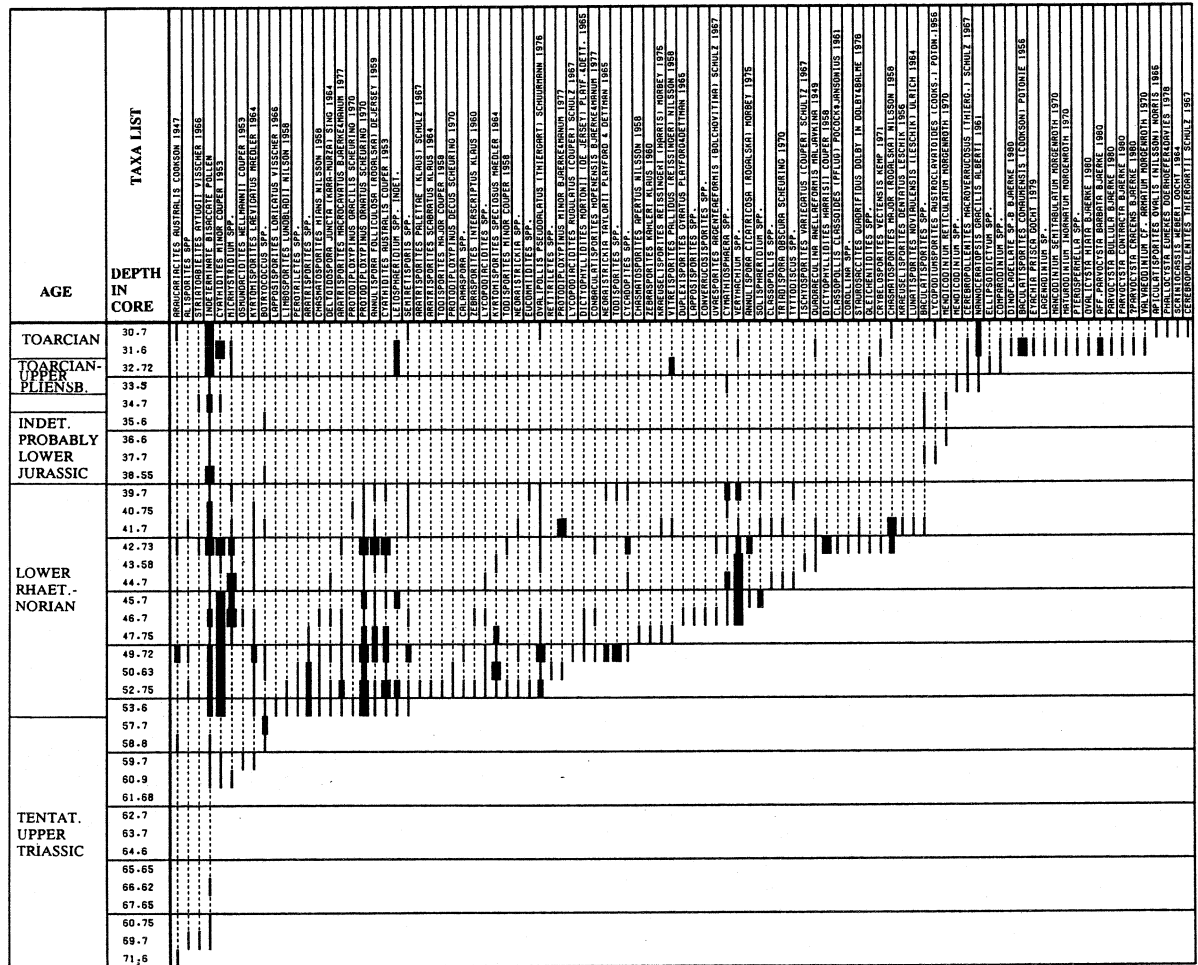


Figure 3.2.5 Palynological range chart, core 7227/8-U-1.

A similar development has been recorded (Bjærke & Manum 1977) in Hopen, in the lower part of the Wilhelmøya Formation. The same pollen and spore taxa have records from Rhaetian layers (Fisher 1979) of the Canadian arctic archipelago. We therefore propose a possible Early Rhaetian age from 47.75 to 39.7 m implying that the younger (upper) Rhaetian is missing in this area. Their absence may be due to the erosion in the early Jurassic as observed from the reworking of Limbosporites lundbladii in assemblages above and between the conglomerates in this core.

38.55 m - 35.60 m (Unit D): Indeterminate, probably Lower Jurassic

The interval has a low recovery of palynomorphs which includes long-ranging Triassic-Jurassic forms: Araucariacites australis, Crybelosporites vectensis, Lycopodiumsporites austroclavatidites, Gleicheniidites senonicus and abundant Cyathidites minor and indeterminate bisaccate pollen.

Botryococcus spp. were evaluated as indigenous while the Triassic forms may be reworked in this part of the core.

33.5 m - 32.72 m Upper Pliensbachian - Toarcian

The presence of Nannoceratopsis gracilis in a poor assemblage at 33.5 m points to a Late Pliensbachian or younger age from this level. A few other marine elements occur here and at 32.72 m where indeterminate bisaccate pollen, Leiosphaeridium spp. and Vitreisporites pallidus dominate.

31.6 m - 30.7 m Toarcian

An assemblage with common Nannoceratopsis gracilis, Eyachia prisca, Ovalicysta hiata, Maturodinium inornatum, Valvaeodinium cf. armatum and several species of Parvocysta/Shublikodinium occur at 31.6 m. Wille (1982) found E. prisca no lower than the lowermost Upper Toarcian H. variabilis Zone whereas Riding (1984) recorded it also in the Lower Toarcian H. bifrons Zone. The co-occurrence of the Parvocysta complex and Phallocysta eumekes favours an H. variabilis to G. thouarsense Zone early Late Toarcian age (Riding 1984) if ranges from Yorkshire are considered more relevant than ranges from Central Europe.

Microfauna

Samples at 30.70 m, 50.63 m and 70.75 m are all barren.

Visual kerogen

Unit A: The lowest interval in this core has a low productivity of organic material comprising mostly oxidized dark wood remains and occasionally poorly preserved pollen grains. Woody tissues occur as coarse irregular spongy fragments.

Unit B. The organic matter consist mainly of oxidized angular wood particles and is connected with a generally transgressive phase.

Unit C. The organic material is dominated by spongy wood fragments.

Unit D. The residues are small, mostly comprising wood remains at variable stages of degradation. In the marine sandstones at the top of the core the organic material is better preserved.

TAI is 3 and 3.5 on an 1-10 scale corresponding to R_o 0.3-0.4.

The mature stage has still not been reached if evaluated on the basis of pollen colours in the Upper Triassic deposits.

However, as a result of oxidative conditions previous to deposition particularly spore colours vary within the individual samples from dark brown to light yellow.

3.2.7 Organic geochemistry

Headspace and occluded gas occur only in very low concentrations (max. 1860 μ l/kg of rock (Figure 3.2.6). The headspace gas contains only methane while the occluded gas consists of methane through propane and only occasionally contains some butane and C_{5+} -hydrocarbons (43.44 m). Wetness is constantly low at 10-17 % and increases only slightly to 26 % at 57.97 m. The carbon isotope ratio of the adsorbed methane (-32.7 0/00 PDB) may reflect a partial oxidation rather than the presence of a metagenic gas. The data therefore suggest that no significant amounts of thermogenic light hydrocarbons have migrated into the rocks.

Core 7227/8-U-1 is quite poor in organic matter (Figure 3.2.7). Two thirds of the samples contain less than 0.5% TOC, but the values may be locally increased where the sandstones contain coaly material such as finely dispersed plant fragments. This is the case for some samples between 38 and 54 m depth. The TOC content drops below 0.2 % in the zone between 57 m and total depth which includes red claystones.

The Rock-Eval pyrolysis data (Fig. 3.2.8) suggest that the kerogen in the rocks belongs to the hydrogen-poor types III and IV, except for a few richer samples which may contain type II-III kerogen (at 33.97 and 38.55 m). The HI values of the organic-poor samples should be interpreted with great care, because of (a) the uncertainty which is introduced by normalising the S2 values to such low TOC contents, and (b) the mineral matrix effects which may significantly decrease the amount of hydrocarbons released per unit TOC (Espitalie et al. 1984).

Four pyrolysis-gas chromatograms were obtained from this core. All of them show high concentrations of toluene, benzene and occasionally of phenols and cresols (38.55 m) above a background of alkene/alkane doublets which extends to about C₂₀. Some differences can be seen in the pyrolysis-gas chromatograms between the samples at 33.97 and 38.14 m, which show an intermediate composition, the phenol-cresol dominated pyrolysate at 38.55 m, and a more aliphatic pyrolysate at 50.63 m. The aromaticity as expressed by the ratio (m+p)-xylene/n-octene of these four samples increases with increasing hydrogen indices which is contrary to the expected trend. The characterization of the organic matter as relatively hydrogen-poor is however basically confirmed by the composition of the pyrolysates.

Amount and type of the organic content suggest that the rocks are unlikely to generate significant amounts of hydrocarbons. Accordingly they show a low low petroleum potential (Rock-Eval S1 + S2) of less than 0.6 mg HC/g rock.

Reliable vitrinite reflectance data were obtained from samples at 38.1 and 46.7 m depth, giving values of 0.28 and 0.34 %Ro, respectively. This low maturity is confirmed by the liptinite fluorescence colours (zone 2 - 4). Rock-Eval Tmax values show quite a large variation due to small and flat S2 peaks. The extremely high values which were recorded

for the red claystones from the deepest part of the well have no significance for maturity determination. The main Tmax population averages around 430 to 435°C. Given a type III kerogen, this would indicate a maturity level just before the onset of oil generation (Espitalie et al. 1985), which is somewhat higher than the maturity indicated by the vitrinite reflectance. It is likely that recycled, oxidised organic material in the rock gave rise to these relatively high Tmax values. The low production index values ($PI < 0.10$), however, indicate that the section is still immature.

Five samples were extracted. The EOM yields range from 360 to 6337 wt ppm of rock and correlate with both the TOC content of the rocks and the hydrogen index of the kerogens (Figure 3.2.9). The proportion of hydrocarbons in the extracts is less than 20% which indicates a low thermal maturity. A higher value (38.7 %) for the sample C-5215 at 32.72 m could possibly indicate that this sample may contain small amounts of migrated hydrocarbons.

The gas chromatograms of the saturated extract fractions show bimodal n-alkane distributions with maxima at C_{17} - C_{19} and C_{25} - C_{27} . A mixed marine/terrestrial source is suggested for these extracts. The relative proportion of the C_{17} - C_{19} hydrocarbons appears to be loosely related with the hydrogen index and may reflect the relative input of hydrocarbons sourced from marine organic matter. Significant "humps" of unresolved compounds and relatively high isoprenoid/n-alkane ratios ($\text{pristane}/n\text{C}_{17} = 1.0 - 2.0$) (Figure 3.2.10) indicate relatively low maturity. The gas chromatogram at 43.58 m suggests a more mature composition.

The gas chromatograms of the aromatic fractions are dominated by a large 'hump' of unresolved polyaromatic compounds, probably aromatic steranes and triterpanes. This is typical for many immature samples. Phenanthrene and methylphenanthrenes predominate among the lighter polyaromatics while alkylnaphthalenes occur in minor concentration. A partial loss of these compounds during evaporation of the solvent cannot be excluded, as the samples were quite small. The relatively high predominance of phenanthrene and 9- and 1- methylphenanthrene over 3- and 2-methylphenanthrene, although suggesting low maturity, should

be interpreted with great care because of the strong influence of the organic facies on the composition of the polyaromatics in immature samples.

The biomarker composition of the saturated extract fractions has been analysed at 38.14 and 43.85 m. The distribution patterns of the terpanes show a low abundance of tricyclic terpanes and $18\alpha(\text{H})$ -trishomohopane (Ts) which both may indicate that the samples are immature. The maturity-dependent isomer ratios $\alpha\beta/(\alpha\beta-\alpha\beta)$ -hopanes and %22S-homohopane suggest however a higher maturity than the one indicated by vitrinite reflectance. The isomer ratio of the $17\alpha(\text{H})$ homohopane (%22S) indicates a higher maturity for the 38.14 m sample than for the 43.58 m sample. This is consistent with a lower pristane/ $n\text{C}_{17}$ ratio, the smaller relative size of the 'hump' in the gas chromatogram of the saturated fraction, and the increased proportion of saturates in the extract.

The m/z 217 mass chromatogram at 38.14 m shows a very low proportion of rearranged steranes relative to regular steranes. The presence of significant amounts of mature hydrocarbons is therefore considered to be unlikely. The predominance of the $\alpha\alpha$ - over the $\beta\beta$ -isomer of the C_{29} regular steranes may point in this direction. No m/z 217 mass chromatograms of reasonable quality could be obtained from the 43.58 m sample.

The carbon isotope profile for the extract fractions of the sample at 38.14 m appears most similar to that of the Upper Oxfordian sample at 51.86 m depth in core 7227/8-U-3.

In conclusion, core 7227/8-U-1 has no significant hydrocarbon generation potential due to its low organic content and the poor source quality of the organic matter. The rocks are thermally immature and do not contain significant amounts of non-indigenous hydrocarbons. The composition of saturated hydrocarbons and biomarkers, however, does not speak against the presence of small traces of hydrocarbons derived from a more mature source.

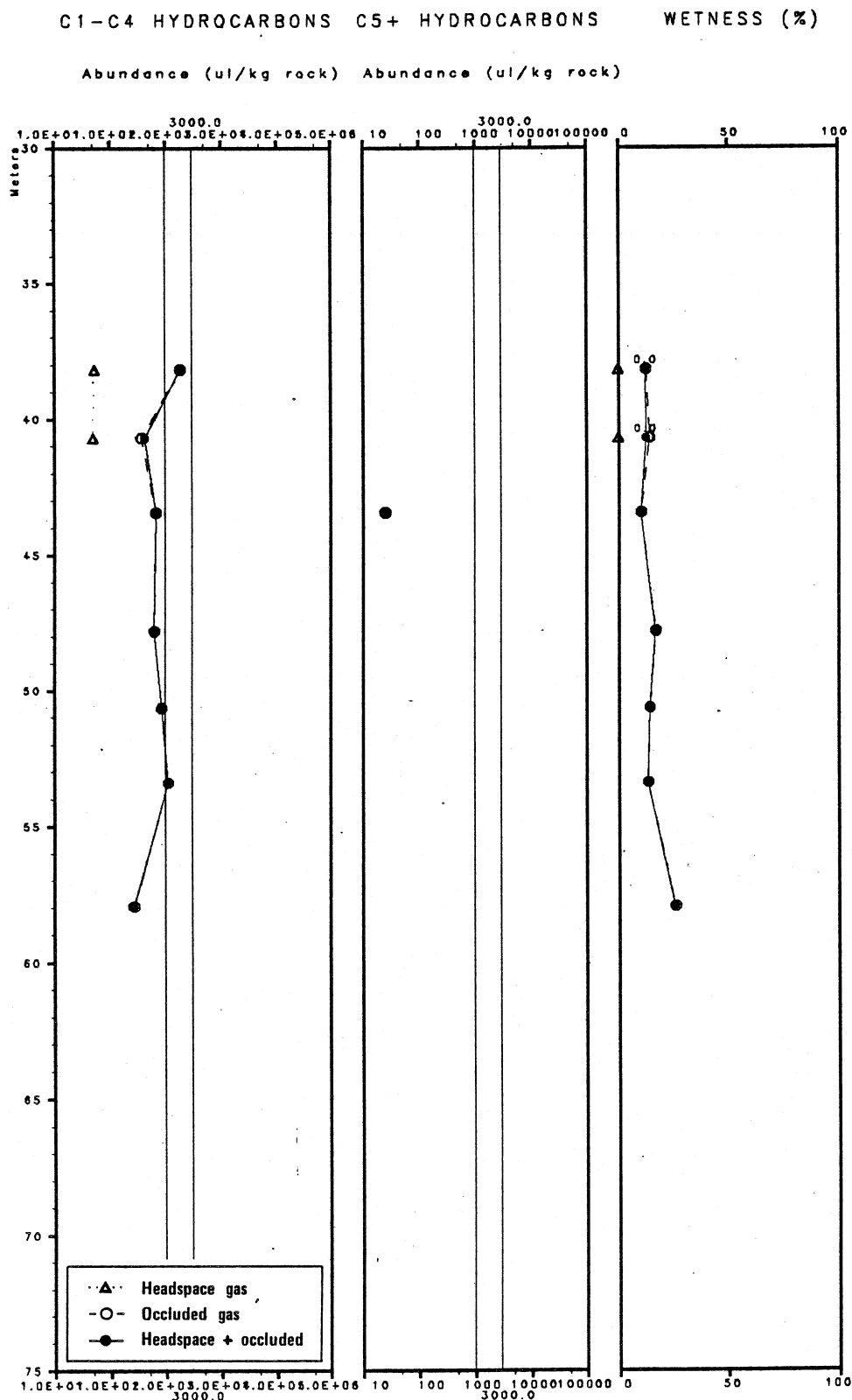


Figure 3.2.6 Yield and composition of headspace/occluded gas of core 7227/8-U-1.

ROCK-EVAL PYROLYSIS DATA

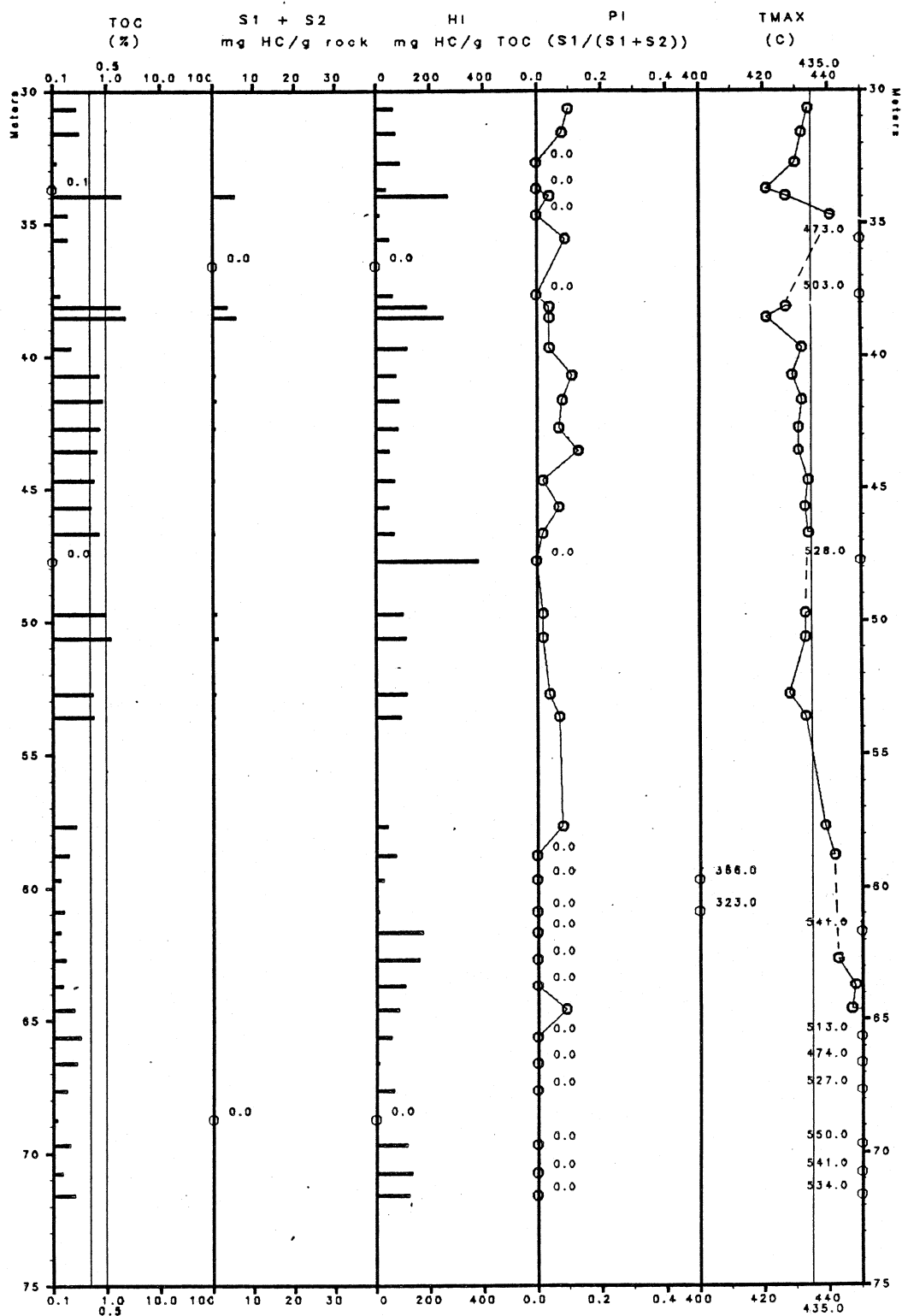


Figure 3.2.7 Total organic carbon content and Rock-Eval data of core 7227/8-U-1.

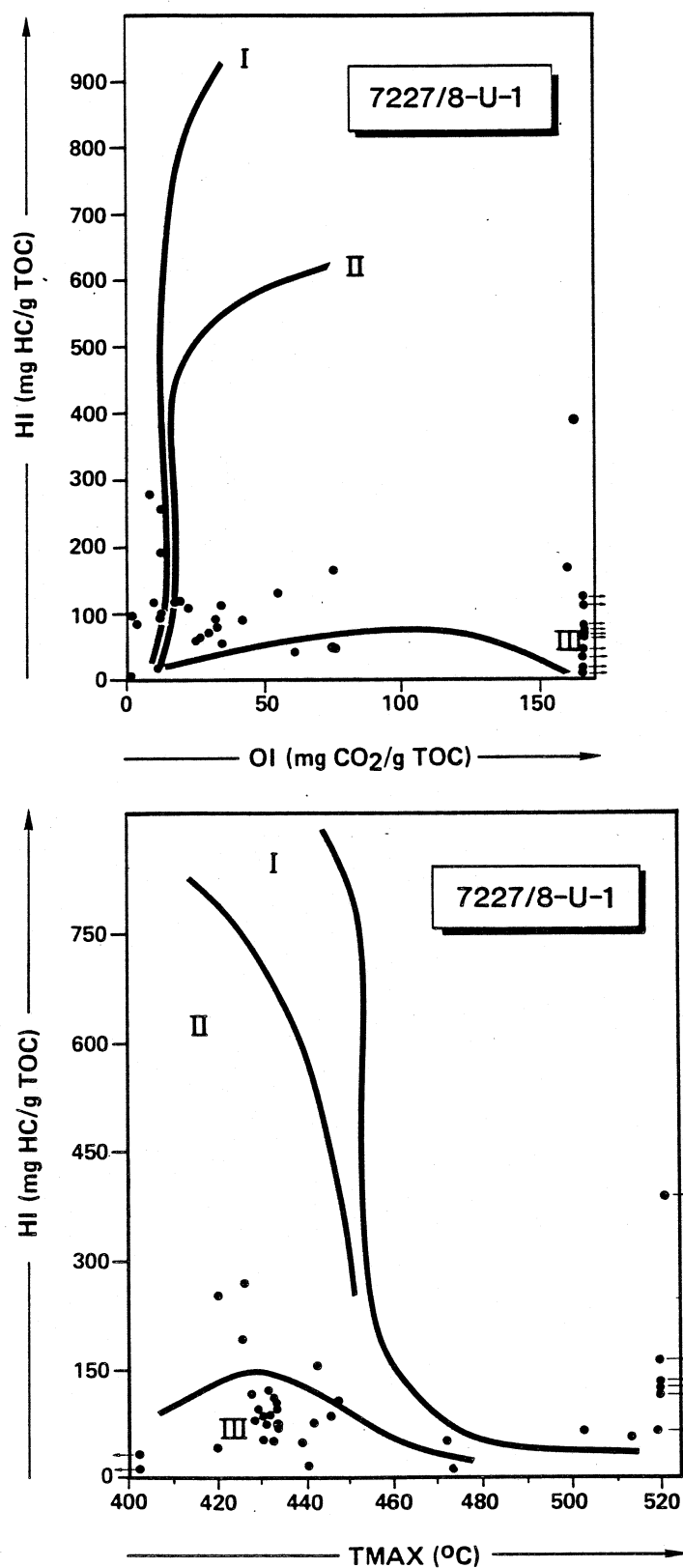


Figure 3.2.8a Rock-Eval hydrogen index vs. oxygen index for core 7227/8-U-1.

b Hydrogen index vs. T_{max} for core 7227/8-U-1.

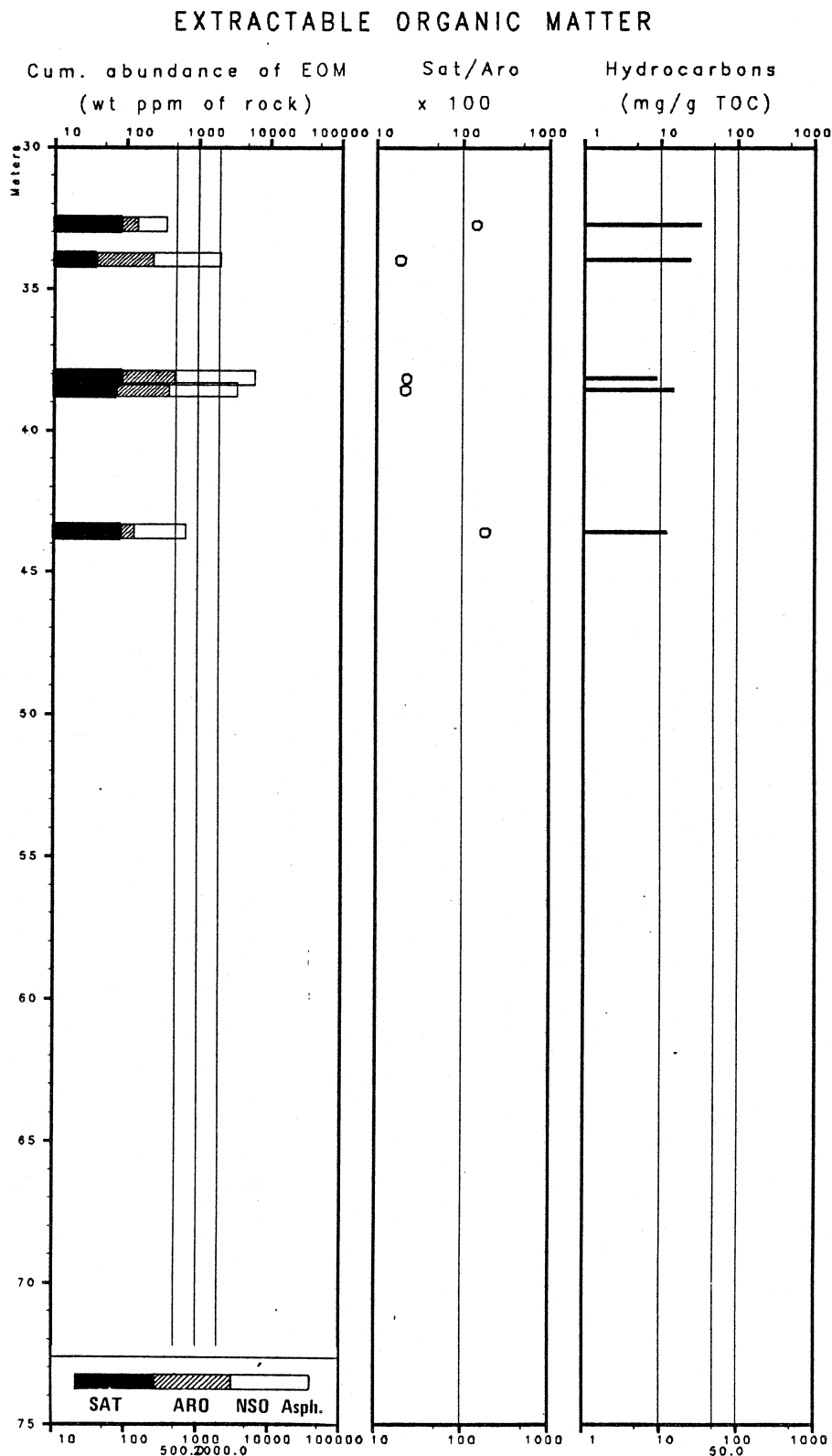


Figure 3.2.9 Extract data for core 7227/8-U-1.

GAS CHROMATOGRAPHIC RATIOS

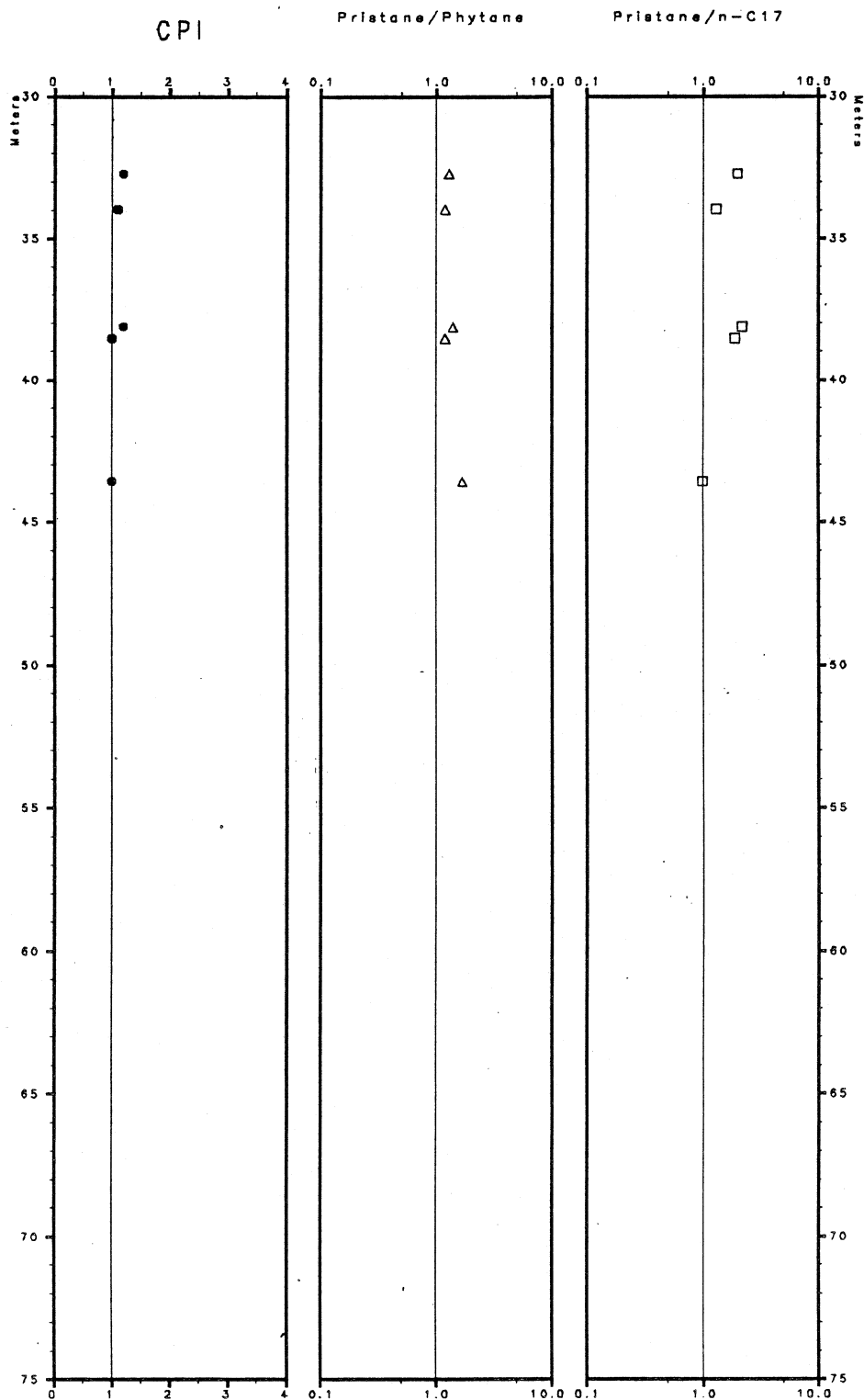


Figure 3.2.10 Compound ratios from gas/chromatograms of saturated hydrocarbon fractions from core 7227/8-U-1.

3.2.8 Depositional environment

In Unit A, below 60.9 m there are several criteria pointing to a continental influenced depositional environment. These include reddish brown to greyish green mottled mudstones, early diagenetic marcasite pseudomorphs and sideritic pisolites. We suggest that the siderite pisolites have formed by sideritization of originally calcite pisolites. This is supported by SEM studies which show that the mineral is a Ca-siderite. Berner (1971) noticed that siderite is common in non-marine environments where it occurs as primary siderite deposits, often in association with coals, and as replacements.

Sideritization of primary calcite is further supported by the dusty appearing microcrystalline and fibrous carbonate association that at 59.5 m consists of calcite in contrast to siderite at about 65 m. Sideritization of calcites may therefore well have occurred and the siderite pisolites suggest subaerial exposure (Esteban & Klappa 1983). At 60.15 m some probable mud cracks also occur and may indicate that this rock has been aerially exposed (Figure 3.2.11).

Pisolites and red colouring of sediments are frequently reported from arid to semiarid climate. However, the flora indicate that some humid vegetated areas must have existed in the drainage system. Such areas may have been restricted to river banks and/or other areas with high permanent ground water table.

The environment that best explains the redcoloured mudstones with associated sandstones and calcite precipitates are shallow peremurial lakes. The mudstones may have accumulated in central low-energetic areas while the sandstones may be beach deposits. Peremurial lakes in (semi)-arid climate show large sea fluctacation of the lake level. During humid periods the lake are almost normal saline and fresh while it may be hypersaline and shrink during day periods. During normal saline periods, benthic faunas may establish while it may dissappear during hypersaline periods. During low stand in the lake calcite may precipitate within the sediments at the exposed part of lake floor. As the lakes are filled by sediments, such calcite crusts may be subjected to weathering conditions and caliche may form.

In the channel fill sandstone at 61 m, some marine palynomorphs occur. The overlying mudstones contain no marine palynomorphs and may indicate that terrestrial, probably lake condition again was established. The marine influence may be caused by a transgression that only for a short period of time resulted in marine conditions. The channel are overlain by mottled mudstones with mud-cracks and may be tidal flat deposits.

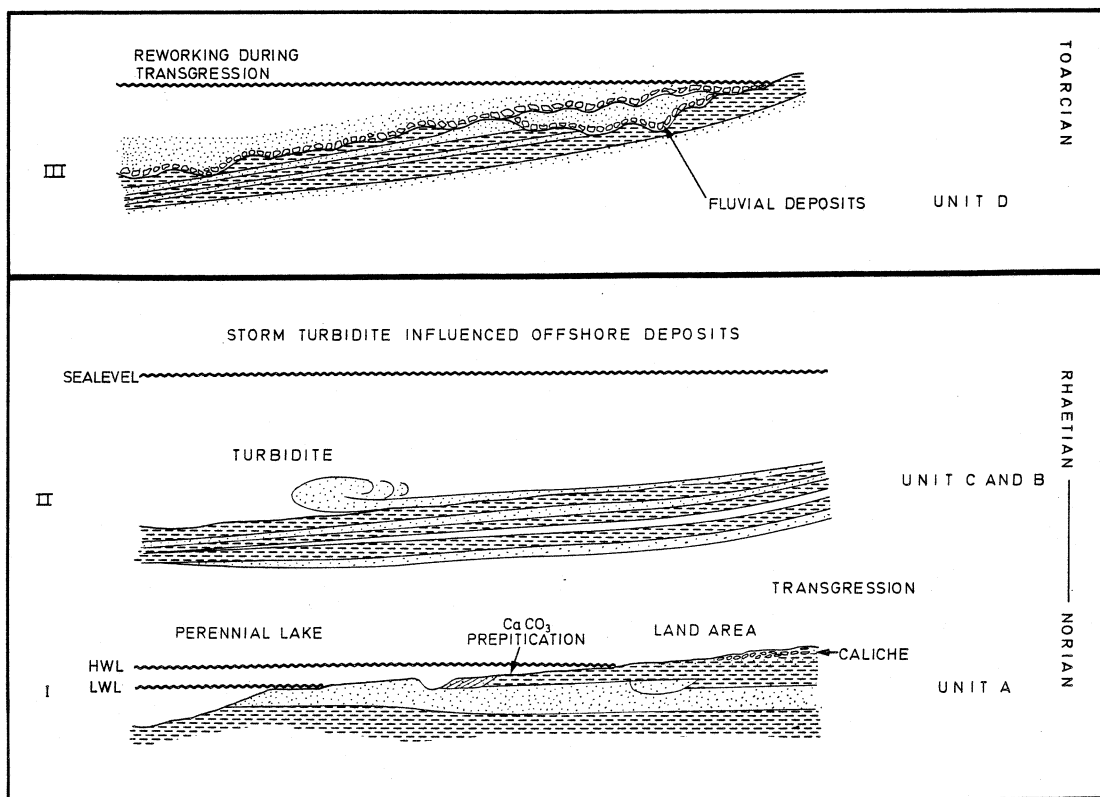


Figure 3.2.11 The three subfigures (A, B, C) schematically illustrate the sedimentology of the different Units. Figure. I illustrates deposition of Unit A on a channeled tidal flat or coastal plain where calcite formed. Deposition of Units B and C in a shallow storm-influenced offshore environment is illustrated in Figure II. Unit D is illustrated in Figure III. Between Units C and D a relative (eustatic?) fall of sea level and subaerial erosion may have taken place. The low stand of sea level was followed by a transgression (?Toarcian).
HTL = High Tide Level.
LTL = Low Tide Level.

Unit B consists of strongly bioturbated sandy siltstone with some escape burrows in the uppermost part. The burrows indicate episodes of rapid deposition, which is consistent with the structures in the sandstone bed indicating high energy. The sandy bioturbated siltstones, however, suggest long periods of quiet conditions. Botryococcus colonies are present as in the unit below and represent evidence of a lacustrine environment into an area where the marine influence (Leiosphaeridium spp. Micrhystridium spp., Veryhachium spp.) becomes gradually stronger. Spores of ferns and clubmosses and gymnosperm pollen representing a local flora dominate the assemblages. The content varies from one sample to the other and may well reflect the vegetation of a delta or marsh land. The well preserved and abundant cuticles of the uppermost sample are evidences of a very short transport and rapid burial. We suggest that Unit B was deposited on a shallow storm-influenced shelf. The abundance of vertical burrows, probably formed by suspension feeding organisms, indicate nutrient-rich well oxygenated bottom water.

The contrast between Unit A and Unit B shows that a minor transgression has taken place and that the transgression surface lies within the interval where we had no core recovery.

Unit C starts with a 1.5 m thick heavily bioturbated sandstone. The sandstone is abruptly overlain by a 6.5 m thick sandy siltstone with remains of the original bedding and many features similar to those in Unit B. Collapsed or shrunk poorly preserved small grey palynomorphs are biodegraded. The samples are rich in Veryhachium spp. and Micrhystridium spp. as well as Cymatiosphaera and Solisphaeridium and suggest stronger marine influence than in Unit B.

The rock is therefore interpreted as a storm-influenced shallow shelf deposit. The bioturbated medium-grained sandstone is interpreted as a transgressive unit and indicates that Unit C has been deposited slightly deeper than Unit B.

Unit D has an erosive contact with the underlying rocks. This is supported by the seismic interpretation. This seismic sequence boundary (reflector ϵ) cuts reflectors in the underlying rocks. Further evidence of the erosion contact is the polymict conglomerate which mainly consists of different sandstones.

The unconformity may embrace most of the Lower Jurassic. The light coloured sandstones and conglomerates below 33.75 m show large scale cross stratification and some horizontal lamination. The conglomerates commonly contain large wood fragments. We suggest that the lower part of Unit D may be a fluvial channel fill deposit. No marine influence is indicated.

A conglomerate is developed at 33.75 m. The rock above the conglomerate is a strongly bioturbated and bedded sandstone with marine palynomorphs and common green glauconite grains. Glauconite is an indicator of slow deposition in a marine environment. We therefore interpret the uppermost bioturbated sandstone as a transgressive deposit.

From seismic records it is evident that reflector ϵ is overlapped by other reflectors (Figure 3.2.2). The overlapping reflectors seem to be due to Toarcian and younger transgressions.

3.3 7227/8-U-3

3.3.1 Summary

21.5 m of very dark grey micaceous shales rich in ammonites, bivalves and belemnite hooks were cored between 53.05 and 31.55 m below sea floor (Figure 3.3.1). The cored section lies immediately below a major sequence boundary (reflector γ). Studies of ammonites show that the core represents a complete Upper Oxfordian and Kimmeridgian (*sensu gallico*) section. Dinoflagellate cysts give supporting biostratigraphic evidence for this conclusion, and the core gives an opportunity for a detailed comparison of ammonite and dinocyst ranges.

The penetrated section is very rich in organic matter (up to 19% TOC), especially in the interval between 40 and 49 m (base Kimmeridgian/top Upper Oxfordian). The kerogen contained in the rock is relatively rich in hydrogen (Rock-Eval types II and II-III) and therefore has a good petroleum generation potential. The rock section is thermally immature (0.27-0.30 %Rm). The composition of the extracted hydrocarbons also indicates an immature stage while the biomarkers tend to show a moderate or early mature composition.

The γ -radiation is markedly higher from the upper than from the lower part of the Upper Oxfordian core interval. In the Kimmeridgian the measured values are relatively stable and similar to those in the uppermost Oxfordian. Exceptionally high radiation comes from the A. mutabilis Zone and particularly from one level in the A. eudoxus Zone.

Some bioturbation and the relatively rich recovery of ammonites and bivalves suggest at least some episodes with oxygenated bottom water during deposition in a marine environment.

7227/8-U-3

Age: U. Oxfordian – Kimmeridgian

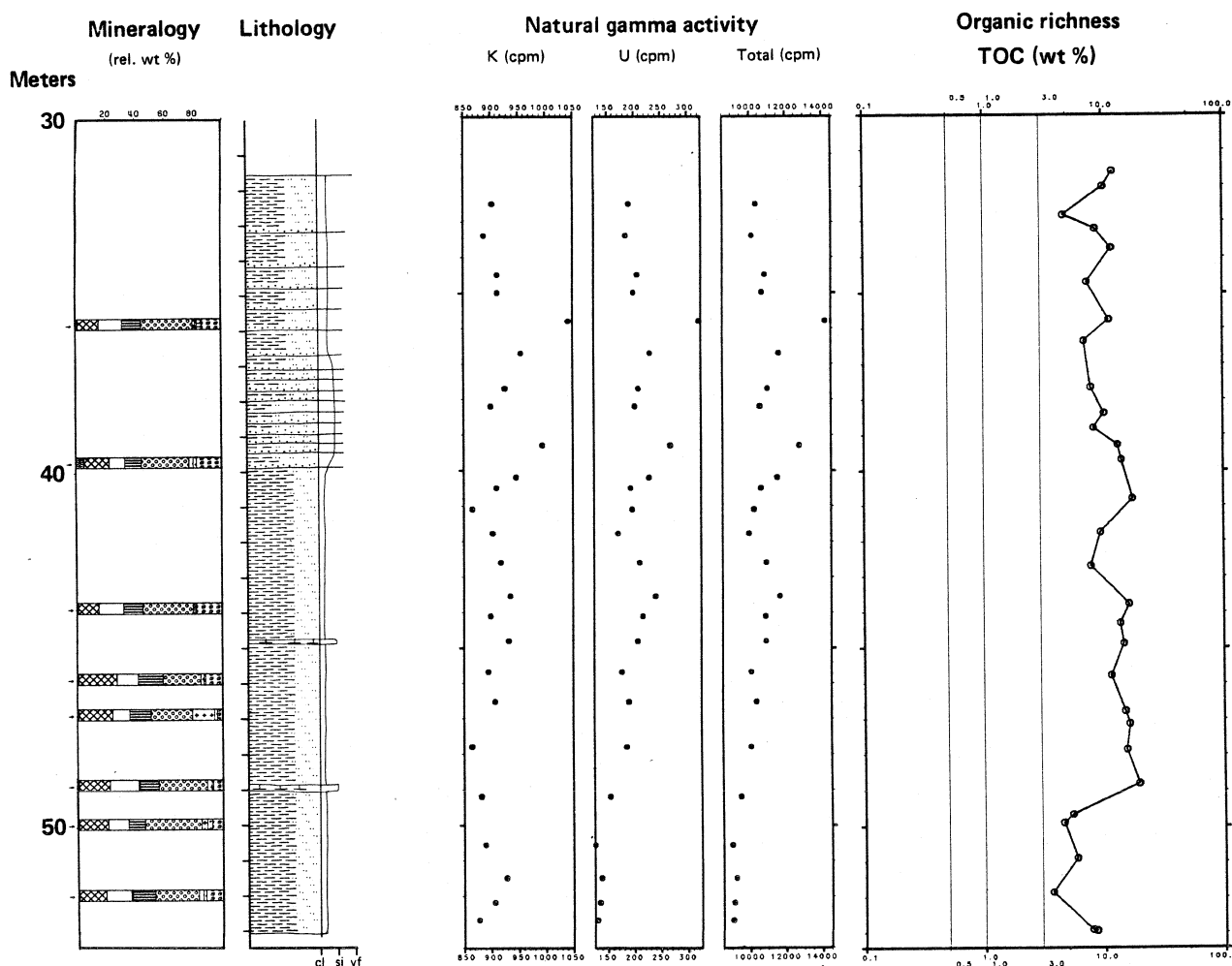


Figure 3.3.1 Summary figure of core 7227/8-U-3.

3.3.2 Seismic interpretation

A thin unit at the base of the Quaternary overburden present at this location pinches out between here and site 7227/8-U-1. The bedrock was reached 31.5 m below sea floor, somewhat lower than at site 7227/8-U-1.

The borehole did not penetrate any major seismic boundaries. The sampled seismic unit is defined by the reflectors γ and δ (Figure 3.3.2). According to the palaeontology, the sediments were deposited during Upper Oxfordian and Kimmeridgian *sensu gallico* time. A seismic sequence boundary, which is well expressed just above the cored

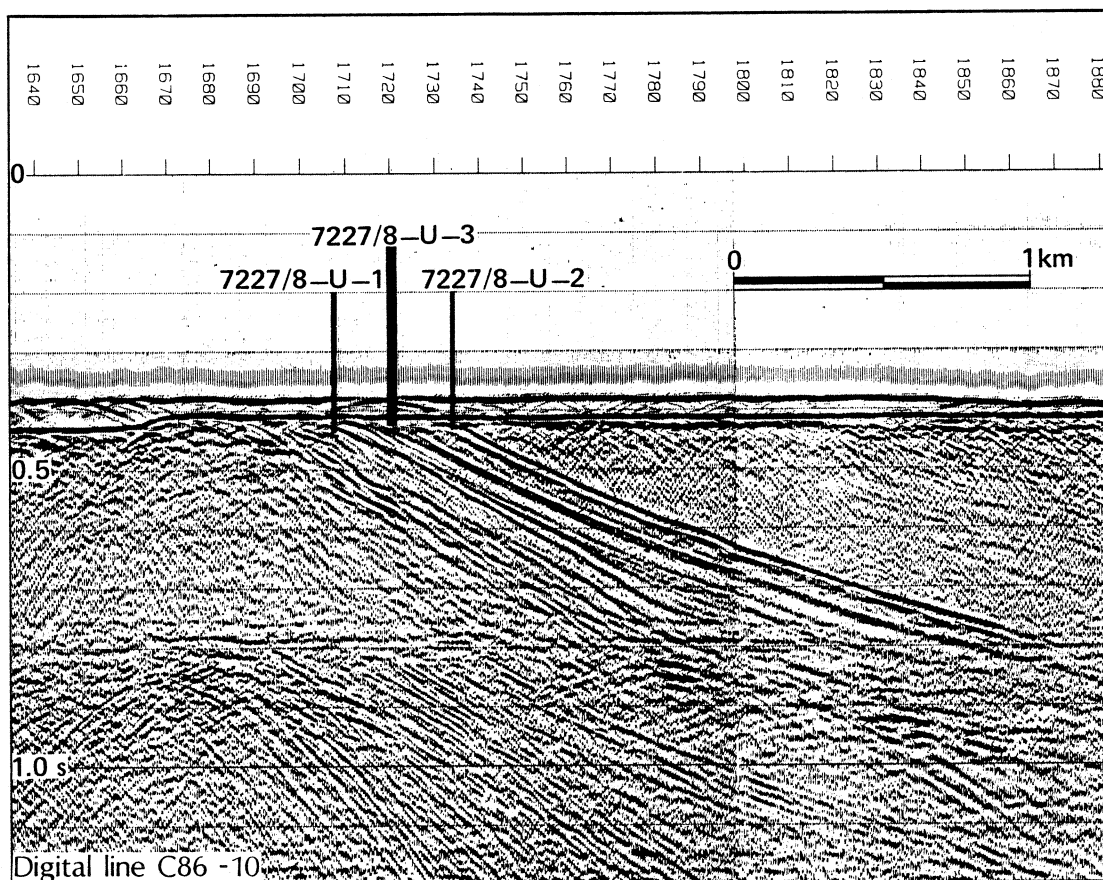


Figure 3.3.2 Digital seismic line showing the position of core 7227/8-U-3 and the related seismic sequence boundaries.

interval, is therefore interpreted as the top Kimmeridgian paleo-surface. Interference from the close-lying Jurassic reflectors makes it difficult to distinguish them over long distances especially where minor faulting has taken place.

3.3.3 Core description

21.50 m of sedimentary rocks were drilled between 31.55 and 53.05 m below sea floor. The core consists of dark to very dark grey micaceous shale. In some intervals the rock has a paper shale appearance.

Two grey calcareous beds/concretions occur around 49 and 45.85 m. The upper one shows cone in cone structures. Each cone is polycrystalline and consists of prismatic crystals, about 2 mm long and have grown

normal to bedding. Clayey matrix and organic material have concentrated along the outlines of the cone during the process of pressure solution.

The lower bed consists of a mixture of black to brown organic material, woody material, clay matrix and pyrite cemented by micritic calcite. Cone textures as described above is partly developed also in this sample. Baryte is present on fractures parallel to the bedding in both samples and was probably crystallized when pore water saturated with respect to barium and sulphate became oversaturated due to a decrease of the pore water pressure. Also up to 1.5 cm x 4 cm pyrite concretions occur in the 51 to 48 m interval. One of these partially replaces woody material.

Horizontal burrows about 1 mm in diameter occur sporadically and fossils are very common. Specimens of the bivalve genus Buchia occur throughout the core, but are most numerous in the upper part. Also a few Inoceramus fragments are observed at 49 m. Ammonite fragments are common, but most of them are poorly preserved. In addition belemnite fragments, belemnite hooks, in situ ?worm tubes and some wood fragments are present.

In an interval between 35.75 m and about 39 m, the rock is calcite cemented with up to 2 mm thick graded siltstone to very fine-grained sandstone laminae. In this interval also some 5 mm thick laminae consisting of grain-supported belemnite hooks occur.

3.3.4 X-ray diffraction analysis

Eight samples from core 7227/8-U-3 are analysed by use of X-ray diffraction. The semi-quantitative results are listed in Table 3.3.1.

All the samples are silty claystones. Clay minerals and clastic micas are the major minerals. Mica, including illite, mixed layer illite-smectite and kaolinite constitute 45 to 55 wt% of the whole rock samples. Chlorite is absent or detected as trace amounts only.

The contents of quartz and feldspars are quite uniform throughout the core; one exception is the sample at 46.78 m which shows a high content of alkali feldspar.

Carbonate minerals are either lacking or present in trace amounts. The weight proportion of pyrite is high in most of the samples.

Table 3.3.1 Mineralogy composition (relative wt%) of samples from core 7227/8-U-3.

SAMPLE (m)	SMEC	MIX	I/M	CHL	KAO	QTZ	ALK	PLAG	CAL	DOL	SID	APA	PY
35.75	2.0	14.0	16.0	0.0	13.0	35.0	2.0	1.0	0.0	3.0	0.0	0.0	13.0
39.70	6.0	17.0	11.0	0.0	11.0	33.0	3.0	2.0	0.0	tr	0.0	0.0	17.0
43.77	1.0	14.0	17.0	0.0	13.0	35.0	1.0	1.0	0.0	0.0	0.0	0.0	18.0
45.78	1.0	26.0	14.0	0.0	17.0	26.0	2.0	1.0	0.0	tr	0.0	0.0	12.0
46.78	1.0	23.0	12.0	tr	14.0	29.0	15.0	2.0	0.0	tr	0.0	0.0	4.0
48.80	1.0	21.0	19.0	1.0	13.0	33.0	3.0	1.0	0.0	tr	0.0	0.0	7.0
49.90	1.0	20.0	14.0	0.0	11.0	39.0	4.0	3.0	0.0	tr	tr	0.0	8.0
51.86	1.0	18.0	17.0	1.0	15.0	30.0	3.0	2.0	0.0	0.0	0.0	0.0	12.0

3.3.5 Petrophysics

Natural γ -radiation

The natural γ -radiation from this core is very variable (Figure 3.3.1). There is a general trend of increasing total activity from the base to 35 m. In the Upper Oxfordian part of the core (52.95-43.8 m) the γ -radiation increases slightly upwards from about 49 m to a local maximum at 43.8 m. At 49 m a sudden increase in the total organic carbon (TOC) content is also observed. In the Lower Kimmeridgian interval, between 43 m and 41 m, the γ -activity decreases and then starts to increase again above 41 m.

Above 39 m, the TOC curve does not correlate to the γ -activity to the same extent as below. The TOC varies over short intervals, and this variation is not totally reproduced by the γ -log. A high organic

content does not necessarily imply a high radioactivity. The pattern described above is also observed in the potassium and uranium spectral logs. The only difference is the high potassium value at 51.5 m, probably due to a high content of mica.

Sound velocity

Twentyfour measurements of the horizontal sound velocity from 52.44 m to 31.77 m have been performed on this core (Table 3.3.2). The mean sound velocity observed is about 2300 m/s in the silty claystones. Some of the low values are probably due to fracturing introduced during and after coring. Two high values 4760 m/s and 3670 m/s are obtained in siltstone. These values are due to carbonate cementation.

Table 3.3.2. Horizontal sound velocity (v) in samples from core 7227/8-U-3.

Depth (m)	v(m/s)	Lithology
31.77	2440	Silty claystone
32.20	2700	"
33.41	2220	"
34.05	2220	"
34.94	2480	"
35.94	4760	Siltstone w/sandy laminae
36.73	2620	"
37.65	2190	"
38.74	2390	"
39.83	2420	Silty claystone
40.26	2330	"
42.30	2080	"
42.73	2110	"
43.45	2270	"
44.57	1920	"
45.66	2500	"
46.40	2420	"
47.57	2060	"
48.44	2350	"
48.83	2590	"
49.00	3670	Carbonate cemented siltstone
50.45	2380	Silty claystone
51.30	2540	"
52.44	1940	"

3.3.6 Palaeontology

52.95 - 43.80 m: Upper Oxfordian

Ammonites

The ammonites found between 52.95 m and 43.80 m are indicative of the Oxfordian. The lowermost, poorly preserved ammonite from 52.95 m is the typical Amoeboceras showing well developed smooth bands along the keel. This indicates that the corresponding lowermost part of the core belongs to the Upper Oxfordian and it cannot be placed below the A. glosense Zone. (The definition of the Upper Oxfordian substage is after Sykes & Callomon (1979); however, it may be noted that in some other subdivisions of the Oxfordian stage, mostly those used in the Submediterranean province, the zones distinguished in the upper part of the Middle Oxfordian correspond to the A. glosense Zone & even A. serratum Zone of the Upper Oxfordian in Sykes and Callomon's subdivision).

The poorly preserved Amoeboceras found at 49.63 m seems to belong to the species Amoeboceras serratum (Sowerby) which eventually indicates the presence of the A. serratum Zone in the studied part of the core. This fits well with the occurrence of the next ammonite fauna between 47.80 m and 44.25 m composed of Amoeboceras regulare Spath and Amoeboceras cf. freboldi Spath indicating the A. regulare Zone and possibly the topmost part of the A. serratum Zone.

The presence of the A. rosenkrantzi Zone, the topmost zone of the Oxfordian stage, is evidenced by the findings of the small ammonites at 43.80 m and 44.0-44.05 m belonging to the A. rosenkrantzi group (i.e. to the species A. rosenkrantzi Spath and/or A. marstonense Spath).

Palynology

Most of the recorded dinocyst species range throughout the interval and are not very age significant. Rhynchodiniopsis cladophora, Valensiella ovula and Paragonyaulacysta borealis are the most common taxa in the

lower part (Figure 3.3.3). Kalyptea diceras which is found only in the lowermost sample at 52.92 m points to an age no younger than somewhere in the upper part of the Oxfordian. Piasecki (1980) did not record it above the basal part of A. glosense Zone in East Greenland.

Stephanelytron redcliffense at 51.86 m according to Sarjeant (1979) ranges into the lowermost Kimmeridgian P. baylei Zone. Woollam & Riding (1983) indicated rare or uncertain occurrences of the genus as high as in the A. mutabilis Zone. This and its presence at 51.86 m conflicts the range given by Raynaud (1978) who did not record representatives of the genus above the Lower Oxfordian in the North Sea. These conflicting ranges probably reflect that Stephanelytron is uncommon in the upper part of its range. A single specimen of Acanthaulax scarburghensis at 50.90 m is somewhat problematic. Raynaud (1978) recorded this species no higher than the Lower Oxfordian whereas Piasecki (1980) reported it slightly higher from the lowermost part of the Middle Oxfordian C. densiplicatum Zone, in good agreement with Woollam & Riding (1983). The occurrence at 50.90 m may most easily be explained by reworking.

Scriniodinium crystallinum is found fairly consistently in samples between 51.86 m and 45.78 m and Scriniodinium galeritum between 51.86 and 44.88 m. Woollam & Riding (1983) and others reported both species to range into the lowermost Kimmeridgian P. baylei Zone (S. galeritum possibly into the A. eudoxus Zone).

Rhynchodiniopsis cladophora occurs in high numbers in the four samples from the interval 52.92 - 49.90 m and also at 45.78 m which is the youngest examined sample with common specimens of this species.

The presence of Chlamydophorella wallala in three samples between 52.92 and 47.85 m may be of some stratigraphic value, but its range is not well known.

Gonyaulacysta jurassica is recorded in high numbers at 44.88 m in the upper part of the A. regulare zone. Most of the specimens are short, fat forms with large antapical openings. The species is far more common in this sample than in any other sample from the core. In the sample

below and above G. jurassica is not recorded at all and the sample above is very poor also in other dinocysts. These differences in abundance and recovery are probably due to environmental changes.

CORE 7227/8-U-3

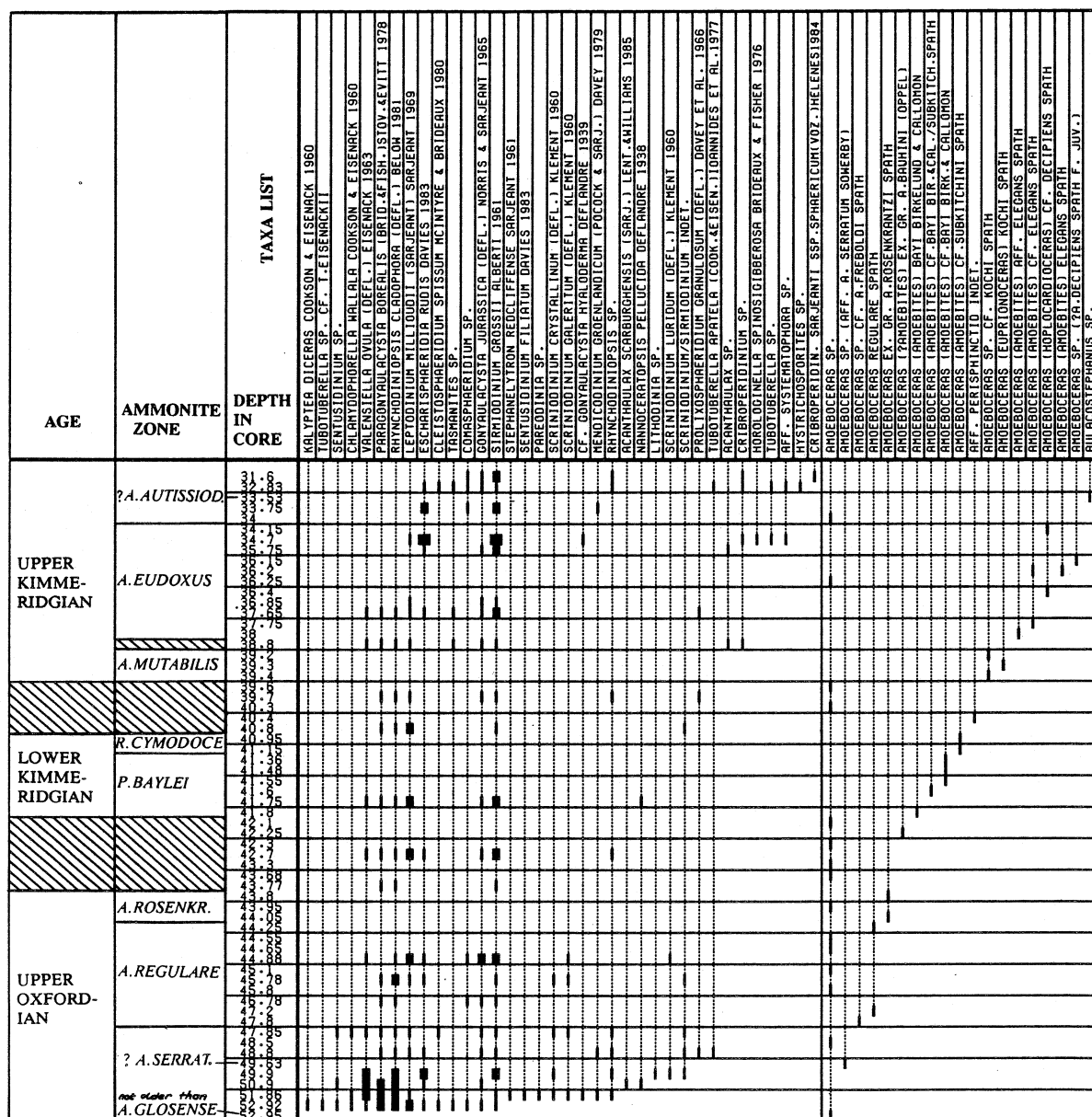


Figure 3.3.3 Palynological and ammonite range chart, core 7227/8-U-3.

42.25 - 33.53 (?31.60) m: Kimmeridgian

Ammonites

The Kimmeridgian (Lower Kimmeridgian, sensu anglico) yielded many ammonites in the studied core, mainly belonging to the genus Amoeboceras. Hence, the subdivision of the stage into the mixed Amoeboceras - perisphinctid horizons worked out by Birkelund & Callomon (1985) in East Greenland seems to be the most applicable for the studied area; it also enables the differentiation of the standard perisphinctid zones of the Kimmeridgian from northwest Europe.

The beds between 41.80 m and 41.36 m have yielded five specimens of Amoeboceras (Amoebites) bayi Birkelund & Callomon - A.(A.) cf. bayi Birkelund & Callomon which generally indicate the Amoeboceras bayi and Pictonia aff. normandiana horizon of Birkelund & Callomon (1985). The single poorly preserved ammonite found at 42.25 m is very close to Amoeboceras (Amoebites) bauhini (Oppel) as discussed recently by Birkelund & Callomon (1985) who have treated the species as characteristic for the very base of the Kimmeridgian. Hence it may be suggested that not only the deposits occurring in the borehole between 41.80 m and 41.36 m, but also those lying below (at least down to 42.25 m) are of Early Kimmeridgian age, and generally correspond to the P. baylei Zone from northwest Europe.

The ammonite Amoeboceras cf. subkitchini Spath has been found at 41.15 and 40.95 m. The species A. subkitchini Spath, and the allied forms occur in East Greenland as well as in other areas in the beds approximately corresponding to the R. cymodoce Zone of northwest Europe.

The microconch of Amoeboceras (Euprionoceras) kochi Spath and fragmentary preserved ammonites described here as Amoeboceras cf. kochi Spath occur between 39.40 m and 39.20 m in the core studied. It is the faunistic horizon of Amoeboceras kochi of Birkelund & Callomon (1985) placed somewhere within the aulacostephanid zones - and most possibly close to the topmost part of the A. mutabilis Zone. Then, between 38.00 m and 34.15 m an ammonite assemblage with Amoeboceras (Amoebites) elegans Spath and the allied forms as well as Amoeboceras

(Hoplocardioceras) cf. decipiens Spath occur. The ammonites are typical of the two faunistic horizons i.e. Aulacostephanus eudoxus and Amoeboceras decipiens horizon and Amoeboceras elegans horizon in East Greenland (Birkelund & Callomon 1985). However these horizons have only a local stratigraphical value, as the Amoeboceras species characteristic for them occur together in one bed not only in the studied borehole, but also in some other areas as well e.g. in Spitsbergen. The beds containing the discussed species Amoeboceras decipiens Spath and A. elegans Spath correspond approximately to the A. eudoxus Zone of northwest Europe.

The last ammonite found at 33.53 m is a poorly preserved, nevertheless typical representative of the genus Aulacostephanus sensu stricto which indicates the A. eudoxus Zone, or even the A. autissiodorensis Zone - the topmost zone of the Kimmeridgian.

Palynology

The presence of Nannoceratopsis pellucida at 41.75 m indicates an age no younger than the lowermost Kimmeridgian P. baylei Zone, in good agreement with the ammonite data. Also higher in the interval the assemblages have most taxa in common with the Upper Oxfordian unit below. Rhynchodiniopsis cladophora is recorded consistently up to 37.65 m, where it seems to disappear. This probable extinction in the lower part of the A. eudoxus Zone is two ammonite zones lower than claimed by Woollam & Riding (1983) who also reported rare or uncertain occurrences of R. cladophora in the Volgian P. scitulus - V. fittoni Zones. Nøhr-Hansen (1986) found scattered specimens of R. cladophora in the R. cymodoce and nearly to the top of A. mutabilis Zone in Westbury, England with no records in the A. eudoxus Zone.

One sample at 34.70 m from the upper part of the A. eudoxus Zone contains abundant Escharisphaeridia rudis and Sirmiodinium grossii. Rare poorly preserved hystrichospheres, possibly a species of Systematophora are present at 34.70 m and 32.83 m. The latter sample interestingly also contains Lower to Middle Devonian Hystrichosporites sp.

Microfauna

Samples at 31.60 m, 40.80 m and 52.92 m are barren or without recognizable microfossils.

Visual kerogen

The samples are richer in unstructured organic material than in woody material except at 51.86 and 36.85 m. At 49.90, 48.80, 43.77 and 37.65 m the amounts are about equal. Blade-shaped wood fragments are particularly common at 50.90 m.

The number of palynomorphs varies considerably from close to none at 43.77, 39.70, 36.85 and 35.75 m to approximately 20% of the organic particles bigger than 15 μm at 42.70 and 32.83 m. Pollen and dinocysts are more important constituents than spores.

TAI-values of 2 to 2+ on an 1-10 scale indicate immature to moderately mature deposits.

3.3.7 Organic geochemistry

High concentrations of $\text{C}_1\text{-C}_4$ headspace and occluded hydrocarbons occur in the middle part of the core section, approximately between 38.38 and 44.31 m, and appreciable amounts of C_{5+} -hydrocarbons were observed in most occluded gases and in the headspace gas at 32.03, 38.38 and 39.28 m (Figure 3.3.4). Although the occluded gases of that middle interval show high wetness, the values for the total gas remain below 25% because of the high proportion of relatively dry headspace gas. The high iC_4/nC_4 ratios (1.2 - 26) suggest that the gases may originate from an immature source. The adsorbed gas shows similar iC_4/nC_4 ratios and an extremely 'wet' composition, whereas the carbon isotope ratios of the adsorbed methane and ethane may rather indicate a source of late catagenetic or early metagenetic maturity. However, these values are not very reliable because some of the samples have obviously undergone partial oxidation (see comment in section 3.1.7). It may therefore not unreasonable to consider the gases as indigenous products of early maturation.

The whole cored section contains abundant organic matter as revealed by TOC contents between 3.7 and 19.2 wt% (Figure 3.3.5). In the richest interval between ca. 40 and 49 m depth (base Kimmeridgian and top Upper Oxfordian) most values exceed 10% TOC, while the samples from 49.67 to 51.86 m depth contain on average only 5% TOC. Rock-Eval hydrogen indices between 250 and 450 mg HC/g TOC and consistently low oxygen indices ($< 20 \text{ mg CO}_2/\text{g TOC}$) suggest that all but one sample contain relatively hydrogen-rich kerogen of type II and II-III with a good potential for the generation of liquid hydrocarbons (Figure 3.3.6). Type II kerogens are mainly found in the organic richest rocks.

The pyrolysis-gas chromatograms show well developed alkane/alkene doublets up to $\text{C}_{20}\text{-C}_{25}$ but also an appreciable amount of aromatic compounds and occasionally the isoprenoid 1-pristene. The moderate content in phenolic compounds and the relatively low ratio of (m+p)-xylenes over n-octene is in accordance with a mixed marine/continental precursor material of the organic matter. This agrees with the Rock-Eval data. The ratios between different aromatic and aliphatic compounds in the pyrolysate vary only little along the whole core.

Vitrinite reflectance data (0.27 - 0.30 %Ro), liptinite fluorescence colours (zone 1 - 3), and low values for the production index (< 0.07) indicate that the rocks are thermally immature. This is basically confirmed by the TMAX values which all are below 430°C , but obviously correlate with the hydrogen index and therefore are of limited value for maturity determination.

Seven samples from this core were extracted. All of them are very rich in both EOM (2554 - 18082 wt ppm of rock) and hydrocarbons (390 - 4232 wt ppm of rock) (Figure 3.3.7). The extractability of the organic matter itself (8.4 - 22.7 mg HC/g TOC) and the hydrocarbon content of the extract (max. 22.5%) are however low which is characteristic of immature samples.

The gas chromatograms of the saturated fractions are dominated by the peaks of pristane and phytane (Figure 3.3.8). Also other acyclic isoprenoids are relatively abundant. Bimodal n-alkane distributions with maxima at $\text{C}_{13}\text{-C}_{17}$ and $\text{C}_{27}\text{-C}_{29}$ and a strong preference of

odd-numbered heavy n-alkanes are consistent with an immature, mixed marine/terrestrial source. The input of land plant material may be slightly reduced at 40.80, 43.77, 45.78, and 47.85 m as suggested by the relatively lower proportion of heavy alkanes.

The gas chromatograms of the aromatic fractions are characterised by a large 'hump' and additional, in part strong, peaks in the high-molecular region. Methylnaphthalenes are the most abundant compounds of the lower molecular range, followed by di- and trimethylnaphthalenes and the phenanthrene group. Two compounds which elute together with the trimethylnaphthalenes and somewhat before the phenanthrene, respectively, are quite abundant in the samples from 32.83 and 51.86 m depth. Based on their mass spectra they were tentatively identified as alkyltetralin and alkyl-naphthalene isomers. Dibenzothiophene occurs in fairly high concentrations as compared to phenanthrene which is not unusual for rocks deposited in marine environments.

The composition of the triterpanes and steranes is little consistent with the other data, as practically all isomer ratios suggest a maturity higher than 0.3 %Ro for these extracts. This is especially indicated by the high proportion of 22S homohopane relative to the 22R isomer (peaks G and H in m/z 191 mass chromatograms), and also by the high abundance of diasteranes compared to the regular steranes (m/z 217, peaks a-g).

Most of the maturity-dependent ratios increase from the bottom sample to the top sample. This unexpected trend is apparently unrelated to the organic matter type and cannot be explained at present.

Carbon isotope profiles for five sets of extract fractions show a good agreement between four of the extracts which indicates a common source. The profile for the 51.86 m sample differs from these extracts by a very low isotope ratio for the saturates and an increased value for the aromatics. This curve shape is somewhat similar to those of the extracts from core 7228/3-U-1.

Summing up, it may be said that the core 7227/8-U-3, although immature, shows a good petroleum generation potential due to both its organic richness and the relatively good quality of the kerogen. Appreciable amounts of indigenous hydrocarbons are present in the rock. A very minor input of hydrocarbons from a different source cannot be ruled out because of the discrepancy between biomarker- and vitrinite reflectance-defined maturity.

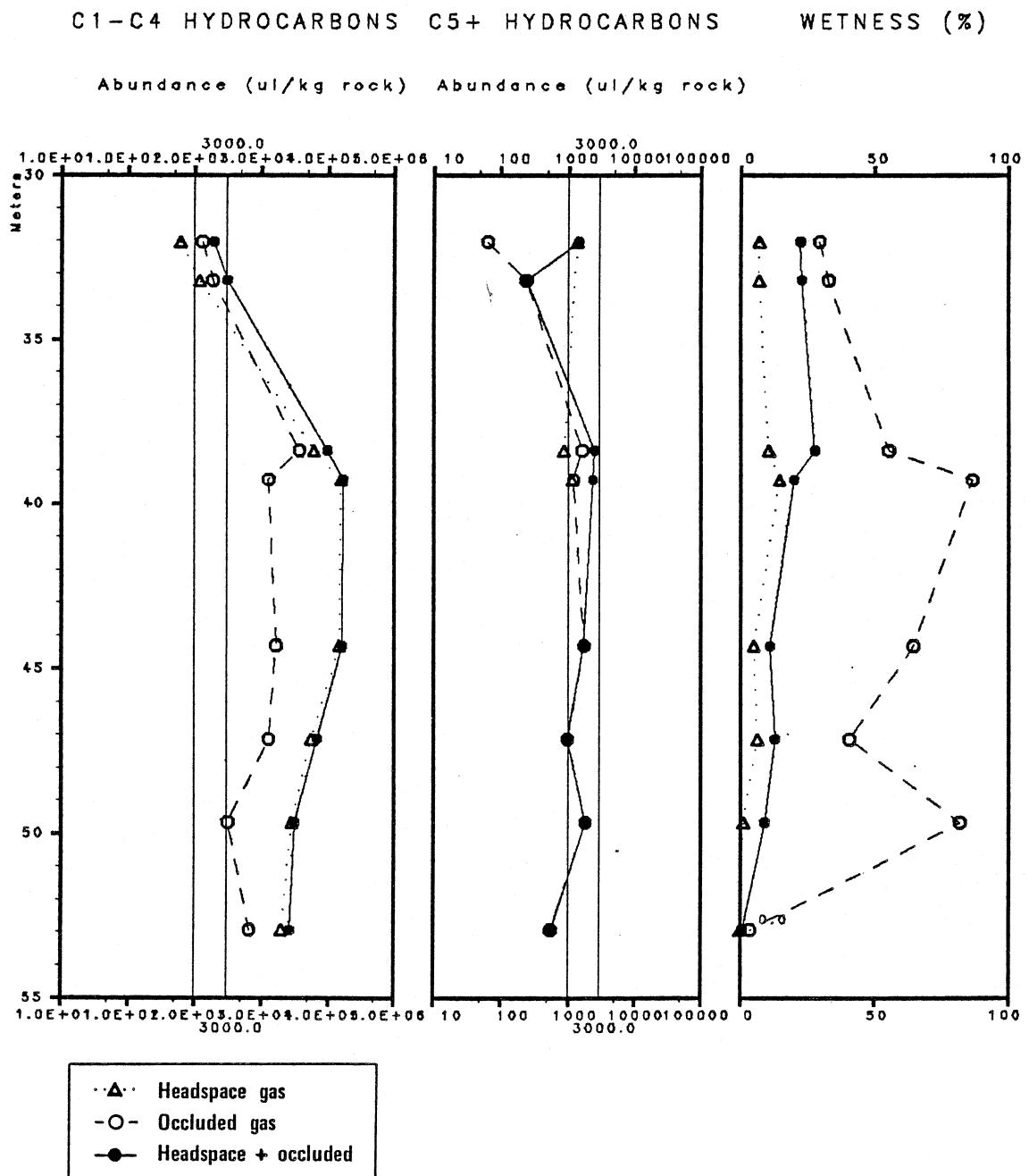


Figure 3.3.4 Yield and composition of headspace/occluded gas of core 7227/8-U-3.

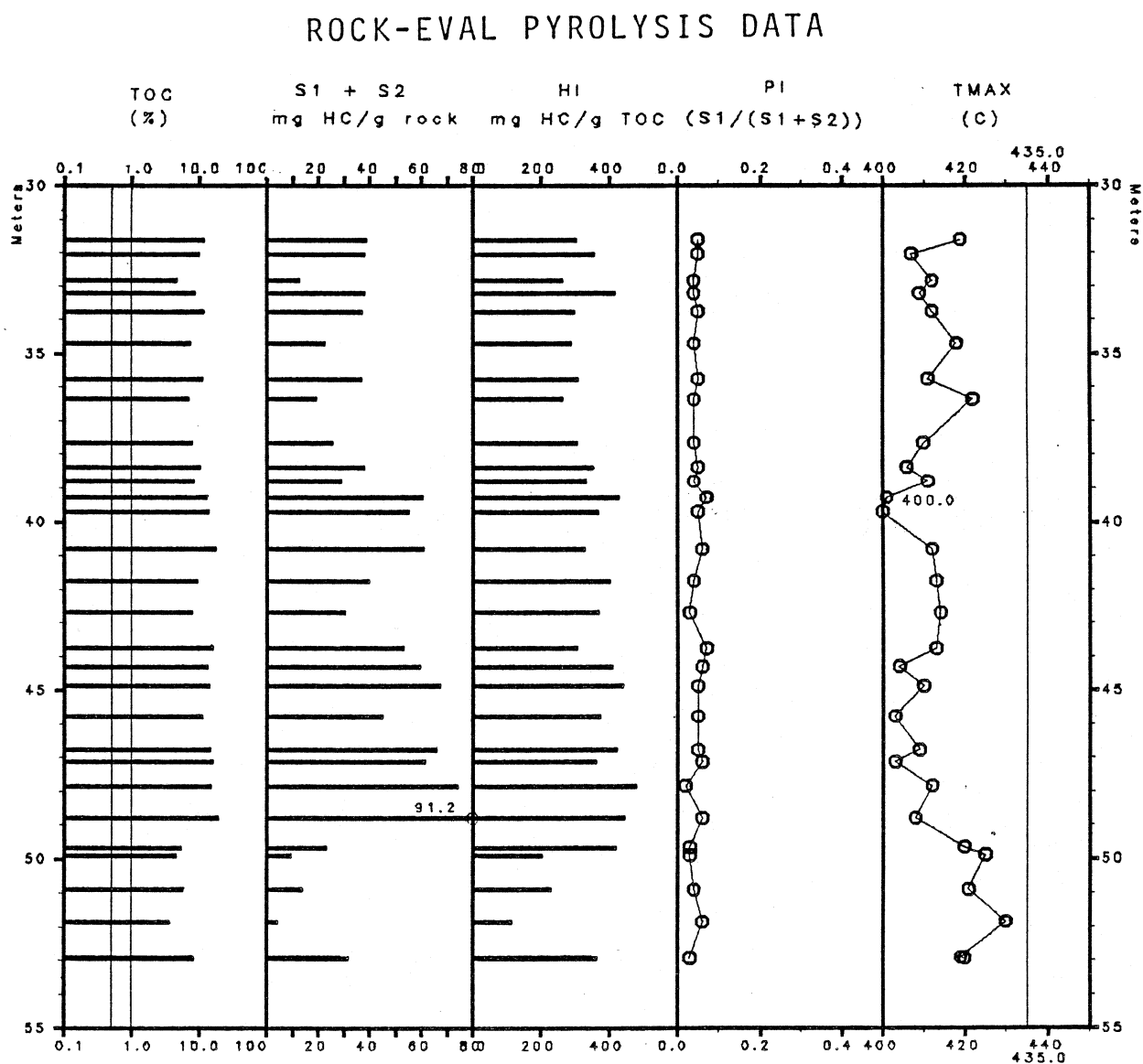


Figure 3.3.5 Total organic carbon content and Rock-Eval data of core 7227/8-U-3.

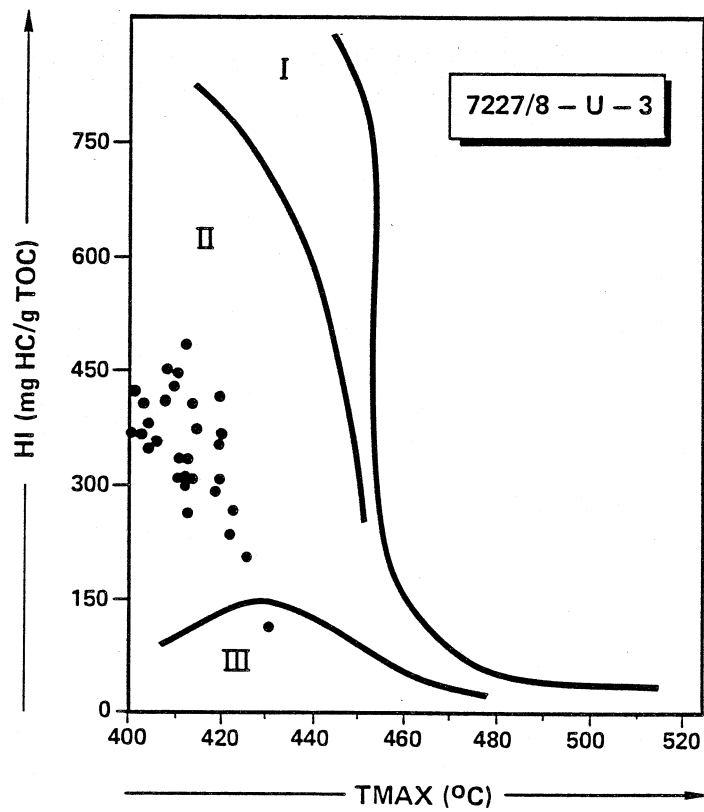
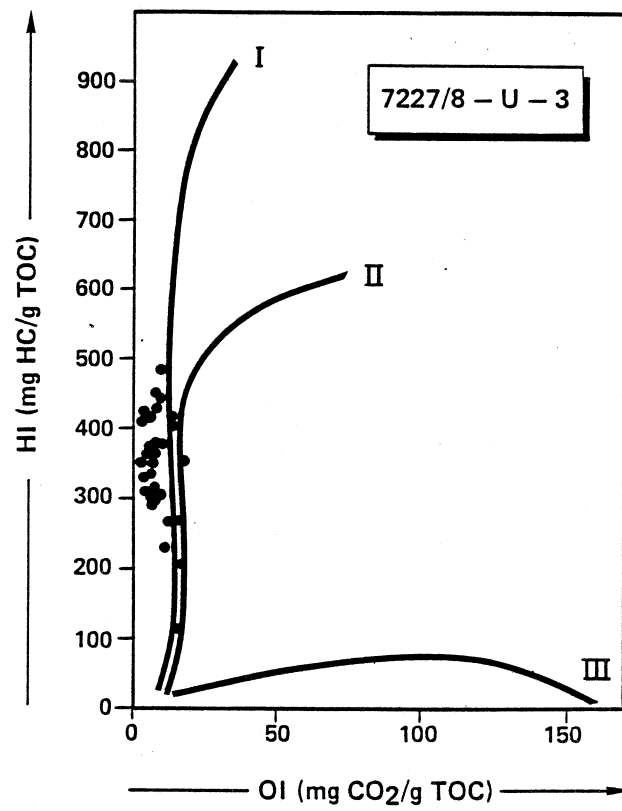


Figure 3.3.6 a Rock-Eval hydrogen index vs. oxygen index for core 7227/8-U-3.

b Hydrogen index vs. T_{max} for core 7227/8-U-3.

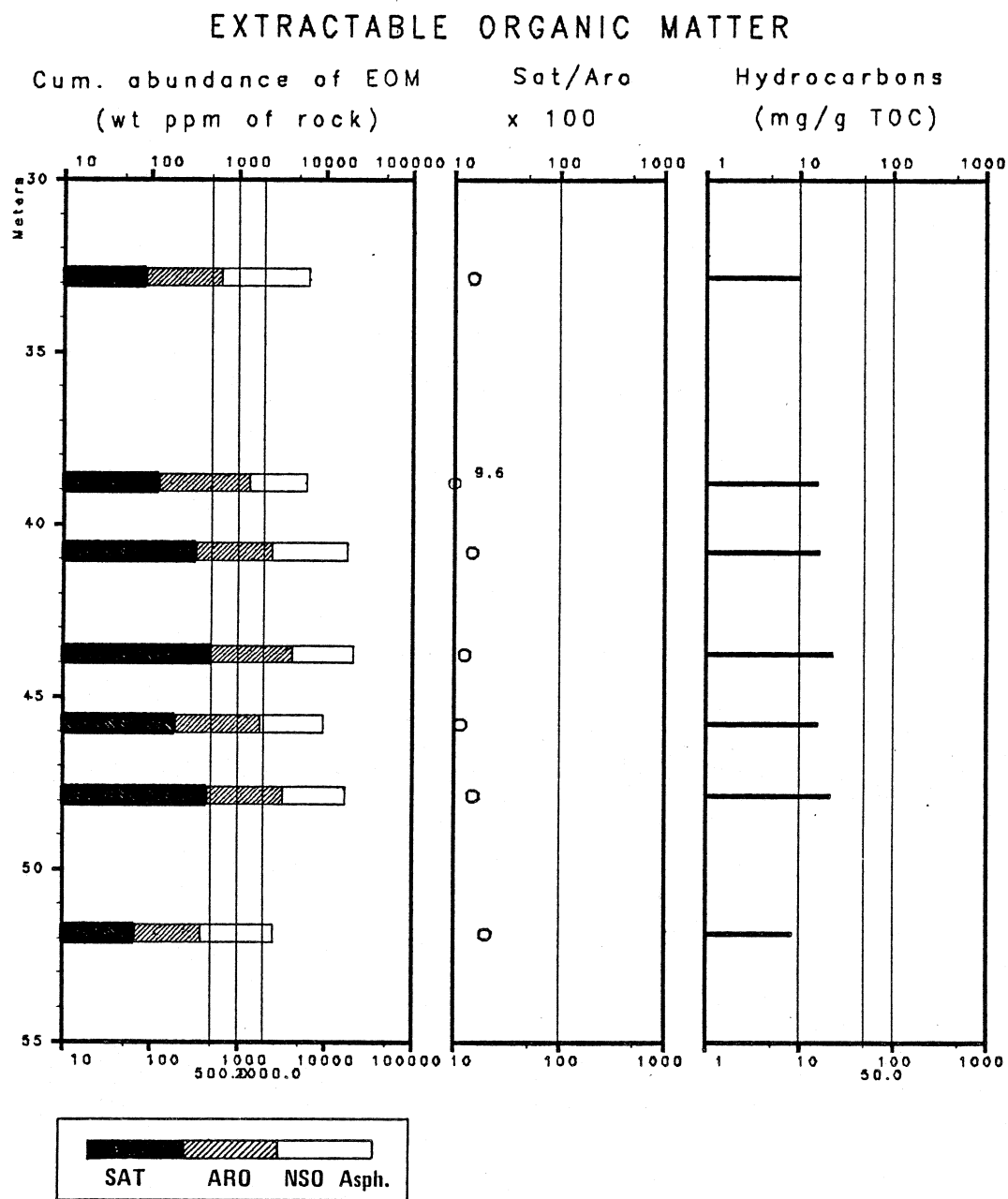


Figure 3.3.7 Extract data for core 7227/8-U-3.

GAS CHROMATOGRAPHIC RATIOS

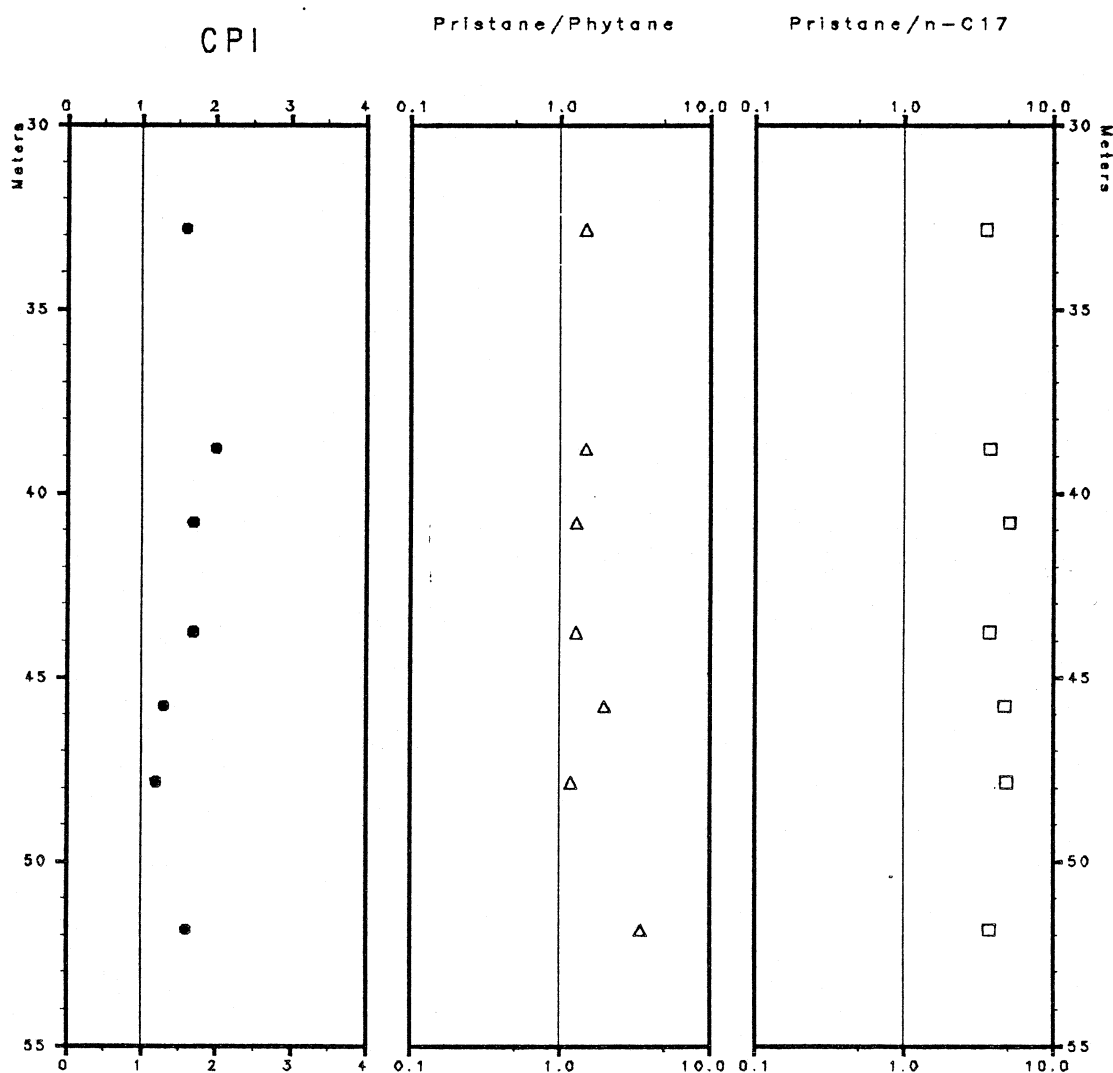


Figure 3.3.8 Compound ratios from gas/chromatograms of saturated hydrocarbon fractions from core 7227/8-U-3.

3.3.8 Depositional environment

Ammonite and bivalve fragments and dinoflagellate cysts occur throughout the core and suggest that the sediments were deposited in normal saline marine environments. The high organic content may be partly due to a very slow clastic sedimentation rate (approximately 3mm/1000 years). The fossil recovery, bioturbation and in situ worm tubes show that the water at the sea floor was at least partly oxygenated, although much of the organic material is preserved. Deposition may have taken place through a stratified water column with periods of oxygen depletion also at the bottom.

The graded siltstone to fine-grained sandstone in the interval between 39 m and 35.75 m indicates at least some episodes when terrestrially derived clastic material was deposited, probably as very distal storm beds. This indicates a slight influence from the coast.

3.4 7227/8-U-2

3.4.1 Summary

9.28 m of in situ grey to dark grey in parts strongly bioturbated clayey siltstone were drilled between 47.13 and 37.85 m below the sea floor (Figure 3.4.1). Three light grey probably bentonitic beds occur. Similar dinoflagellate cyst assemblages occur throughout the core and point to an Albian, probably lower Middle Albian age. No major sequence boundaries have been penetrated but the core is recovered from an Albian unit immediately below a major regional sequence boundary (reflector α in Figure 3.4.2).

Most samples from this core contain between 0.5 and 1 % total organic carbon. The organic matter consists largely of recycled material which corresponds to kerogen type IV according to the Rock-Eval data and does therefore not have any potential for hydrocarbon generation. Vitrinite reflectance (0.28 %Ro), production index, and extract yields suggest that the organic matter is immature. A higher maturity for the extract is indicated by the composition of the extract and of the saturated hydrocarbon fraction. The presence of non-indigenous hydrocarbons can therefore not be absolutely ruled out, but the amounts involved would be extremely low as revealed by the very low extractability of the organic matter.

Dominance of marine forms in the planktonic faunal and floral assemblages suggests an open marine environment far from land. Fairly poor benthonic assemblages indicate that the bottom water masses were depleted with respect to oxygen.

3.4.2 Seismic interpretation

The Quaternary can be divided in two major seismic units. The base of the lowest unit was reached at 37.8 m and the well went into the bedrock between reflectors α and β (Figure 3.4.2). This seismic unit shows uniform internal reflections and has a constant thickness of about 12 m in the area. The boundary on top of this unit, which we interpret as an equivalent to the Cenomanian sequence boundary seen elsewhere, is a significant reflector also here and can be traced regionally.

We will not exclude that this boundary is of Albian age. In Svalbard Upper Albian and younger Cretaceous rocks are missing.

7227/8-U-2
Age: Middle Albian

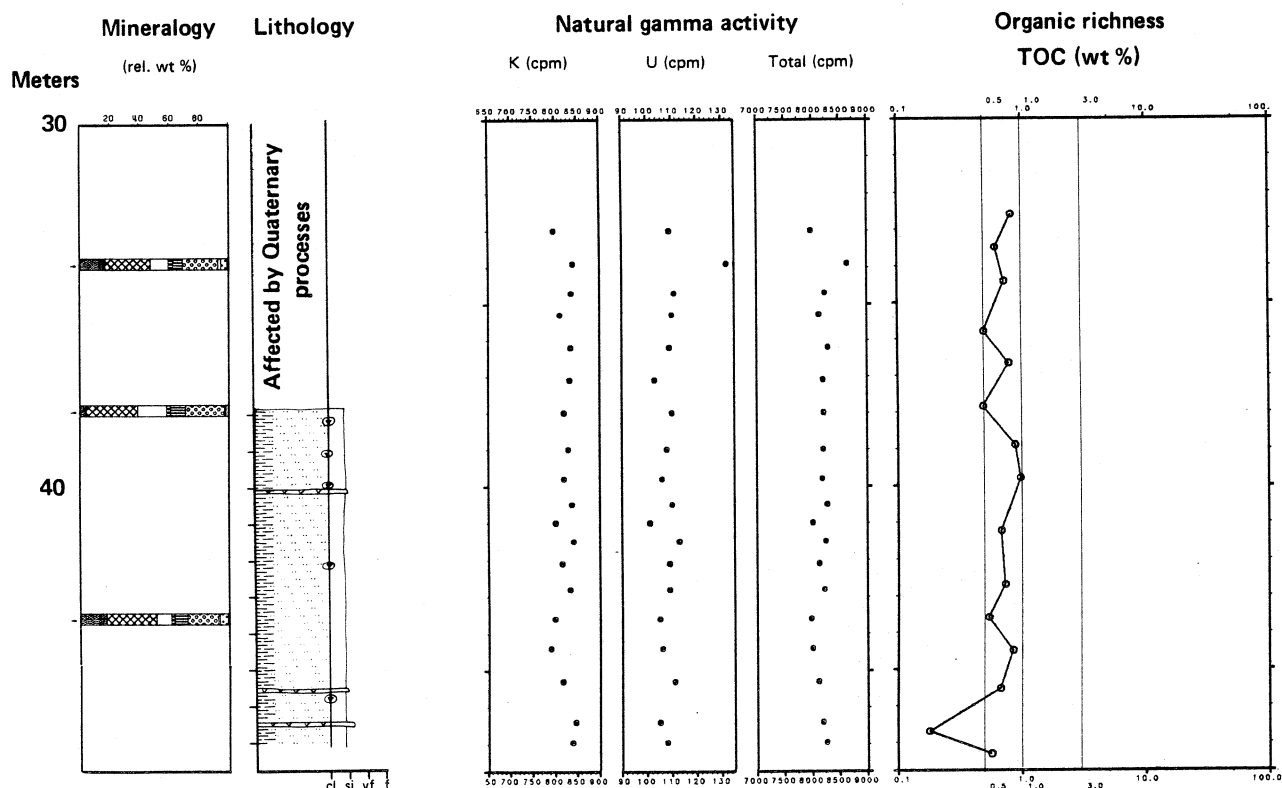


Figure 3.4.1 Summary figure of core 7227/8-U-2.

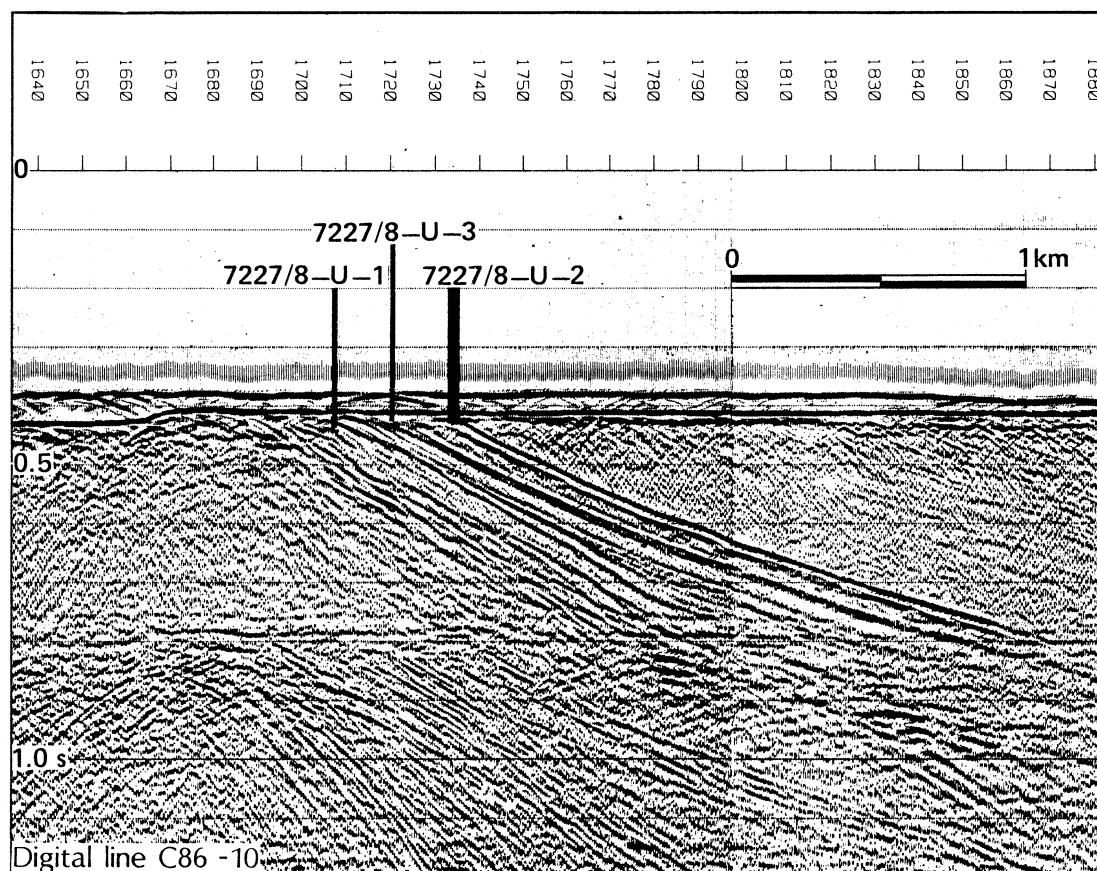


Figure 3.4.2 Digital seismic line showing the position of core 7227/8-U-2 and the related seismic sequence boundaries.

3.4.3 Core description

9.28 m of in situ sedimentary rocks were drilled between 47.13 m and 37.85 m below sea floor.

The strata consist of a dark slightly laminated bluish grey clayey siltstone with dark grey, few mm thick horizontal laminae. The core is strongly bioturbated by predominantly horizontal burrows. The diameter of the burrows varies from less than 1 mm to 13 mm with a mean of about 5 mm. They normally are filled with dark grey silty clay, but occasionally by pyrite and/or brown chert.

Three light grey clays up to 9 cm thick, probably represent bentonitic beds. Some coarser grains occur, particularly in lower part of the clays. Thin section microscopy show that they consist of grey clay minerals with very few siltsized quartz grains. Siderite has grown by

replacement of some of the clay matrix. Burrows occur only in the uppermost part of the upper bed. A concretion at 45.75 in association with a bentonite bed consists of abundant radiolarians in a brown cherty matrix (Figures 3.4.3 and 3.4.4). This supports our interpretation of the beds as bentonites.

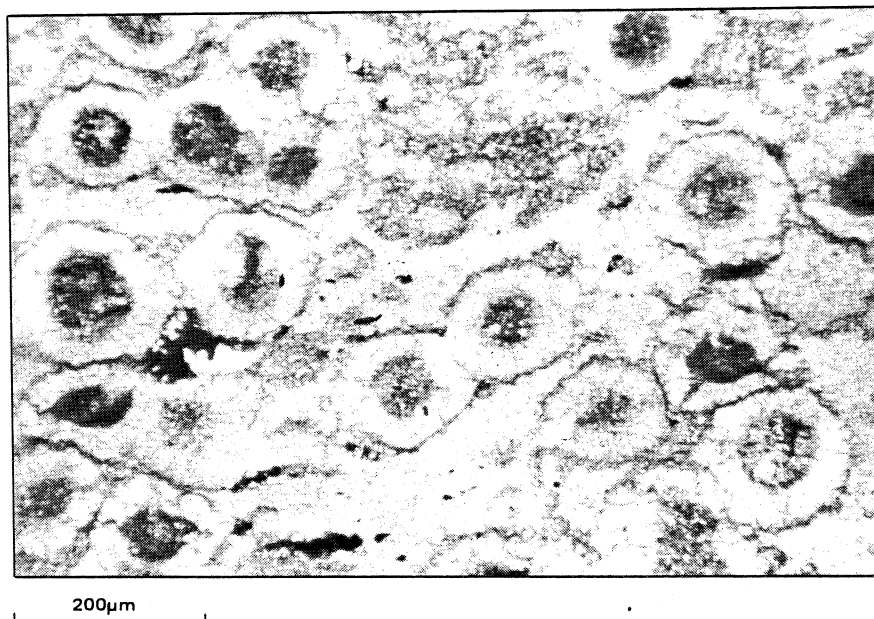


Figure 3.4.3 Thin section of radiolarite bed (45.75 m) showing cross sections of spherical radiolarians.



Figure 3.4.4 Thin section of radiolarite bed (45.75 m), showing section of a nassellarid radiolarian.

3.4.4 X-ray diffraction analysis

Three samples from this core has been analyzed by use of X-ray diffraction (Table 3.4.1).

The sample from 39.80 m is a clayey siltstone with about 70 wt% clay minerals including detrital mica. The rest is mainly quartz and small amounts of feldspars.

The sample from 45.54 m is from the clayey siltstone just above a light grey bentonite layer. It contains mainly clay minerals, with mixed layer illite-smectite as the most important. The sample from 46.75 m is of a bentonite. The major minerals are illite-smectite mixed layer and

siderite cement. Under the microscope, the siderite is observed as single rhombohedrons "floating" in a clay matrix.

Table 3.4.1 Mineralogical composition (relative weight %) of samples from core 7227/8-U-2.

SAMPLES (m)	MEC	MIX	I/M	CHL	KAO	QTZ	ALK	PLAG	CAL	DOL	SID	APA	PY
39.80	4.0	35.0	19.0	3.0	10.0	26.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0
45.54	4.0	39.0	11.0	3.0	10.0	24.0	2.0	6.0	0.0	0.0	0.0	0.0	1.0
46.75	1.0	20.0	-	-	3.0	tr	-	6.0	-	-	70.0	-	-

3.4.5 Petrophysics

Natural γ -radiation

The natural γ -radiation of the pre-Quaternary part of this core shows little variation with depth (Figure 3.4.1). In the Quaternary affected part at 34 m, a relative high uranium value is registered, but there are no other data to explain this local uranium anomaly.

Sound velocity

Eleven measurements of the horizontal sound velocity of the pre-Quaternary core has been performed. The measured values are uniform ranging from 2200 m/s to 2400 m/s (Table 3.4.2).

Table 3.4.2 Horizontal sound velocity (v) in samples from core 7227/8-U-2.

Depth (m)	v(m/s)	Lithology
38.05	2260	Clayey siltstone
38.70	2250	"
39.38	2250	"
40.78	2320	"
41.00	2190	"
41.60	2410	"
42.50	2360	"
43.40	2230	"
44.35	2420	"
45.28	2430	"
46.45	2400	"

3.4.6 Palaeontology

Palynology

Middle Albian

Odontochitina operculata, Palaeoperidinium cretaceum, Lithodinia imperfecta, Cribroperidinium muderongense group, Cauca parva and Oligosphaeridium spp. dominate the dinocyst assemblages throughout the core (Figure 3.4.5). Brideaux & McIntyre (1975) found L. imperfecta (as Dictyopyxidia imperfecta) in upper Lower and Middle Albian strata. Davey & Verdier (1971) reported C. parva to range up into the lower Middle Albian L. lyelli Zone whereas they found Rhombodella natans exclusively in Middle and lower Upper Albian strata. We have recorded the latter (as Rhombodella paucispina) from 42.70 m upwards and its co-occurrence with C. parva points to a lower Middle Albian age from this level. Odontochitina singhii at 38.48 m supports this. Foucher (1981), however, reported C. parva to range throughout the Albian of France, but according to our experience the species does not occur consistently in post early Middle Albian deposits on the northern Norwegian continental shelf.

CORE 7227/8-U-2

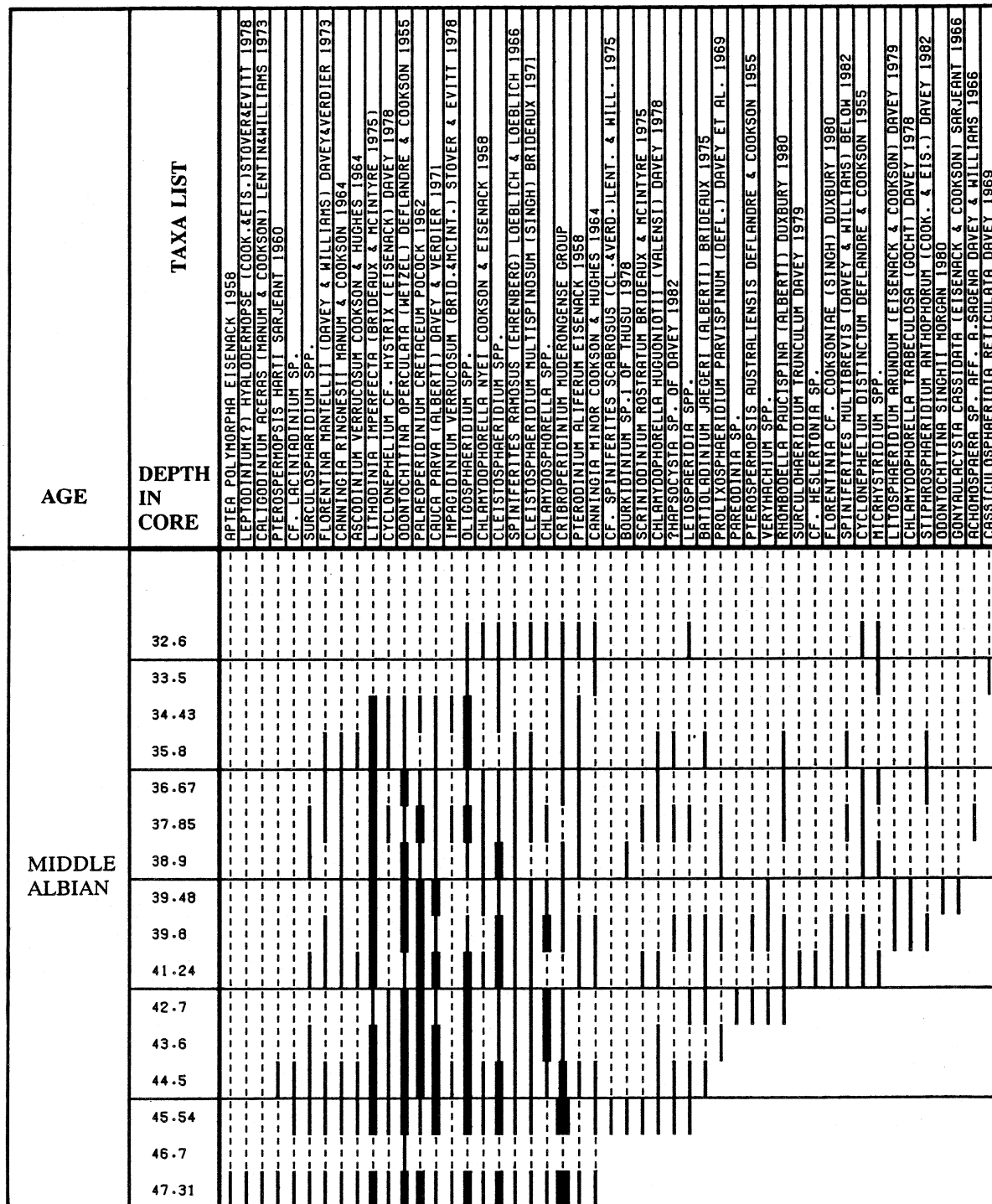


Figure 3.4.5 Palynological range chart, core 7227/8-U-2.

The lowermost 5 metres of the core are probably also Middle Albian in age because of the numerous specimens of P. cretaceum and only scarce Chlamyphorella trabeculosa. C. trabeculosa occurs consistently in what we interpret as the Lower Albian in Tromsøyflaket whereas P. cretaceum is more common higher in the section.

Above 37.20 m the core is affected by Quaternary processes, but still representative of the bedrock. We have not found contaminants in our bulk samples below 32.60 m, a sample in which Triassic, Lower and Upper Cretaceous and Quaternary palynomorphs occur.

Visual kerogen

All samples contain high proportions of woody material (35-80%) consisting mainly of dark brown to black angular/elongated blade-shaped phytoclasts. Liptinitic material is also well represented (25-50%) in all the examined 16 samples, except at 46.70 m where coaly fragments comprise 60-70% of the organic matter. The liptinitic fractions are dominated by dinoflagellate cysts and bisaccate pollen while spores and cuticle fragments are generally more rare. Unstructured material is only present in minor amounts.

The examined samples show low thermal alteration with TAI-values of 2.5 to 3 on a 1-10 scale indicating immature deposits.

Microfauna

From the samples at 47.31 m to 35.80 m a fairly uniform assemblage of arenaceous foraminifera is met (Figure 3.4.6). The faunas are characterized by common occurrences of the agglutinated genera Haplophragmoides, Glomospira/Glomospirella, Hyperammina, Trochammina and Recurvoides. The foraminifera are to varying degrees greenish stained, and occur together with frequent to common nassellarid radiolarians. These general features fit well with the palynological conclusion with respect to age, as experienced from sediments in the Troms I area to the south.

CORE 7227/8-U-2

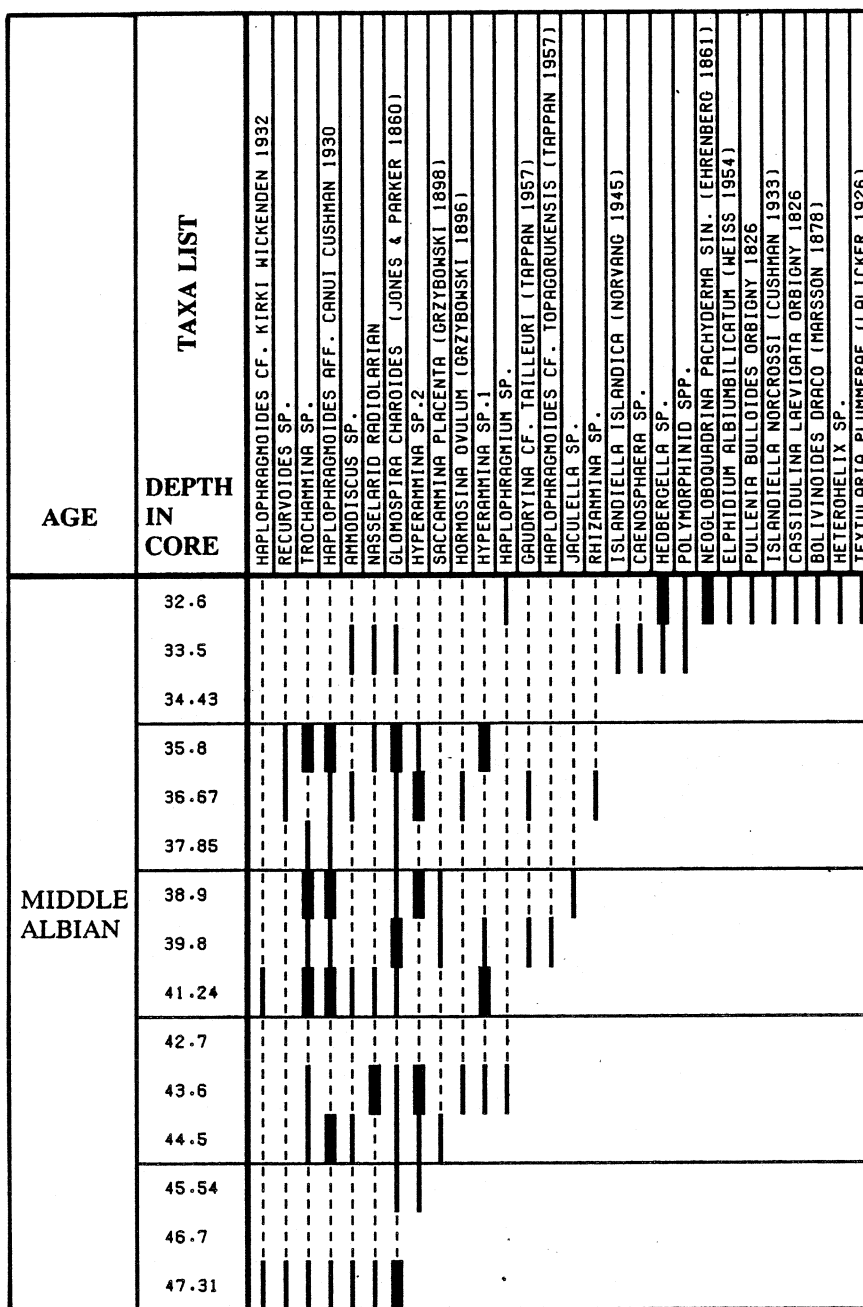


Figure 3.4.6 Foraminiferal range chart, core 7227/8-U-2.

Because of their moderate preservation most specimens cannot be attributed with certainty down to species level. Haplophragmoides topagorukensis and Gaudryina tailleuri are both mentioned from Aptian-early Albian strata of Alaska (Tappan 1962) and from the

Hauterivian of Spitsbergen (Nagy & Løfaldli 1985, IKU project). Similar forms occurred in the present sequence. Hyperammina sp. 1 and sp. 2 may be similar to Bathysiphon brosgei and Bathysiphon sp. of Nagy & Løfaldli (1985). We conclude that the assemblages are strongly facies controlled, and that stratigraphical index taxa are lacking. However, the combination of a greenish stained agglutinated fauna and nassellarid radiolarians support the mid Albian age suggested from other fossil groups.

In the bulk samples at 33.50 m and 32.60 m, Neogloboquadrina pachyderma and Islandiella islandica are suggested to be of a Pleistocene age. Reworking of deposits from various ages is testified by the presence of Textularia plummerae, Heterohelix sp., Hedbergella sp. and Bolivinoidea draco (Upper Cretaceous), and Haplophragmium sp. and nassellarid radiolarians (probably Lower Cretaceous).

3.4.7 Organic geochemistry

The amounts of headspace gas recovered from the samples were too low for determining reliable concentration values. Also the occluded gas is present only at very low concentrations. It consists of methane, ethane, and propane. C₅₊-hydrocarbons were detected only at 47.29 m (Fig. 3.4.7).

The analyzed rock samples contain a fair amount of organic matter (on average 0.67% TOC) (Figure 3.4.8). Low values for the hydrogen index (<58 mg HC/g TOC) as well as for the petroleum potential (Rock-Eval S1 + S2 < 0.4 mg HC/g rock) suggest that the organic matter is poor in hydrogen and that the rock has no generation potential for hydrocarbons (Figure 3.4.9). This is also indicated by the low methane yield, the abundance of benzene and toluene and by the lack of alkenes/alkanes beyond C₁₀ in the pyrolysates. Benzene occurs at higher concentrations than toluene which is in contrast to the samples from the other wells.

Microscopic investigation showed that practically all of the vitrinite consists of reworked material which shows reflectance values between 0.65 and 1.19 %Ro. Although of poor reliability, the value of 0.28 %Ro which was determined on a small population of vitrinites at 44.5 m

depth appears to be more representative for the maturity of the rock section. Also the fluorescence colours and the low production index values (<0.10) of this sample suggest that the rocks from this well are thermally immature.

The $T_{\max}$ values vary considerably and are sometimes quite high (416 - 455°C and outliers at 403, 472, and 530°C). This may be due to the small and flat S2 peaks which do not show a distinct maximum (low TOC content), but it may also reflect a substantial variation in the abundance of reworked organic material. The values are therefore of no use for determination of maturity.

The four extracted samples yielded low amounts of EOM (max. 376 ppm of rock) (Figure 3.4.10). Hydrocarbon yields of less than 13.4 mg HC/g TOC, a low saturates/aromatics ratio and a relatively small proportion of hydrocarbons in the total EOM (ca. 30%) are in accordance with the poor source quality and low maturity of the rocks.

The gas chromatograms of the saturated fraction show bimodal distributions of the n-alkanes with a high proportion of n-alkanes with 17 to 19 C-atoms. The relative amount of unresolved heavy compounds is smaller than with the extracts from well 7227/8-U-1. The ratios pristane/ nC_{17} and phytane/ nC_{18} and the CPI are remarkably low for all the samples and suggest that these hydrocarbons derive from a source which is more mature than the kerogen in the present rocks (Figure 3.4.11). The presence of non-indigenous hydrocarbons can therefore not be entirely excluded. Supporting evidence from biomarker composition could unfortunately not be obtained because the mass fragmentograms were too noisy.

The gas chromatograms of the aromatic fraction are characterized by a relatively large 'hump' of unresolved compounds in addition to several strong peaks in the range of the mono- and triaromatic steranes. The three-ring compounds are dominated by phenanthrene, 9- and 1-methylphenanthrene. Alkylated naphthalenes are almost missing and may have been lost during evaporation because of the low sample weights. The overall appearance of the gas chromatograms suggests an early maturation stage.

This core contains a fair amount of organic matter, but has no hydrocarbon generation potential, because of the hydrogen-poor nature of the kerogen. Vitrinite reflectance and low extract yield suggest that the rocks from this core are immature, although the molecular composition suggests a higher maturity for the extract. The presence of non-indigenous hydrocarbons can therefore not be absolutely excluded, but the amounts involved would be extremely low as revealed by the very low extractability of the organic matter.

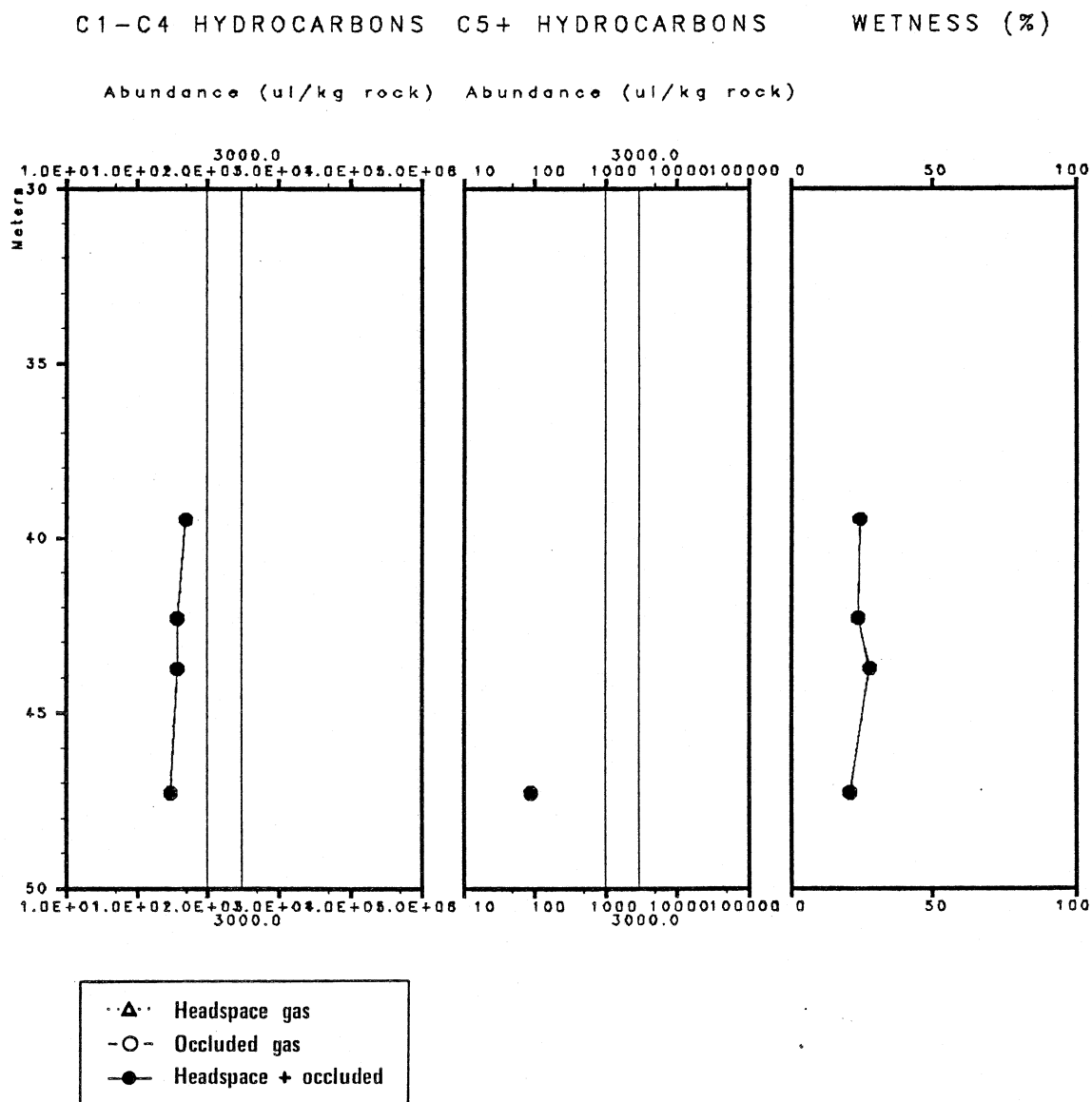


Figure 3.4.7 Yield and composition of headspace/occluded gas of core 7227/8-U-2.

ROCK-EVAL PYROLYSIS DATA

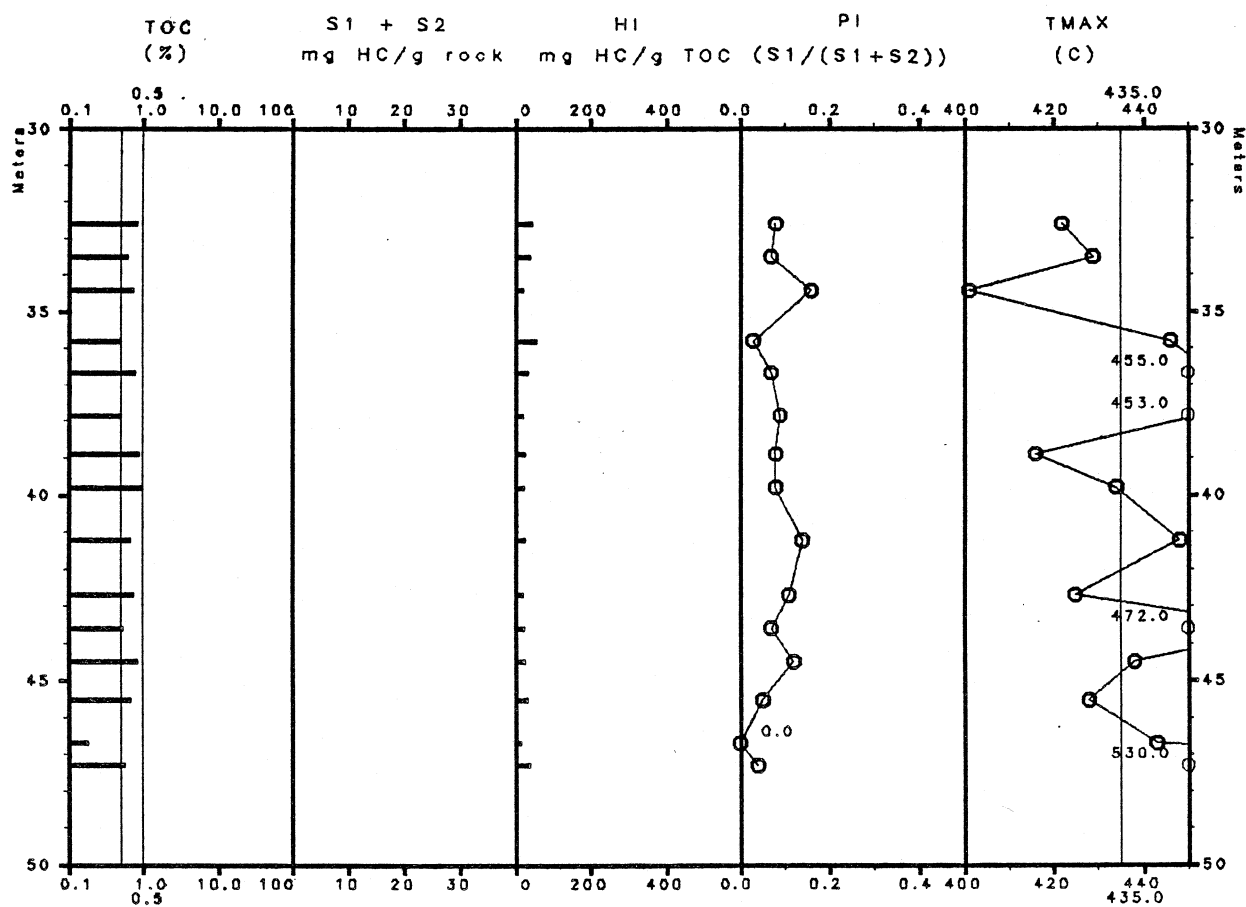


Figure 3.4.8 Total organic carbon content and Rock-Eval data of core 7227/8-U-2.

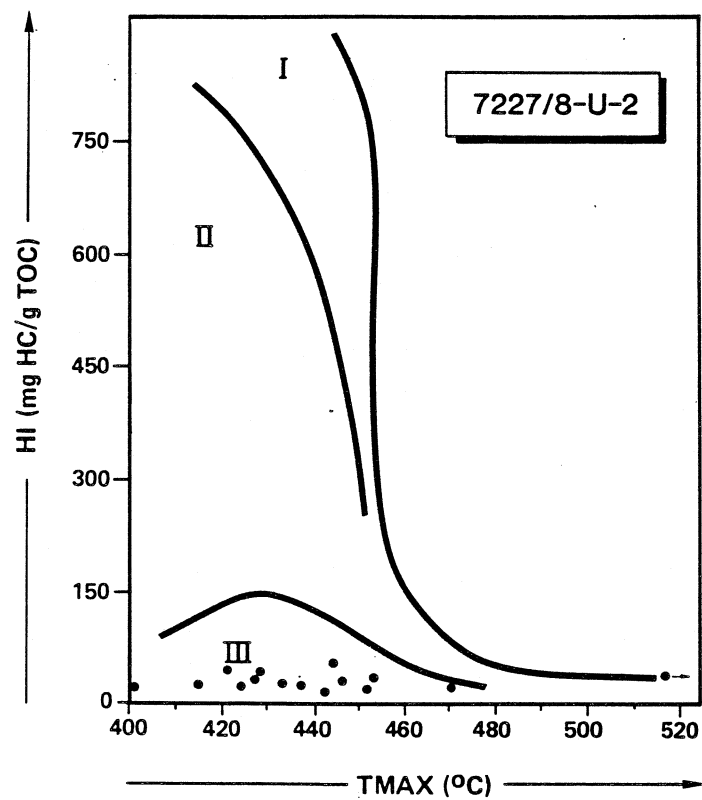
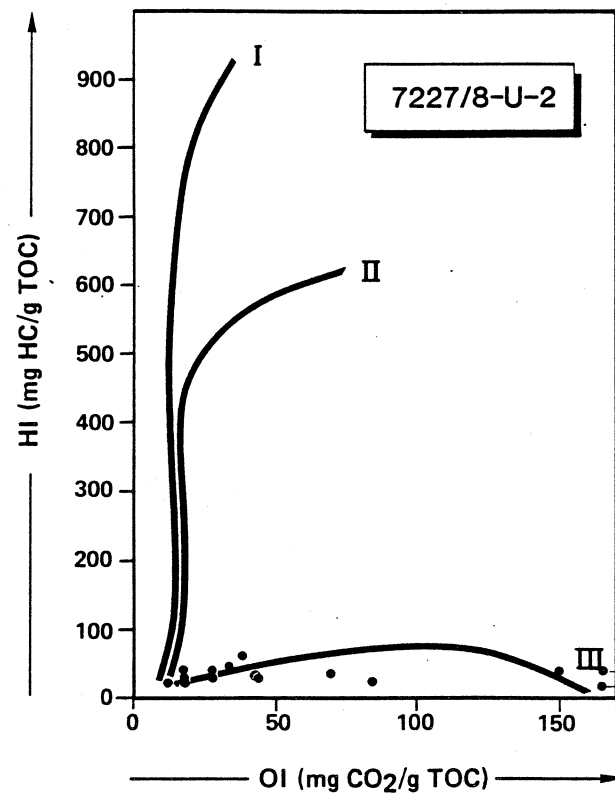


Figure 3.4.9 a Rock-Eval hydrogen index vs. oxygen index for core 7227/8-U-2.
b Hydrogen index vs. Tmax for core 7227/8-U-2.

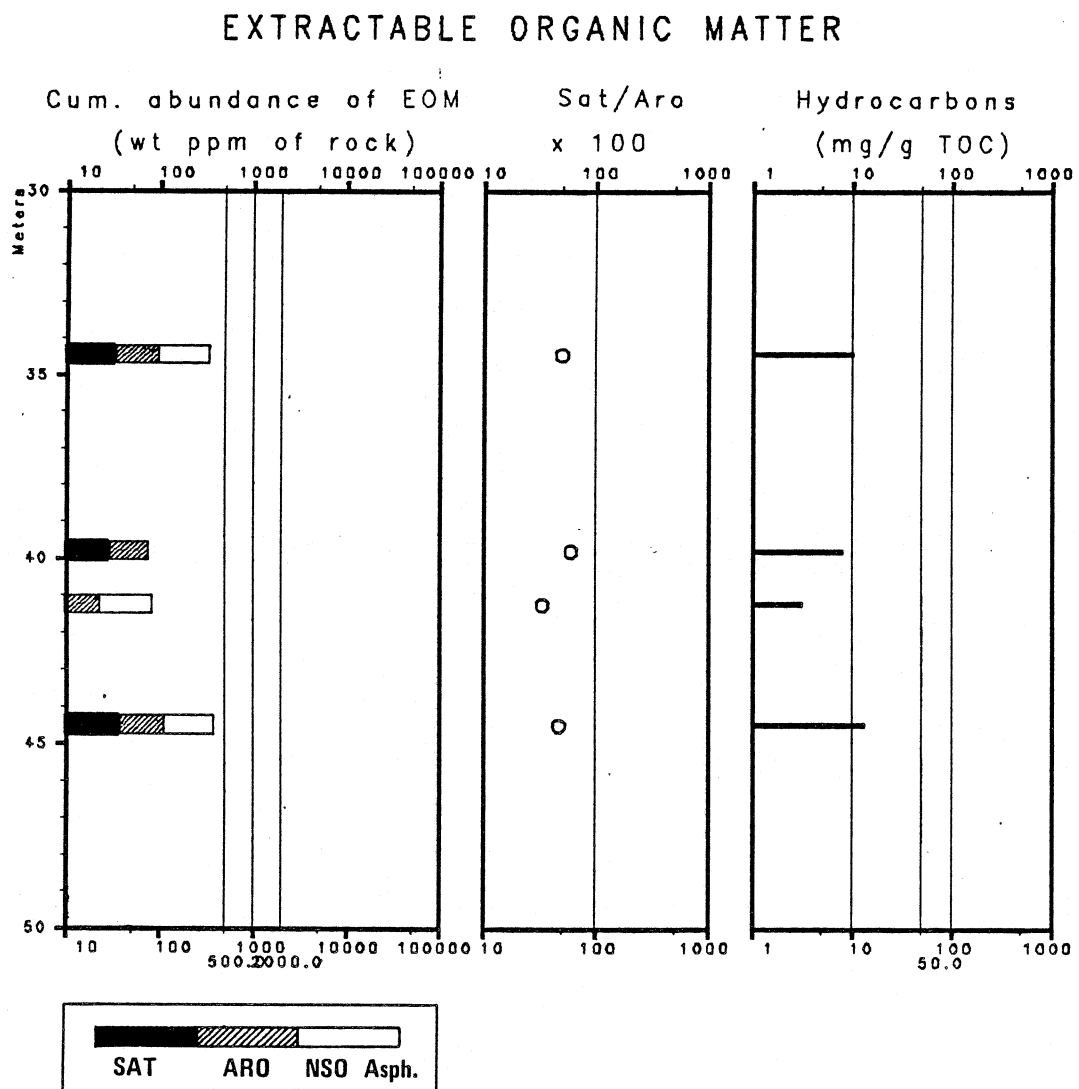


Figure 3.4.10 Extract data for core 7227/8-U-2.

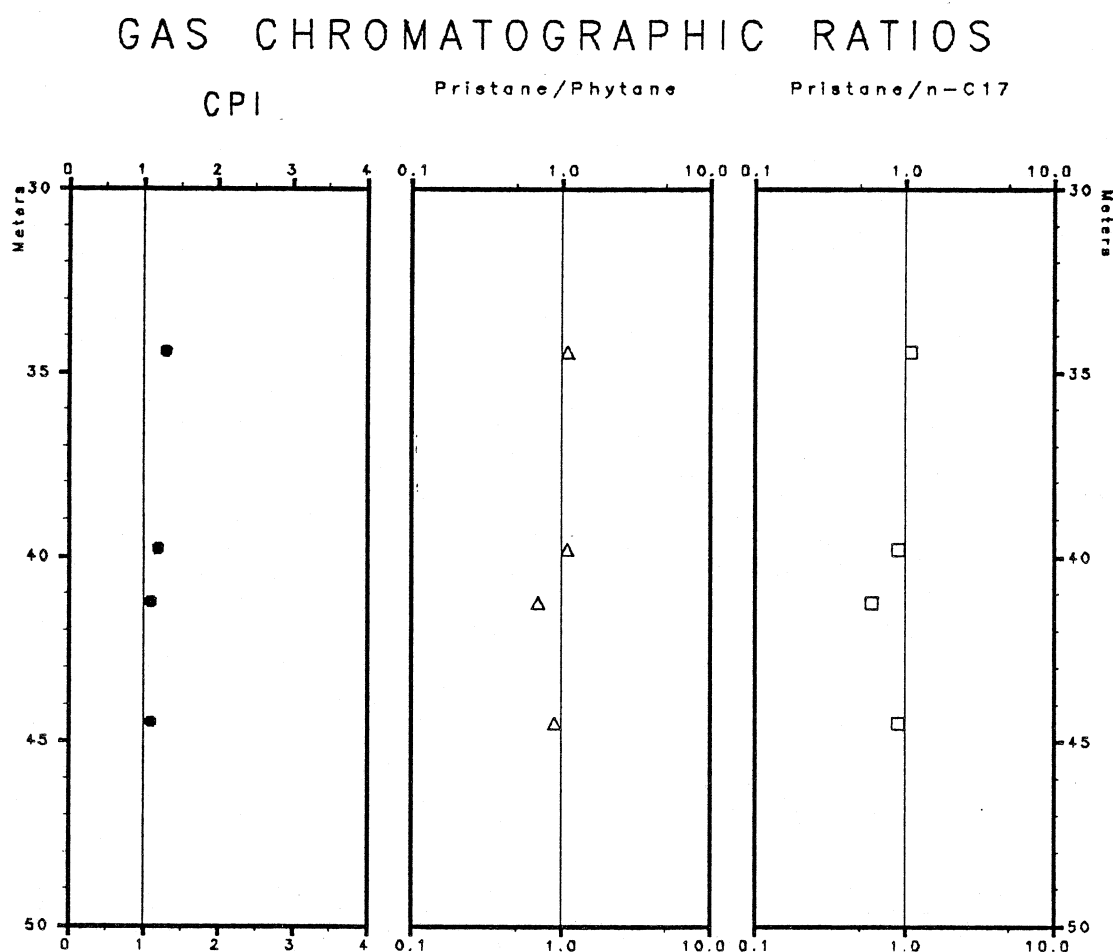


Figure 3.4.11 Compound ratios from gas chromatograms of saturated hydrocarbon fractions from core 7227/8-U-2.

3.4.8 Depositional environment

Palynostudies show a dominance of dinoflagellate cysts which indicate an open marine environment far from land. This is supported by common to abundant radiolarians. The core reflects varying conditions with respect to oxygen content in the bottom water masses, but never optimal conditions for a benthic population. The changing conditions are shown by strongly bioturbated sediments interlayered with laminated beds. The solely agglutinated foraminiferal assemblages indicate restrictions in dissolved oxygen throughout.

4. SEISMIC INTERPRETATION OF THE NORDKAPP BASIN AND ADJACENT AREAS

4.1 Seismic interpretation of adjacent areas

A preliminary bedrock map of the areas adjacent to the Nordkapp Basin is presented in Figure 4.1. The map is based on available shallow seismic and borehole data and shows the bedrock units subcropping below the Quaternary sediments. The thickness of the overburden varies from a few metres in some areas and up to 100-200 m.

The tentative dating of the units is partly based on published literature (e.g., Berglund et al. 1986; Rønnevik & Jacobsen 1984), partly on data obtained in the present project and partly on data obtained previously in the Barents Sea Mapping Program.

Along the coast of Finnmark, probable Palaeozoic rocks onlap the crystalline basement. The basement boundary is obviously influenced by faults which can be followed onshore. More exact location of these faults would require more detailed mapping. The Palaeozoic units are tentatively assigned to the Permian and Carboniferous. The Permian unit is supposed to range from Lower Permian into Upper Permian, which implies that the boundary towards the mapped Carboniferous unit may belong to the Lower Permian (Berglund et al. 1986; IKU data). In the eastern part of the mapped area the Carboniferous unit seems to consist of two sub-units with an angular unconformity dividing them. From shallow seismic data the Carboniferous and Permian sediments show progradation from south indicating a southerly source area.

A thick Triassic sequence onlaps the Palaeozoic sediments in the south. We have mapped a prominent seismic reflector about half way up in the Triassic sequence, but there are at present no data that can be used for a confident dating of the Triassic in this part of the area.

The interpreted top Jurassic boundary is correlated with a faulted and eroded interface, which is supposed to represent the main phase of the Late Kimmerian tectonic episodes. Data from the Nordkapp Basin (this report) and the Hammerfest Basin (Berglund et al. 1986) indicate that the Jurassic

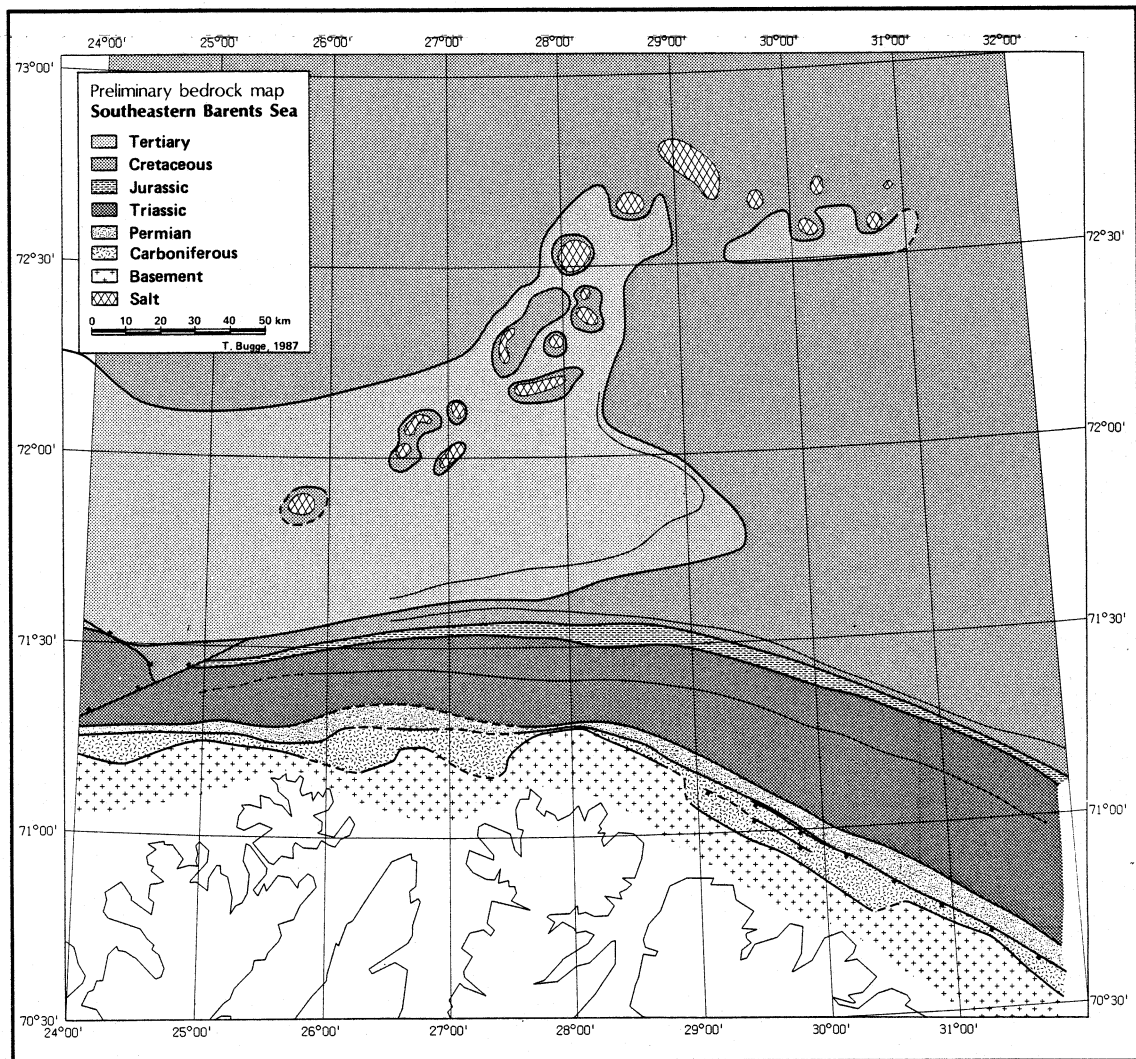


Figure 4.1 Preliminary bedrock map of the southeastern Barents Sea.

succession most probably is relatively thin (50-80 msec close to hole 7227/8-U-1). From regional data we would not expect to find the top Triassic as a prominent seismic reflector, but as an approximation we have assigned an about 150 msec. thick unit as possible Jurassic.

An intra Cretaceous reflector has been mapped to the south of the Nordkapp Basin. The mainly east-west orientation of the subcrop of this boundary may indicate that the Upper Cretaceous is relatively thick to the east and northeast of the Nordkapp Basin.

A strong lower Tertiary reflector is found in the entire area. Above this reflector there is an appr. 50-80 msec. thick strongly layered sequence, dated as Paleocene by IKU, in the southern part of the mapped area. On the northern side of the Hammerfest Basin and the western side of the Nordkapp Basin this layered facies is not seen. The Paleocene datings suggest that the regional reflector at the base represents a lower Paleocene paleosurface.

Tertiary sediments are mainly restricted to the Hammerfest and Nordkapp Basins, but extend some way on the outside of the main basins. The geology of the Nordkapp Basin will be discussed in more detail below.

4.2 Seismic interpretation of the Nordkapp Basin

In this chapter we will give a general description of the Nordkapp basin based on the collected shallow seismic data, supported by the deep seismic line (18 sec.) IKU-84-A and published literature. Due to the limited penetration and the open grid of the shallow seismic, it will not be possible to present a very complete description of this complex basin. In general the Nordkapp Basin is a northeast-southwest trending basin with several salt structures as dominant features. The salt is deeply rooted and could have an Upper Devonian or Lower Carboniferous age (Riis et al. 1985). The salt was deposited in a half graben bounded by a down to the east fault on the western flank (Rønnevik & Jacobsen 1984). Later tectonism has influenced the eastern flank of the basin. The faults probably involve the basement (see Figure 4.2).

Salt tectonism

Salt tectonism plays an important part in the geology of the basin. Salt movements have contributed to differential subsidence and uplift which can be detected from the Permian/Triassic time. The salt tectonics have now reached a late stage of piercement diapirism and there are no signs of present day salt tectonics.

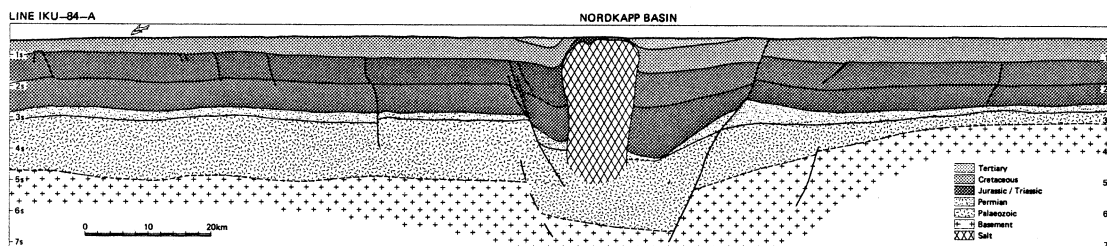


Figure 4.2 Geoseismic section SE-NW through the Nordkapp Basin.

The sedimentary record from the Nordkapp Basin suggests that multiple phase salt tectonism has taken place. There are also indications from seismic data that there are two separate salt units, both of Palaeozoic age. In the Triassic, salt deformation influenced the local subsidence and thereby the palaeogeography. A significant anomalous salt related subsidence is also suggested to have taken place in the late Cretaceous (see paragraph "Upper Cretaceous").

From the seismic data it appears that the most significant diapirism probably took place in the Tertiary when early Paleogene and older sediments were folded and later exposed for erosion. This is clearly shown in a south-north profile through the Basin (Figure 4.3). The inversion of the basin in Tertiary led to a substantial erosion of the area in the late Tertiary and Quaternary time. Some of the salt cones may have been affected by this erosion.

Salt karsting is indicated on several of the diapirs and is likely to have taken place in the late Neogene as the area was exposed and fresh water could percolate into the exposed or nearly exposed salt. The latest phase of karsting may have taken place in the Pleistocene and be related to the glacial meltwater. There are, however, no indications of salt karsting after the deposition of the latest glacial sediments.

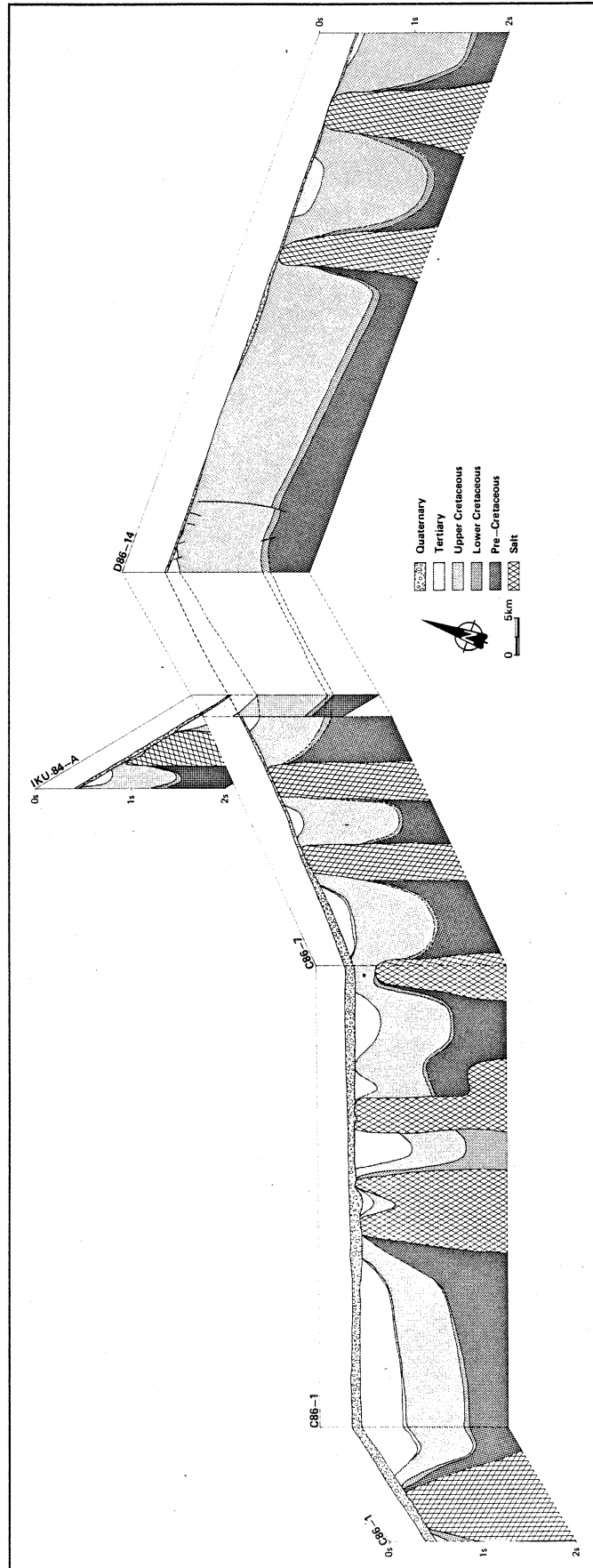


Figure 4.3 Interpreted south-north profile of the uppermost 2 sec. through the Nordkapp Basin.

Palaeozoic

Except for the salt diapirs which involve salt of probably Palaeozoic age, our seismic data indicate that Palaeozoic sediments are not found subcropping around the diapirs, but are only found in the deep part of the basin, i.e. below the penetration range of our data.

Triassic - Jurassic

A relatively thick Triassic sequence is found in the basins between the salt structures. The deep seismic line IKU-84-A indicates thicknesses of more than 2000 m. It seems as if the creation of some of the salt diapirs occurred simultaneously with deposition of the Triassic sediments. Triassic sediments are found subcropping around some of the salt diapirs where the Triassic sequence is usually not as complete as in the basins. Our data do not allow us to tie this properly.

Jurassic sediments were encountered in two cores in Block 7227/8 and show that the Jurassic was here only about 60 m thick. The seismic data indicate that the unit thickens slightly into the basin. With the seismic grid available it is not possible to map the unit through the area from line to line.

Lower Cretaceous

An about 45 m thick lower Cretaceous seismic unit was detected in Block 7227/8. The seismic data show a thickening of the unit towards the northeast in the Nordkapp Basin to about 125 m. It also thickens slightly from the subcrop area into the basin between the diapirs except at the southwestern-most diapir where the opposite seems to be the case.

A major unconformity within this unit is related to reflector β (Figure 5.1), which is located a few metres below the Middle Albian core 7227/8-U-2. This is further discussed in Chapter 5.

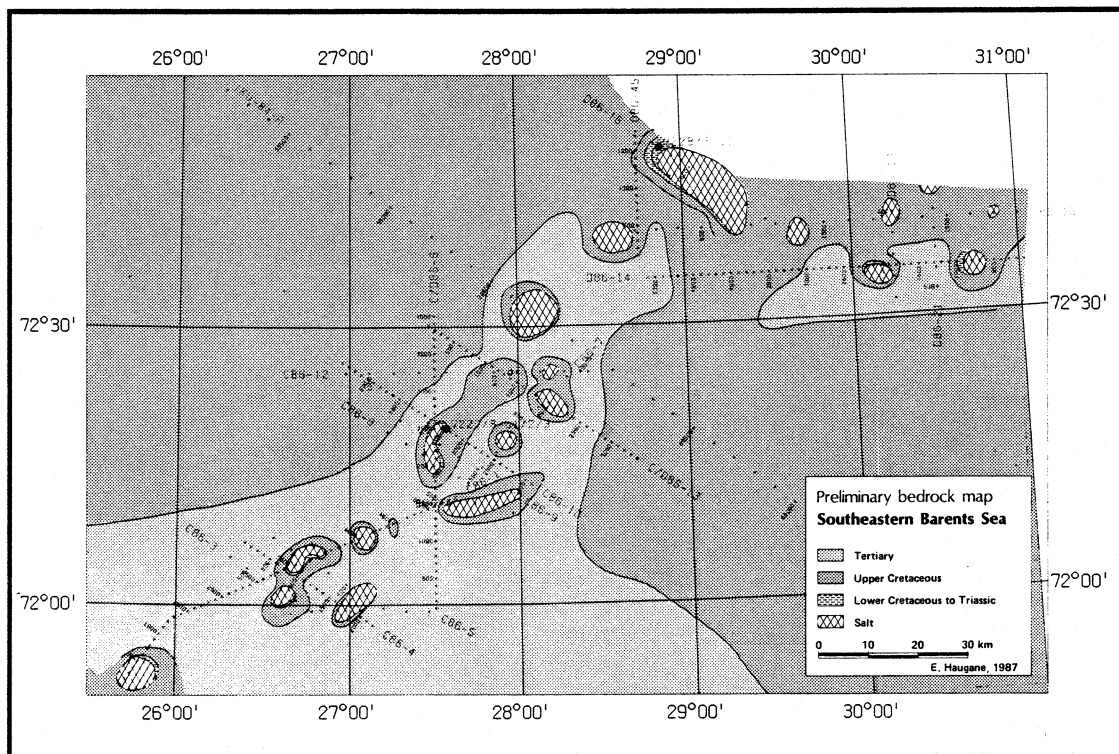


Figure 4.4 Preliminary bedrock map of the investigated part of the Nordkapp Basin.

Upper Cretaceous

The probable base of the upper Cretaceous unit is defined by a pronounced regional seismic reflector (reflector α in Figure 5.1). This reflector is interpreted as a Cenomanian sequence boundary (see Chapter 3.2.2). The lower part of the upper Cretaceous unit shows chaotic internal reflections. Sequence boundaries can, however, be detected in the upper part of the section.

The regional trend with subsidence towards the northeast is more evident in the upper Cretaceous than in the lower Cretaceous. The upper Cretaceous unit thickens prominently towards the east-northeast, from about 700 m to more than 1400 m.

In Block 7227/8 there are anomalous thicknesses of the upper Cretaceous unit. Similar thickness variations do not occur elsewhere in the area. A likely explanation for this anomalous thickness variation may be syn-depositional salt tectonics, where salt withdrawal and subsequent diapirism created space for further deposition of Cretaceous sediments. Differential loading of these sediments would then enhance the process of salt diapirism.

Tertiary

The Tertiary sediments, probably Paleogene, thin towards the northeast. This is reflected in the bedrock maps in Figures 4.1 and 4.4. with pinch-out of Tertiary unit towards the northeast. Several seismic sequences can be traced in the Tertiary unit. They are, however, difficult to tie around due to the abundance of the salt-diapirs. The distribution of the Tertiary sediments shows that the basin was tectonically inverted in mid-Tertiary time.

At the assumed Cretaceous - Tertiary boundary a seismic unit with several fan-like structures with local thicknesses of more than 70 m appear. This unit is associated with the rim synclines formed by salt tectonism in the middle and southern part of the area (see the map in Figure 4.4 and the cross-section in Figure 4.3).

The age of this deposit is not known, but is here regarded as lower Tertiary.

Quaternary

The Quaternary is no item in this report, and only a few comments are made here. Terraces, salt karst and fluvial valleys more than 70 m deep (line C86-12) are observed on the bedrock surface. Pleistocene deposits of glacial and glacial marine origin cover most of the area with variable thickness, and the bedrock topography has no impact on the present sea bed. Some of the salt diapirs have been onlapped by glacial debris showing that these structures existed prior to deposition.

5. DISCUSSION

This chapter contains two parts. The first part is a discussion of the correlation between seismic interpretation and the three cores in the Triassic - Cretaceous succession in Block 7227/8. In the second part we present two tentative models of how local areas could have been sources for sediment input to the Nordkapp Basin in Triassic time.

5.1 Correlation of cores and seismic data Block 7227/8

The three wells in Block 7227/8 provide a good basis for stratigraphic control of the Mesozoic succession in the seismic data. The interpretation of this will be further discussed below.

Changes of relative sea level have probably played a significant role in controlling the sedimentary cycles in the Nordkapp Basin in general. This is well expressed in the seismic data as well as in the cores (see Chapter 3). A detailed seismic stratigraphic interpretation of these strata may add valuable information of the depositional history of the sediments. The seismic sequences are here defined by the criteria of Vail et al. (1977) and are equivalent to extensions of unconformities. The regional significance of these boundaries cannot be evaluated from these data.

The high resolution shallow digital seismic line interpreted here permits detection of subtle seismic geometry patterns. It is, however, limited how far the interpretation can be extrapolated.

A seismic stratigraphic interpretation of line C86-10 is given in Figure 5.1 together with a synthetic chronostratigraphic chart based on the seismic data. The numbers and duration of hiatus in this chart are clearly underestimated, because continuous accumulation is assumed. The diagram shows the various cores correlated to the seismic record based on the palaeontological datings given in Chapter 3.

Two onlapping seismic units below reflector ϵ are clearly visible together with significant thickening of these units. The upper one of these, below sequence boundary ϵ , is interpreted to cover strata related to a major hiatus in core 7227/8-U-1. In this core undated fluvial and marine Toarcian sediments overlie marine sediments of Norian to lower Rhaetian age.

There is no indication from the seismic data of any significant hiatus between the fluvial and the Toarcian sediments, and we therefore believe that the discovered hiatus includes most of the upper Rhaetian and the Lower Jurassic.

Two seismic sequence boundaries can be detected in the middle Jurassic, reflector δ and δ' . Only reflector δ is marked on the seismic sections. The apparent uniform thickness of the seismic sequences between reflectors ϵ and α , combined with some truncation/onlap patterns suggest a slow subsidence with periods of shallow marine depositional environment. This is also indicated by the hiatus shown in Fig. 5.1 where we suggest that both the Upper Jurassic and the pre Albian seismic units become progressively younger towards the paleohighs and that these deposits are two separate transgressive system tracks.

5.2 Tentative models for local sediment source areas

Most palaeogeographic reconstructions for the southern Barents Sea are based on the existence of a few major sediment source areas in Triassic/Jurassic time; these areas mainly parallel the present exposed mountainous areas surrounding the Barents Sea. The Triassic and Jurassic sediments encountered in the present project comprise sediments deposited in shallow marine and continental environment which implies that a nearby sediment source must have existed in the Nordkapp Basin. Below we present tentative models of how such local areas may have been lifted above sea level and thus acted as local sediment source areas.

As mentioned in Chapter 4.2 there are indications that the first salt movements started in the Triassic, possibly in the Lower/Middle Triassic. At that time the sediment overburden was probably too thin to support a buoyancy model for salt movements, even though less than 1000 m would be required (Spencer 1977, p. 275-278). We therefore imply that the early salt diapirism can be explained by lateral salt flow initiated by sediment accumulation close to the coast, as illustrated in Figure 5.2. This model may explain the creation of salt pillows and beginning salt diapirism in the Triassic. It also indicates a mechanism for formation of small areas within the Nordkapp Basin that were lifted up to or above sea level. The seismic data indicate that this may have been the case where the three Triassic-Cretaceous cores were obtained in Block 7227/8.

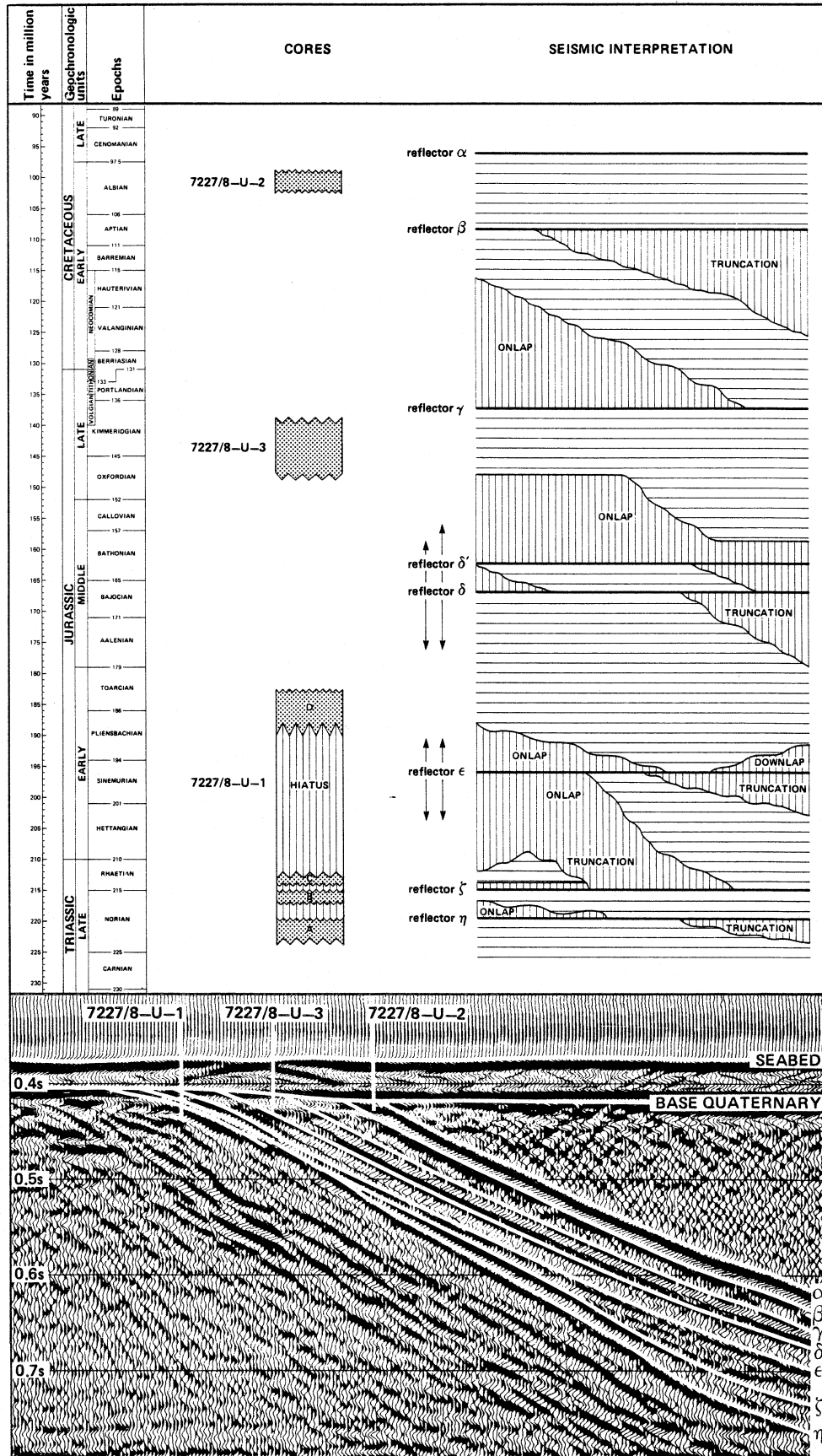


Figure 5.1 Chronostratigraphic chart from wells 7228/3-U-1, U-2, U-3 with correlation of core data and seismic data. The calculations of hiati are conservative.

In Block 7228/3 two alternative models may be suggested to explain a local source area. Onlap patterns observed in the seismic data indicate that the sediments drilled in well 7228/3-U-1 probably were deposited with a local shoreline to the east, i.e. the local sediment source was situated to the west of where the salt diapir is found today which is different from Block 7227/8 where the local source area coincides with the position at the diapir.

The seismic line D86-16 shows that the cored Anisian-Ladinian sediments are truncated by a surface of presumably Upper Triassic age and later by a possible Lower Cretaceous surface. The two angular unconformities and the limited thickness of the lower Mesozoic sediments suggest significant hiatus in this area and that parts of the five equivalent deposits discovered in Block 7227/8 further south may be missing.

The significant rotating of the Middle Triassic sediments shown here may well be related to salt tectonics. The unconformities may be due to significant salt movements in middle/upper Triassic and in Jurassic/lower Cretaceous time.

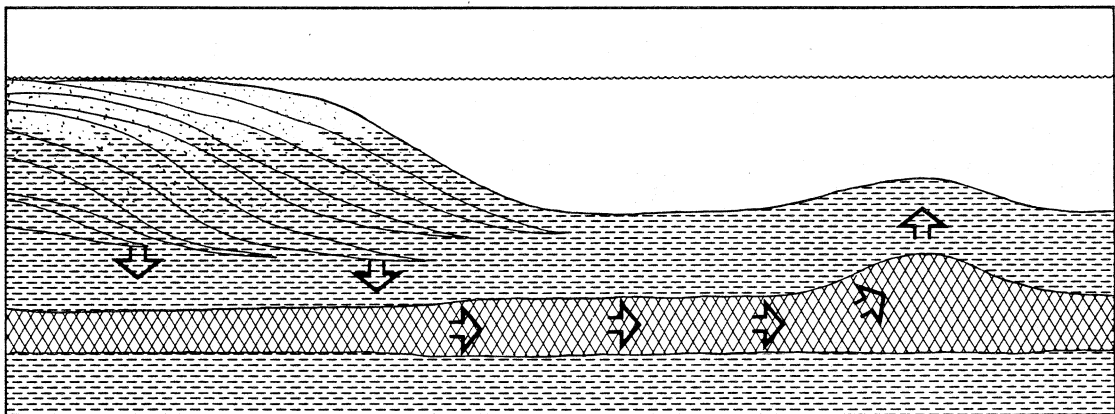


Figure 5.2 Schematic diagram of hydraulic salt diapirism when prograding shore deposits creates differential pressures and thereby salt flow or creep. Salt pillows are then created distally to the coastline.

An alternative model for uplift and creation of a local sediment source area to the west or northwest of drillsite 7228/3-U-1 is illustrated in Figure 5.3.A'. Lifting of the footwall blocks along flanks of the graben EXT/c/12/mas

system in the Nordkapp Basin may here have created the local highs. The deep graben structures are described in Chapter 4.2 (Figure 4.2).

Figure 5.3.A illustrates that the local highs may also in Block 7228/3 have been created in the same way as described above for Block 7227/8 (Figure 5.2).

The local high may have subsided in various ways. If salt originally created the high, the salt may have developed into a piercement diapir which was dissolved and then disappeared, or the possible salt pillow may have aborted. If the high was tectonically created, the high may have subsided by a reversed movement. Neither of these models are critical, but the point is that the highs disappeared in the Jurassic/early Cretaceous.

Significant regional subsidence took place in the Upper Cretaceous, and more than 1000 m of sediments were deposited in the area of Block 7228/3. There is no indication of simultaneous salt tectonics in this area, in contrast to the investigated area 40 kms to the southwest in the Nordkapp Basin.

During Tertiary major changes took place, partly because the Nordkapp Basin was inverted, but mainly because of intensive salt tectonism. At this specific location a salt pillow started to grow southeast of the Triassic local high that existed in the Triassic. The diapiric growth was probably due to mobilization of deeper salt deposits. This movement was driven by the heavy load of Cretaceous/Tertiary sediments. A piercement diapir was created and the subsequent erosion probably involved the salt cone. This is illustrated in Figure 5.3.B and B' where B relates to model A and B' to model A'.

From the existing data it cannot be concluded which of the two models is the most probable. The main point is, however, that local sediment source areas may have existed in the Nordkapp Basin and that we are not dependant on having the main coastline in the vicinity of the drillsites to explain the shallow marine and continental deposits encountered in the Triassic/lower Jurassic sediments in the Blocks 7227/8 and 7228/3. However, the abundant well-cemented sandstone pebbles at the base of Unit D in core 7227/8-U-1 indicate deep erosion (kms), and the salt-movement model close to a shore line may thus be favoured.

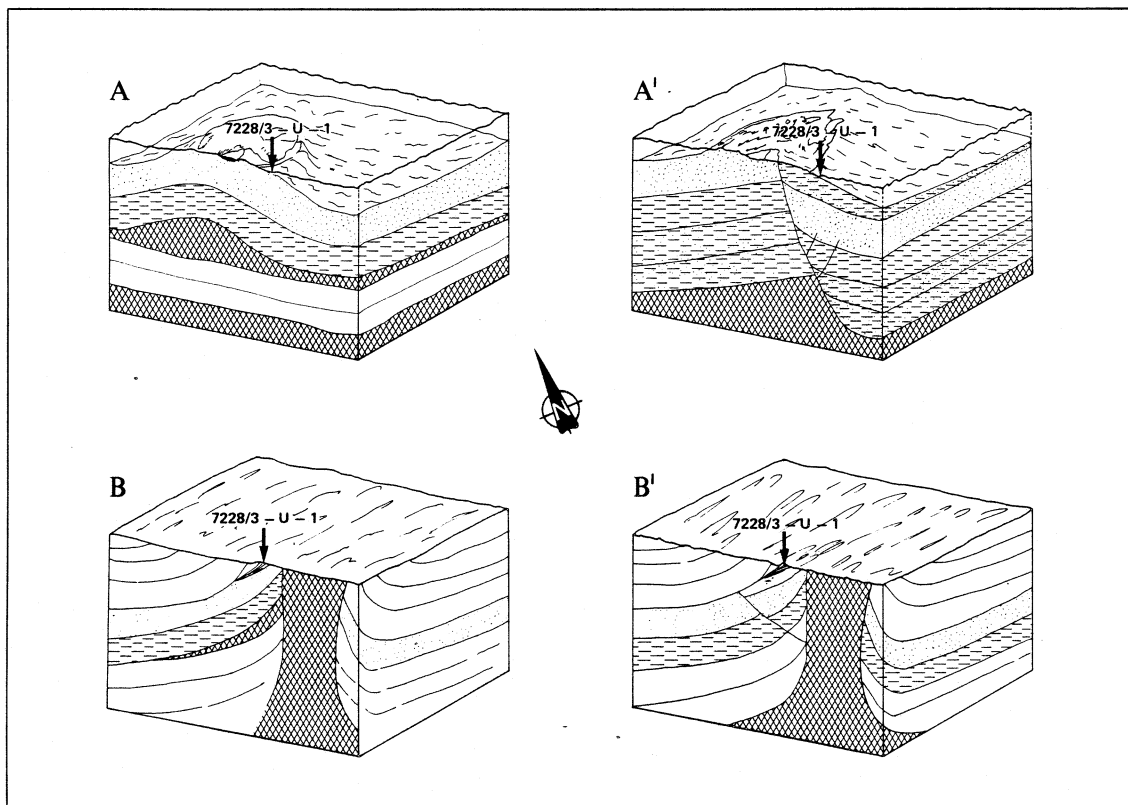


Figure 5.3 A sketch diagram of a possible reconstruction of the structural development at drillsite 7228/3-U-1. Model A is based on the creation of salt pillows or diapirs as shown in Figure 5.2 and illustrates a possible situation in the Middle Triassic. B illustrates the situation in Tertiary time when the present day salt diapir had penetrated the sediments further to the east or southeast. Model B shows an alternative explanation based on extensional faulting. B' illustrates the result of this in Tertiary time.

Further investigations will verify or invalidate this theory. We suggest, however, that a major clastic source area lay in the vicinity of the basin in Triassic and perhaps lower Jurassic time, possibly to the east or south. Sediments may also have been derived from the Loppa High.

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A.1 DRILLING OPERATION

A.1.1 General

Main contractor for the field operations was von der Lippe (Ship management) A/S. The drill ship M/S "Bucentaur" was used for the drilling operations, the push sampling and heat flow measurements were subcontracted to Fugro BV, Holland and they hired the US-company Omegalink International Ltd. for support for the heat flow measurements. The bedrock coring machine was manufactured by Diamant Boart, Belgium/Norway, and they also provided diamond drilling staff.

A.1.2 Technical data

Drill ship

Length over all	78.07 m
Breadth moulded	16.00 m
Draft fully loaded	5.55 m
Displacement	4.470 tonnes
Gross register tonnage, international	2.768 tonnes

Main engine: Four Wärtsilä diesels, type Vasa 8R22HE, each driving a van Kaick generator of 1200 kW at 1200 RPM, 600V/60 periods AC.

Propulsion units: Two azimuthing thrusters with CP propeller in nozzle, make Liaaen.

Bow thrusters: Two tunnel thrusters with CP propeller, make KaMeWa.

Dynamic positioning system: One GEC simplex system with GEC-Elliot 2050 computer, video display and joystick. Positioning reference by deep water tautwire system and by Simrad HPR T209 hydro-acoustic system.

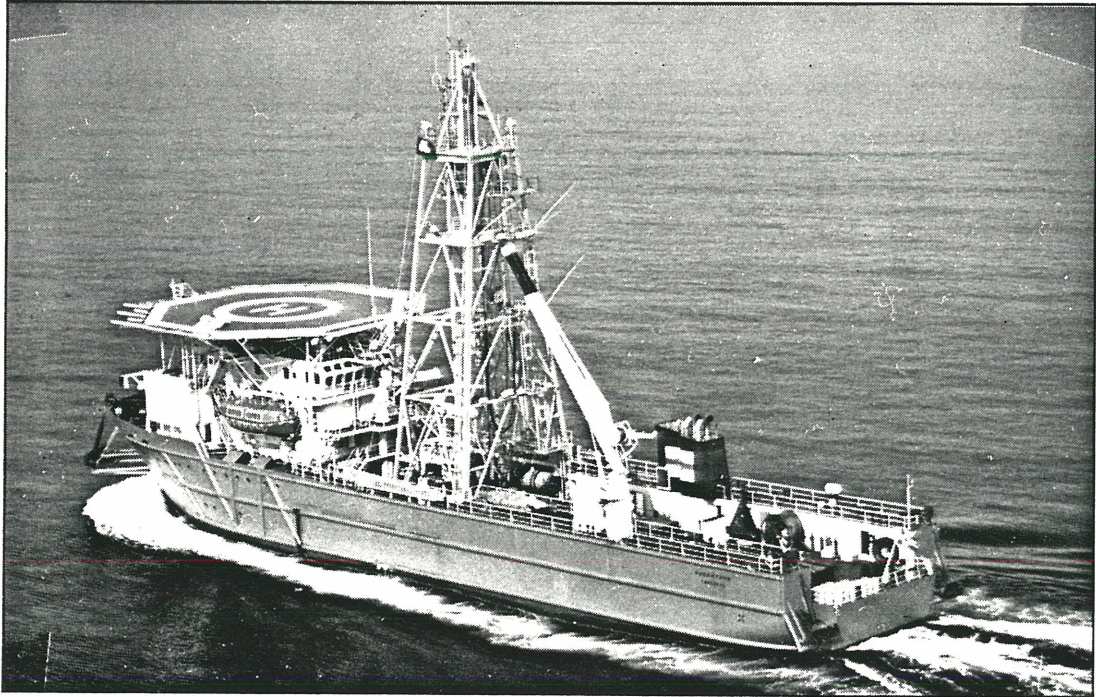


Figure A.1.1 The drill ship M/S "Bucentaur".

Main drilling machinery

Derrick: 26 m high from deck to water table. Max 40 tonn dynamic hookload, 80 tonn static hookload.

Drilling winch: One hydraulic winch, make SAS, max linepull 12 tons, 4 speed ranges, max linespeed 136 m/min.

Heave compensator: One Fugro/Hydraudyne type CSC90-23 max 40 tons dynamic load, 80 tons in locked position, accomodates for max heave of 7 m.

Power swivel: Wirth, type B3, max torque 3000 kgm, max speed 194 rpm, 3-speed gear box, hydraulic-operated ball valve 100 mm dia. opening for easy operation of wireline tools.

Sampling winches: Two Lohman type FW10 free fall winches.

GA5/c/2/mas

Hard-tie winch: One Ingersoll Rand, max pull 10,000 lbs, with auto. failsafe brake.

Elevator: Wirth, type special pipe pick-up chuck, suitable for 5½" F.H. joints.

Slips: Wirth power slips type B12, with inserts for 5" pipe.

Heavy lift winch: One winch make Pusnes, capacity on single drum 2 lengths each 1200 m wire 36 mm dia. Braking force 90 tonn.

Mud system: Complete dry mud system with mud mixing equipment mud storage, and mud pumps (three X: WIRTH TPK 5½" x 5½", 84 HP hydraulic motor, capacity 1600 l/min at 20 bar).

Main drill string

Drill pipe: 2000 m of API-5" Grade E, range II, 19.5lbs/ft with 5½" tool joints, 4" I.D.

Drill collars: Sixteen, each 5 m long, 7" O.D. and 4" I.D. with 5½" tool joints.

Diamond core drill system

Drilling machine: DBH 1500S electro/hydraulic drill.

Spindle opening: 127 mm

Rotating speed: max 900 rpm.

Drill string: Wireline HR Heavy duty O.D. 88.9 mm, I.D. 70 mm, length 10 ft, weight 38 kg. Back-up NR Heavy duty wire line drillrods O.D. 69.9 mm, I.D. 60.3 mm.

Core barrels: Triple tube, 10 ft with split tube.

Core diametres: HR triple tube 54.6 mm, NR triple tube 38.1 mm.

Drilling capacities: HR - 1000 m, NR 1500 m.

Sea bed template

Fugro SEACLAM with clamping system, inclinometers and underwater TV camera.

A.1.3 Standard drilling operation at piggyback drilling sites

- (a) M/S "Bucentaur" moves onto position and sets the dynamic positioning system (D.P.) in operation.
- (b) Sea bed re-entry template is lowered to the sea bed, and constant tension applied to the template cables via the template heave compensation system.
- (c) The 5" API modified drill pipe with open centre bit is lowered on a guided template cable rider to the sea bed.
- (d) The Quaternary overburden is penetrated without any sampling until the drillbit is drilled into rockhead.
- (e) The powerswivel heave compensator is then set to give a main bit weight slightly in excess of the maximum weight that may be required by the diamond core bit used for the coring, and the API drill string is clamped to the template by using the hydraulic template clamp.
- (f) The wireline coring pipe and core barrel is then run into the hole.
- (g) Core drilling commences, with length of each run being determined by the length of the inner tube (3.05 m), or by the drilling conditions encountered. The hole is then drilled to completion and the HQ pipe and subsequently the 5" API pipe are pulled and stored on the deck.
- (h) The sea bed template is hoisted into the moonpool, D.P. is disengaged and the vessel proceeds to the next location.

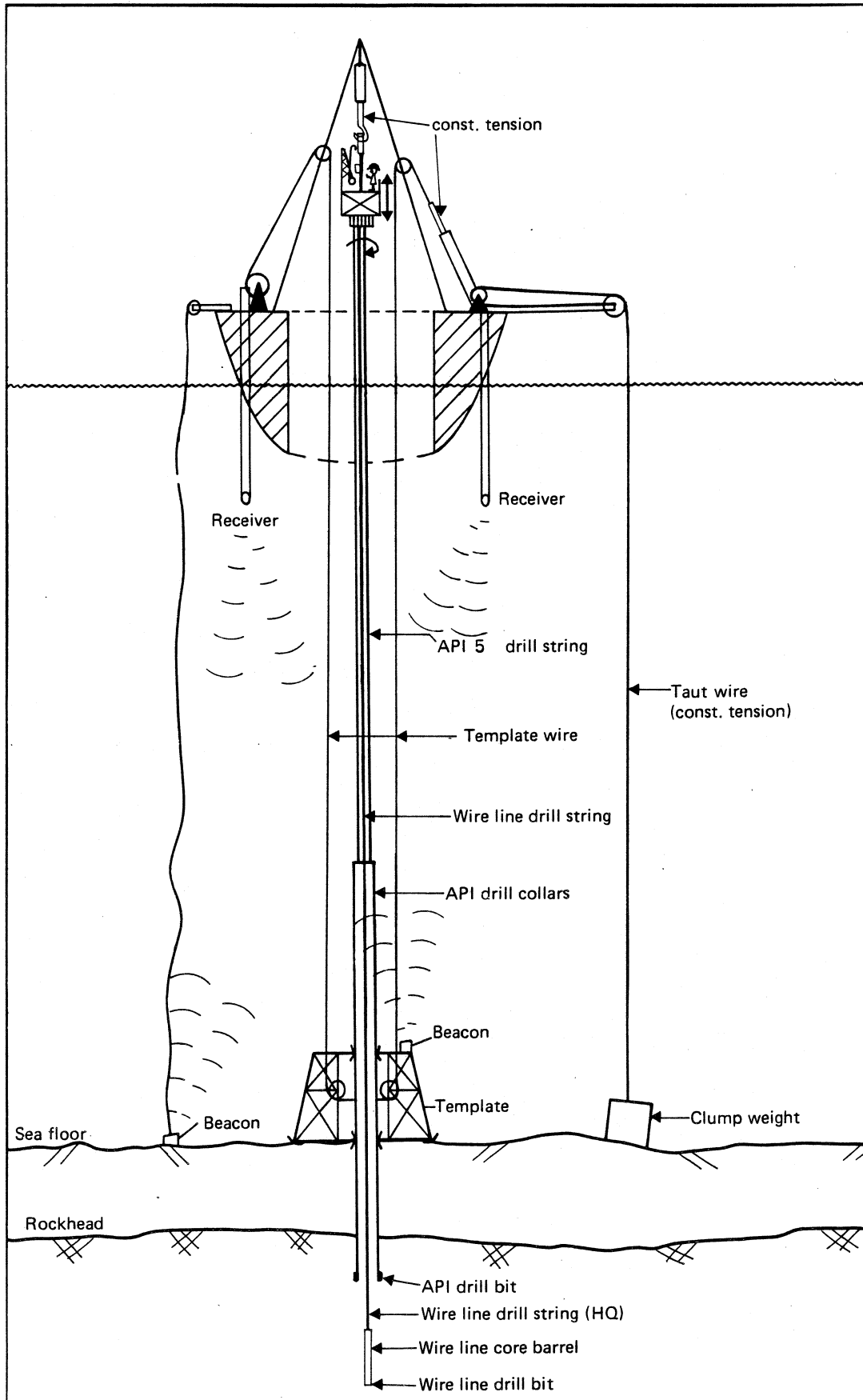


Figure A.1.2 Sketch showing the dynamic positioning system and the drilling operation for M/S "Bucentaur" 1986.

The operation procedure at the heat flow sites is described in a separate report. Piggyback coring and heat flow measurement were not both performed at the same site in the Nordkapp Basin.

A.1.4 Field operation

The field operations started with mobilization of the ship and a technical test drilling off Kristiansund 28th June 1986. Then the drill ship performed drilling at the Dia-Structure NW of the Nordkapp Basin for another IKU project. The Dia-Structure cruise was completed 29th of July with a portcall in Honningsvåg. The drill ship was then remobilized for the Nordkapp Basin project and headed towards the survey area in the afternoon the same day.

The total survey period of approx. 17.3 days (exclusive main mobilization and testing in Kristiansund, and steaming to and from Tromsø) was used as follows:

Steaming, positioning	Approx.	1.9 days
Working	"	10.1 "
Repair	"	0.9 "
Alongside	"	0.2 "
In port for moon pool rep. (of hire)	"	3.1 "
Waiting on weather	"	1.1 "
Total	"	17.3 days

The time spending expressed as per cent of total time is shown in the diagram on next page (Figure A.1.3).

A total of 8 boreholes were drilled at 5 different sites and 120.4 m of bedrock core was collected from 4 of the sites at depths ranging from 47.65m to 88.65 m below the sea floor. Average core recovery was 95.9%. The longest continuous core, 47.5 m long, was obtained at site 7228/3-U-1. Further key data for the bedrock sites is given in Table A.1.1.

SHALLOW DRILLING NORDKAPP BASIN 1986

Drilling operation summary:

(TOTAL TIME 17.3 DAYS)

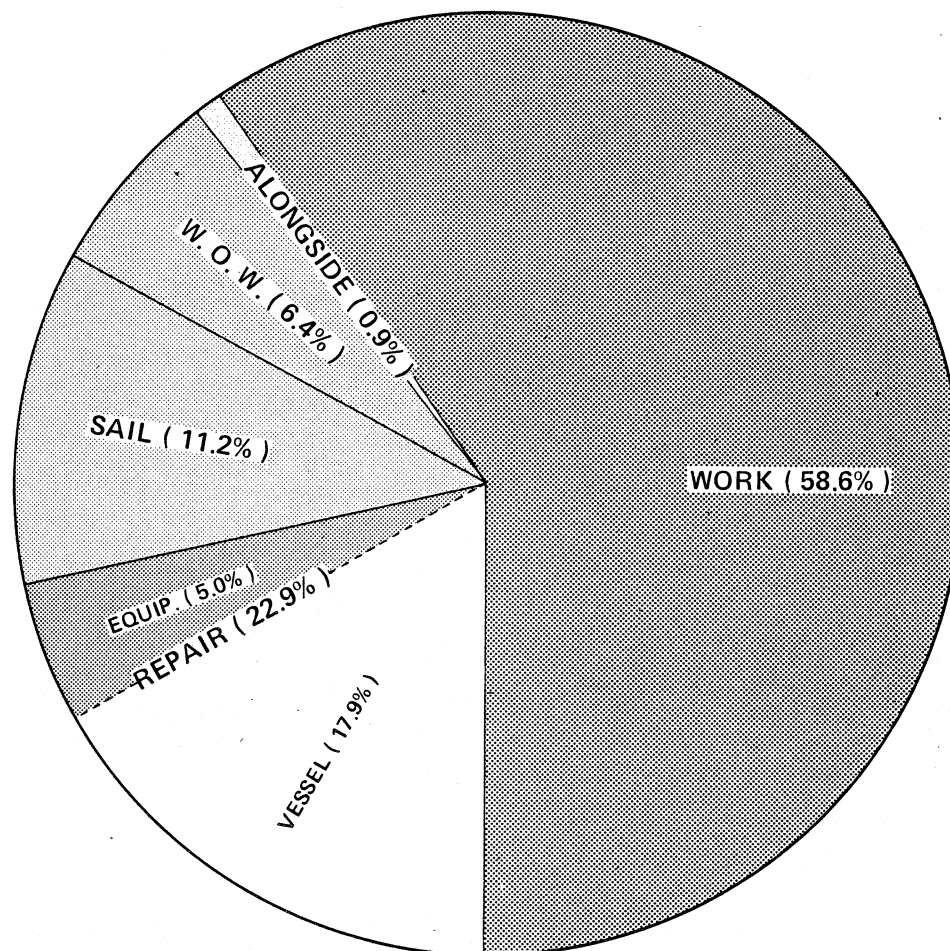


Figure A.1.3 Duration of activities during the Nordkapp Basin shallow drilling cruise 1986 (total operation time 17.3 days).

Table A.1.1 Key data for the 1986 Nordkapp Basin shallow drilling and heat flow measurements.

Bedrock coring sites	Seismic line	Fix pt.	Water depth (m)	Quater- nary thickness (m)	Cored length (including Quaternary) (m)	Core recovered (m)
7228/3-U-1	D86-16	670.0	294	41	47.65	47.54
7227/8-U-1	C86-10	1708.1	277	30	41.61	36.47
7227/8-U-2	C86-10	1734.8	279.5	37.85	15.25	14.61
7227/8-U-3	C86-10	1720.3	282.5	31.3	21.05	21.77
Total length				140.15	125.6	120.4
Heat flow sites			Levels for testing and sampling (m)			
7227/7-U-1	C86-10	239.8	278	35	10,15,20,22 (24,29,30,32,35)	
7227/7-U-1B	C86-10	239.8	278.5	39	10,15,20,25,29,35,39	
7120/6-U-1			316.5	15	11,13,15	
7120/6-U-1B			316.6	29	10,12,17,20,25,29	
Total length				252.7		

Technically the operations went very well, and a far higher production than expected was achieved. This is largely due to several modifications in equipment compared with the operations last year:

- The use of a new API bottom hole assembly allowed piggy-back drilling after API drilling without any API round trip (saving approx. 10hrs. per hole).
- The main mud system had increased capacity.
- The DBH 1500 S diamond drilling machine is stronger than the DB 1500 prototype used in 1985.

Only minor drilling problems were encountered and we believe that the experience gained will result in even further improvements of the equipment.

A.2 POSITIONING

A.2.1 General

Bentech A/S in Tromsø was operator for the navigation chains and provided equipment and personnel for positioning of the drilling vessel.

Hyperfix was used as the main system. Syledis was used as a reference system for Hyperfix calibration. Both systems worked very well during the cruise.

A.2.2 Chain performance and final positions

Final positions for the drill sites are based on Hyperfix, range-range. The positions are given in Table A.2.1.

Table A.2.1 Final positions for the Nordkapp Basin project 1986.

Site	Latitude/Longitude	Northing/Easting
7228/3-U-1	LATITUDE 72° 49' 3.739" LONGITUDE 28° 52' 14.819"	NORTHING 8 097 384.6 EASTING 758 862.3
7227/7-U-1	LATITUDE 72° 25' 34.667" LONGITUDE 27° 0' 31.789"	NORTHING 8 046 822.6 EASTING 702 205.6
7223/7-U-1B	LATITUDE 72° 25' 35.006" LONGITUDE 27° 0' 32.678"	NORTHING 8 046 822.6 EASTING 702 205.6
7227/8-U-1	LATITUDE 72° 19' 8.867" LONGITUDE 27° 33' 21.335"	NORTHING 8 036 857.0 EASTING 721 855.5
7227/8-U-2	LATITUDE 72° 19' 1.824" LONGITUDE 27° 33' 57.331"	NORTHING 8 036 676.9 EASTING 722 216.4
7227/8-U-3	LATITUDE 72° 19' 5.655" LONGITUDE 27° 33' 37.635"	NORTHING 8 036 774.8 EASTING 722 019.0
7120/6-U-1	LATITUDE 71° 37' 12.117" LONGITUDE 20° 56' 30.079"	NORTHING 7 946 767.6 EASTING 497 947.7
UTM ref.	CM 21° EAST	
6308/7-U-1 (Test site)	LATITUDE 63° 15.30' LONGITUDE 9° 9.49'	NORTHING 7 016 080 EASTING 508 030
UTM ref. Geograph. co-ordinates:	CM 21 DEG EAST ED 50	

A.3 ANALYTICAL METHODS

A.3.1 Core description and sampling

The cores were briefly described and sampled on board the drill ship. Further sampling and a more detailed description was performed in the laboratory. The legend of the sedimentological columns is given in Figure A.3.1. Samples for organic geochemistry, dating and X-ray diffraction were taken at 1 m intervals; however, not all samples are analysed at this stage of reporting.

A.3.2 X-ray diffraction analyses

Most of the samples were poorly cemented. They were gently crushed with ethanol in an agat mortar. Sandstones and well cemented samples had to be crushed in a "Spex" ball mill.

The powders were dried and mounted on sample holders or dry powder. The analyses were performed on a Philips diffractometer with the setup described below:

Radiation: Monochromatic $\text{CuK}\alpha$
Voltage: 40 kV
Current: 30 mA
Speed: 2° /minute, $2\theta = 2-35^\circ$

The quantification (Figure A.3.2) is based on the peak height multiplied by the width of the peak at half maximum and by a weighted factor of the following reflections:

Quartz	(Qtz)	$4.26\text{\AA} \times 1$
K-feldspar	(Alk)	$2.24\text{\AA} \times 0.5$
Plagioclase	(Plag)	$3.19\text{\AA} \times 0.5$
Muscovite/ Illite	(M/I)	$10.0\text{\AA} \times 1.2$ (Musc) or $10.0\text{\AA} \times 1.4$
Mixed layer minerals	(Mix)	$10/14\text{\AA} \times 0.55$
Chlorite	(Chl)	$4.74\text{\AA} \times 3 \times 0.7$
Kaolinite	(Kao)	$7\text{\AA} \times 0.7$ - Chl
Smectite	(Smec)	$(14\text{\AA}-4.74\text{\AA}) \times 0.35$
Calcite	(Cal)	$3.04\text{\AA} \times 0.25$
Dolomite	(Dol)	$2.89\text{\AA} \times 0.20$
Siderite	(Sid)	$2.79\text{\AA} \times 0.25$
Pyrite	(Pyr)	$2.71\text{\AA} \times 0.7$
Apatite	(Apa)	$2.80\text{\AA} \times 0.3$
Gypsum	(Gyp)	$7.56\text{\AA} \times 0.8$

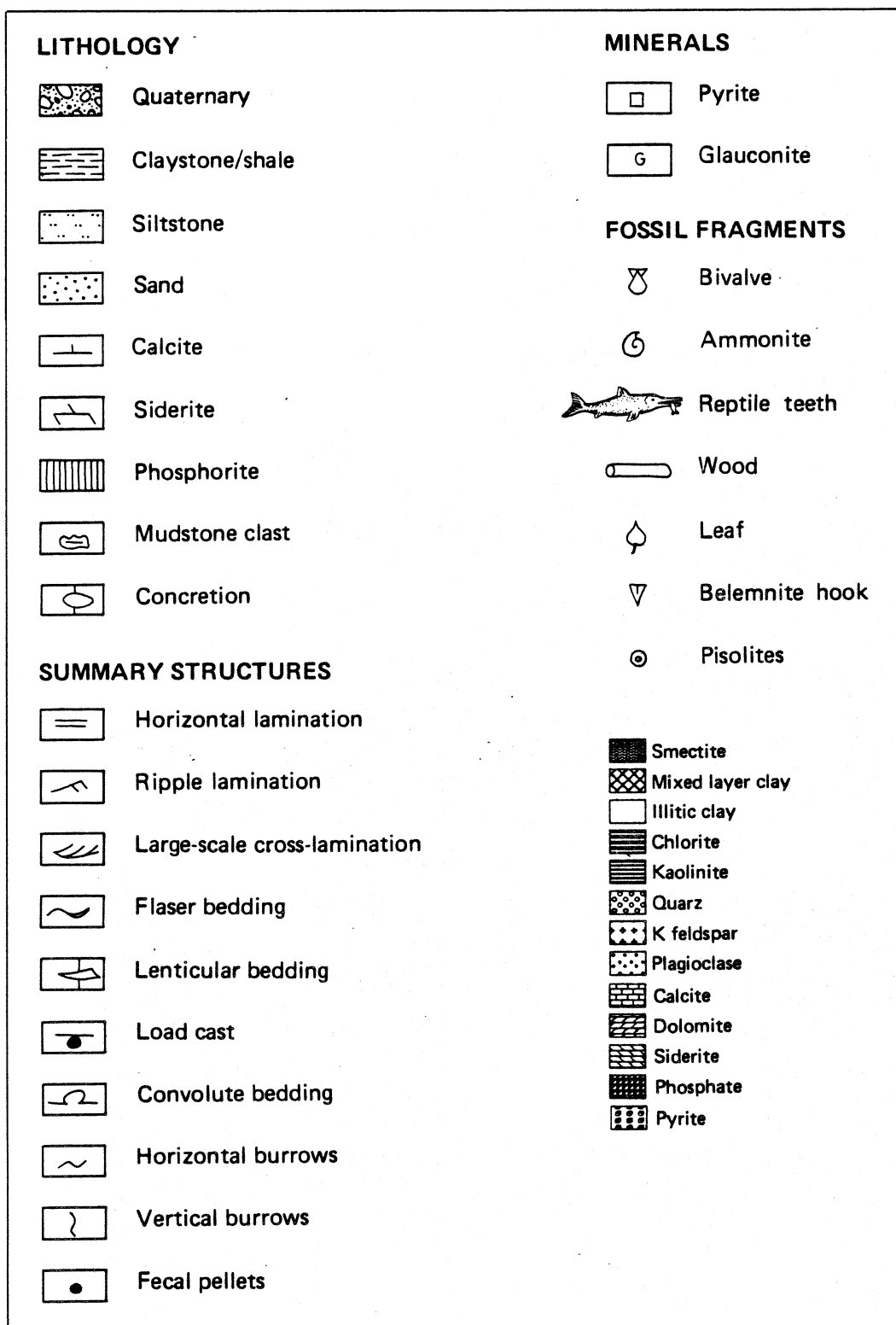


Figure A.3.1 Legend to the sedimentological columns and legend to the semi-quantitative mineralogy plots.

A.3.3 Thin section microscopy

The studies were undertaken on a Leitz ortholux polarizing microscope. Due to the friable nature of some samples and to avoid destruction of pore filling minerals, most samples had to be impregnated by epoxy resin prior to preparation.

Scanning electron microscope/microprobe studies.

Analyses were carried out on an Jeol 733 Superprobe with a Tracor Northern EDS System on polished carbon coated thin sections.

A.3.4 Sound velocity measurements

Sound velocity measurements were carried out normal to the cores (horizontal velocity) on wet, consolidated core pieces, using a portable ultrasonic (100 kHz) non destructive digital indicating tester, (PUNDIT).

The pulse velocity (v) was calculated using $v = \frac{L}{T}$

where L is the path length and T is the transit time.

A.3.5 Natural γ -radiation

The detector used was a 5"x5" NaI-detector connected to a 4048 channel analyzer of the Canberra 40 series. The core was placed below the detector with its long axis parallel to the detector window. In that position a spectrum was accumulated for 1200-1800 sec. To reduce the background radiation, the detector and the samples were shielded by lead. The method requires a minimum sample length which is equal to the detector diameter if the collimation is 100% effective. To avoid this problem, only core pieces longer than 2 times the detector diameter (= 26 cm) were analysed.

The measured peaks are:

API-units cannot easily be applied to our system, therefore the results are presented as cpm (counts per minute). The logs show the relative amount of radiation and not the absolute abundances of K, Th and U.

A.3.6 Palynology

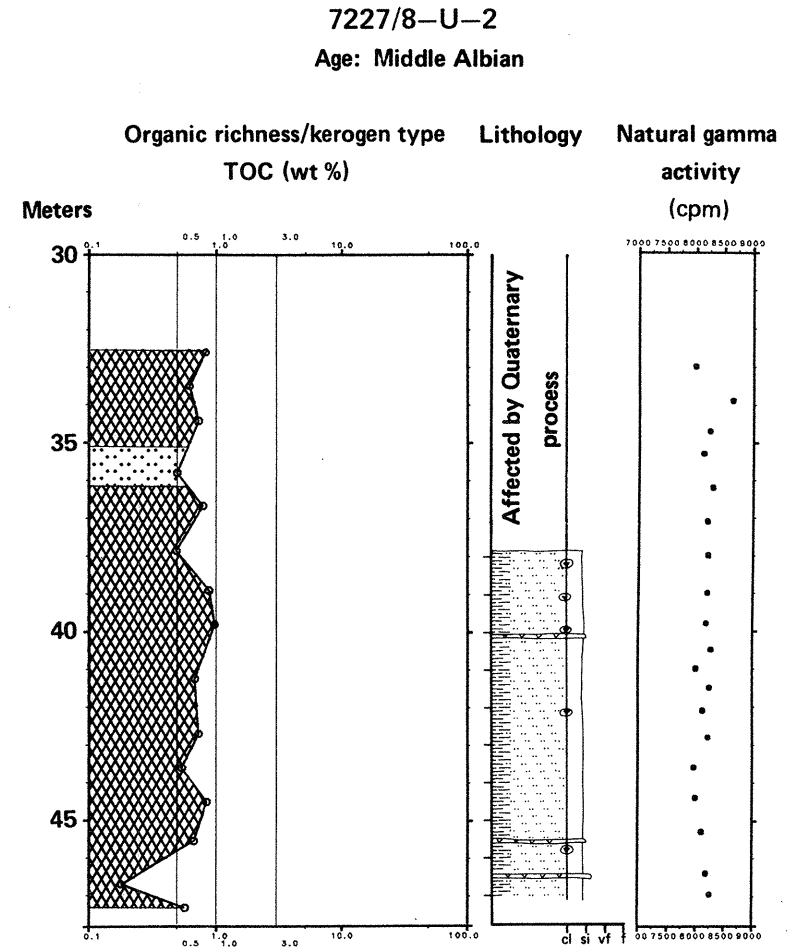
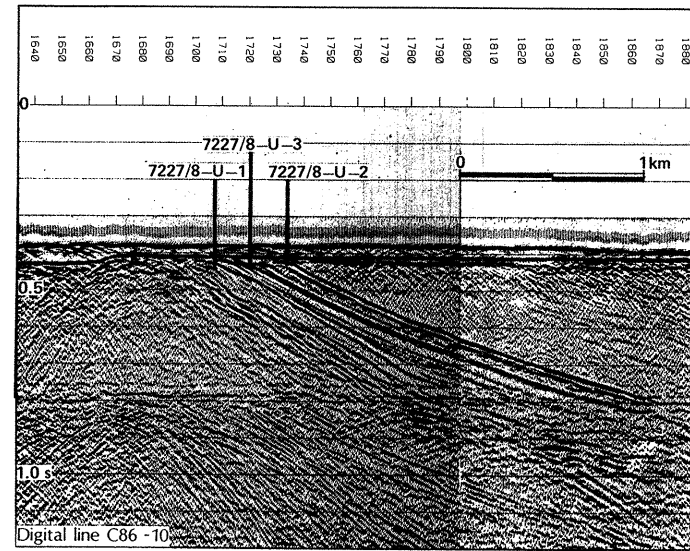
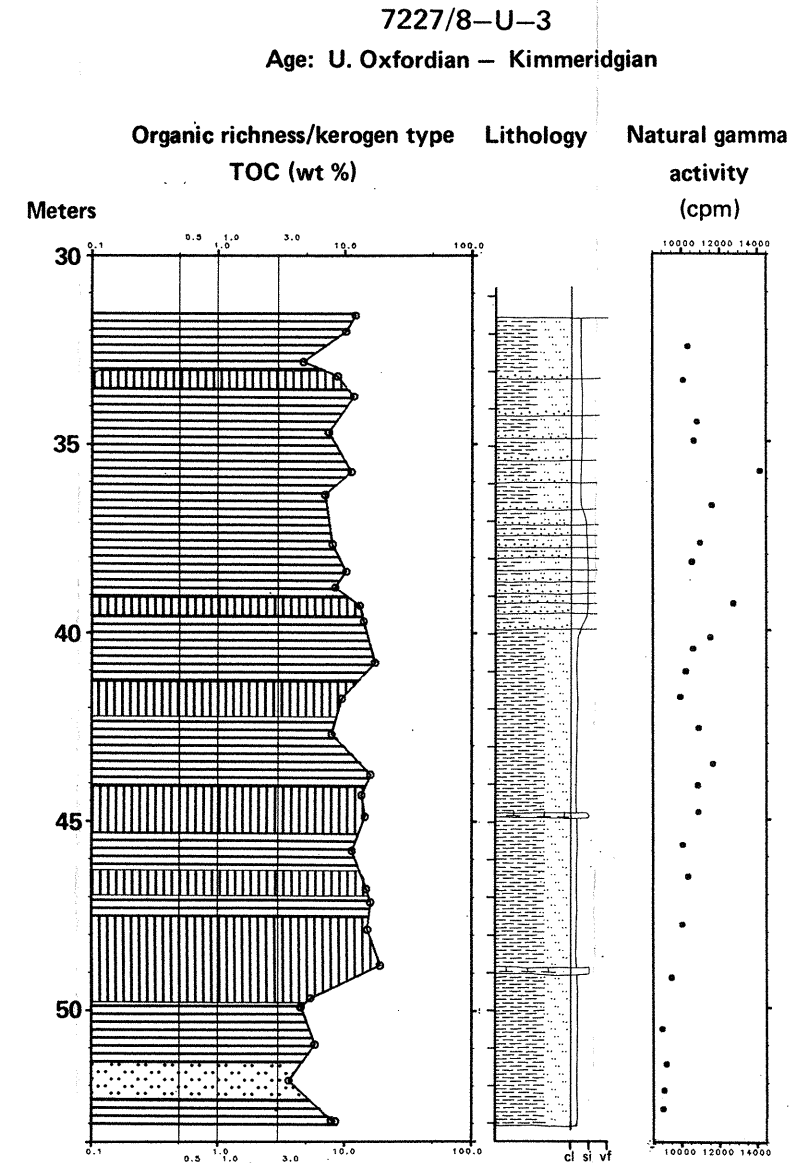
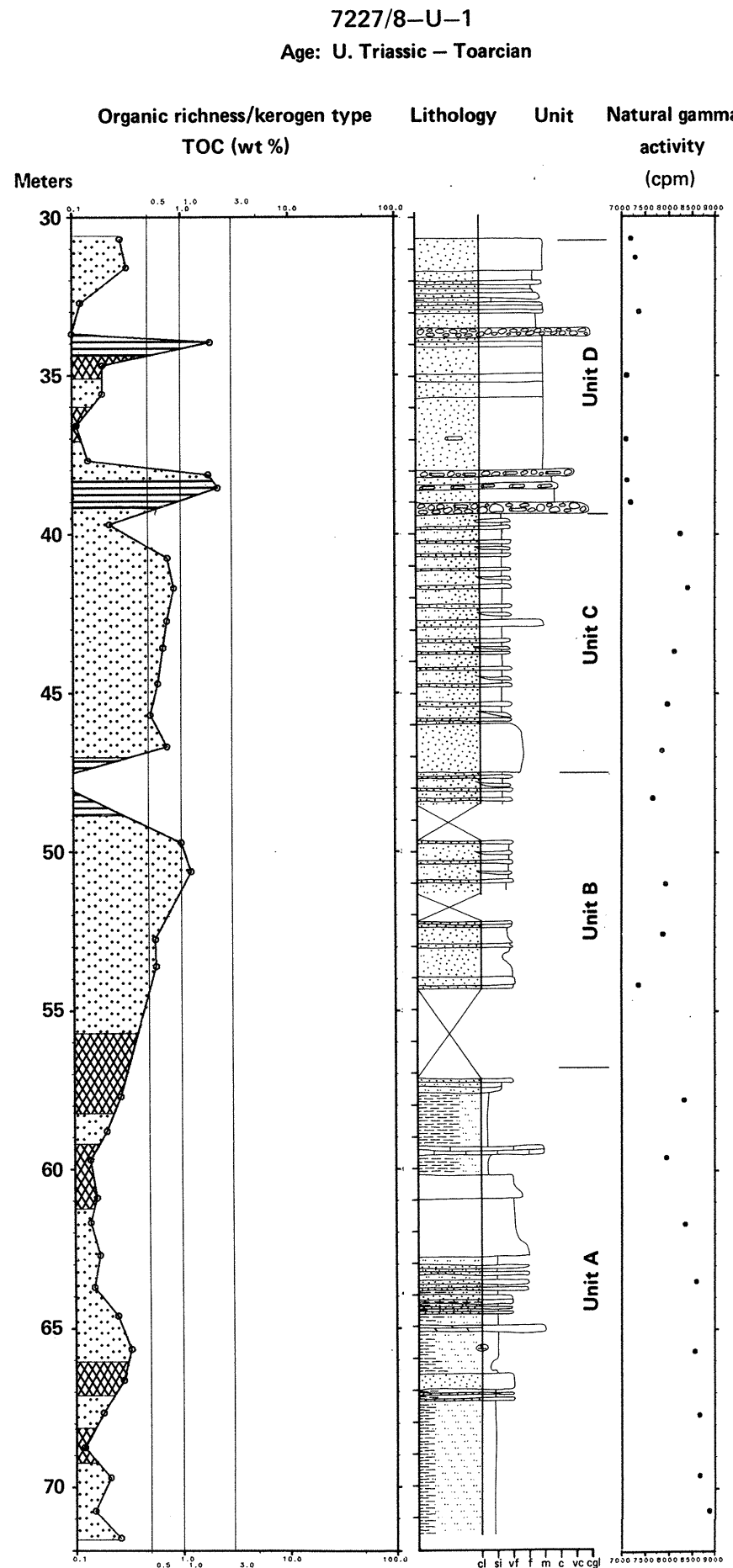
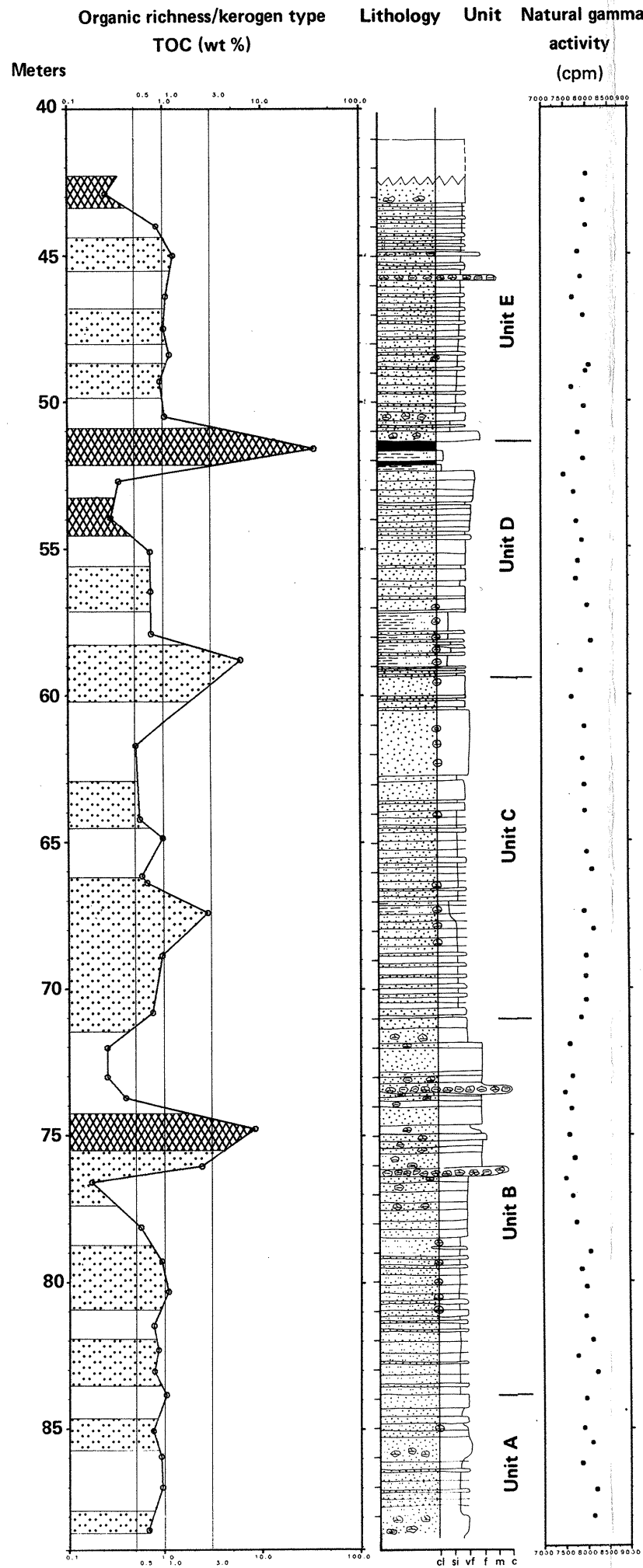
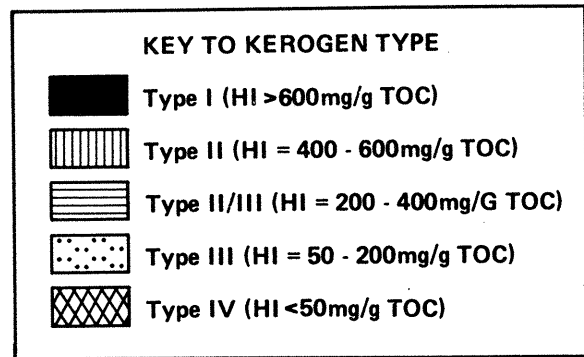
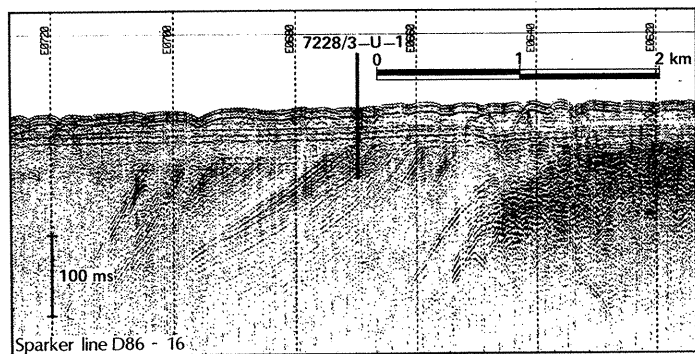
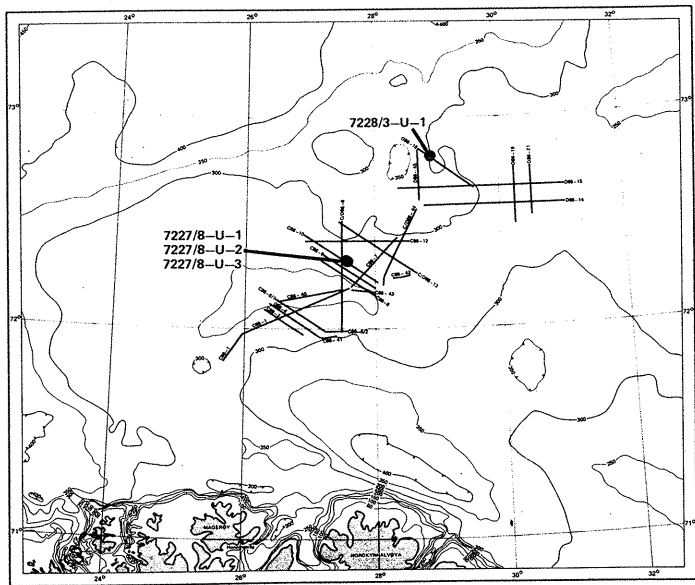
The standard processing for palynology included hot hydrochloric and hydrofluoric acids with continuous stirring. In most cases the organic residues were oxidized by the use of nitric acid (app. 3 minutes) followed by KOH. If necessary this process was repeated.

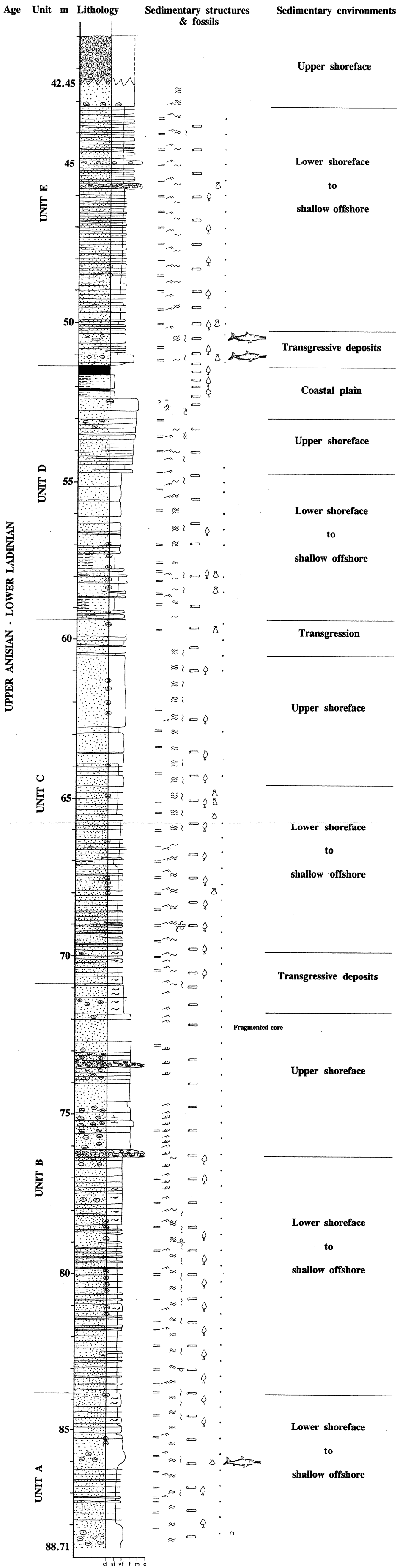
Samples from the cores were prepared at approximately 1 m intervals, leaving reference material at all levels. In lithologies with poor recovery an extra set of samples was later processed. The best preserved and richest samples were selected for microscopy.

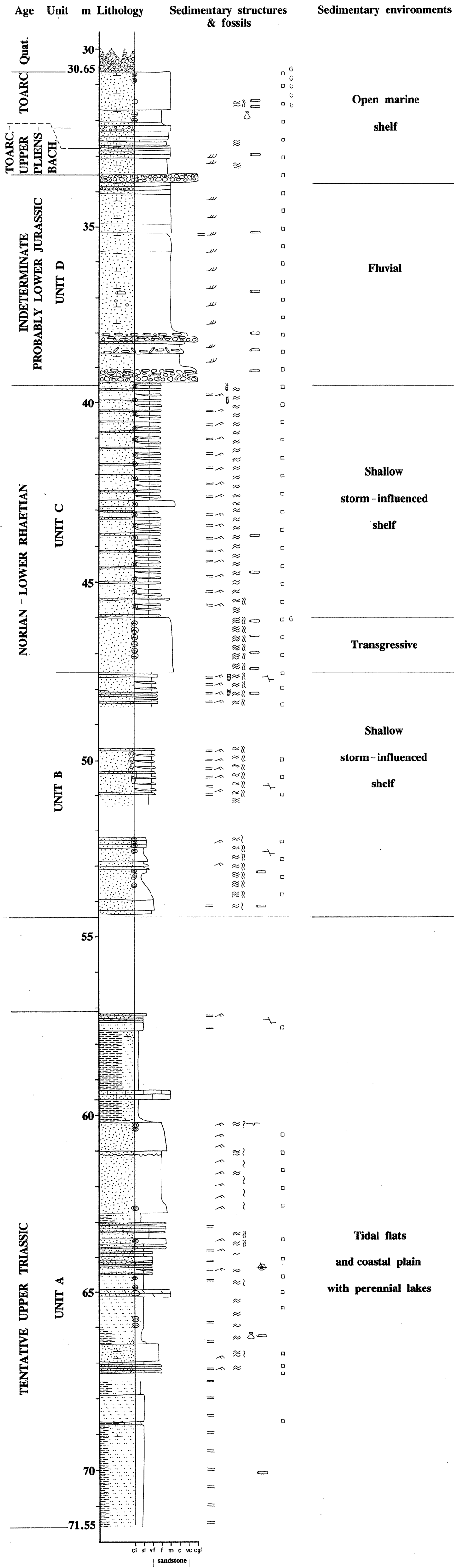
Slides were prepared of; the total residues, unoxidized sieved residues, and oxidized residues at various stages. Extra slides of selected, good samples were prepared for the participants.

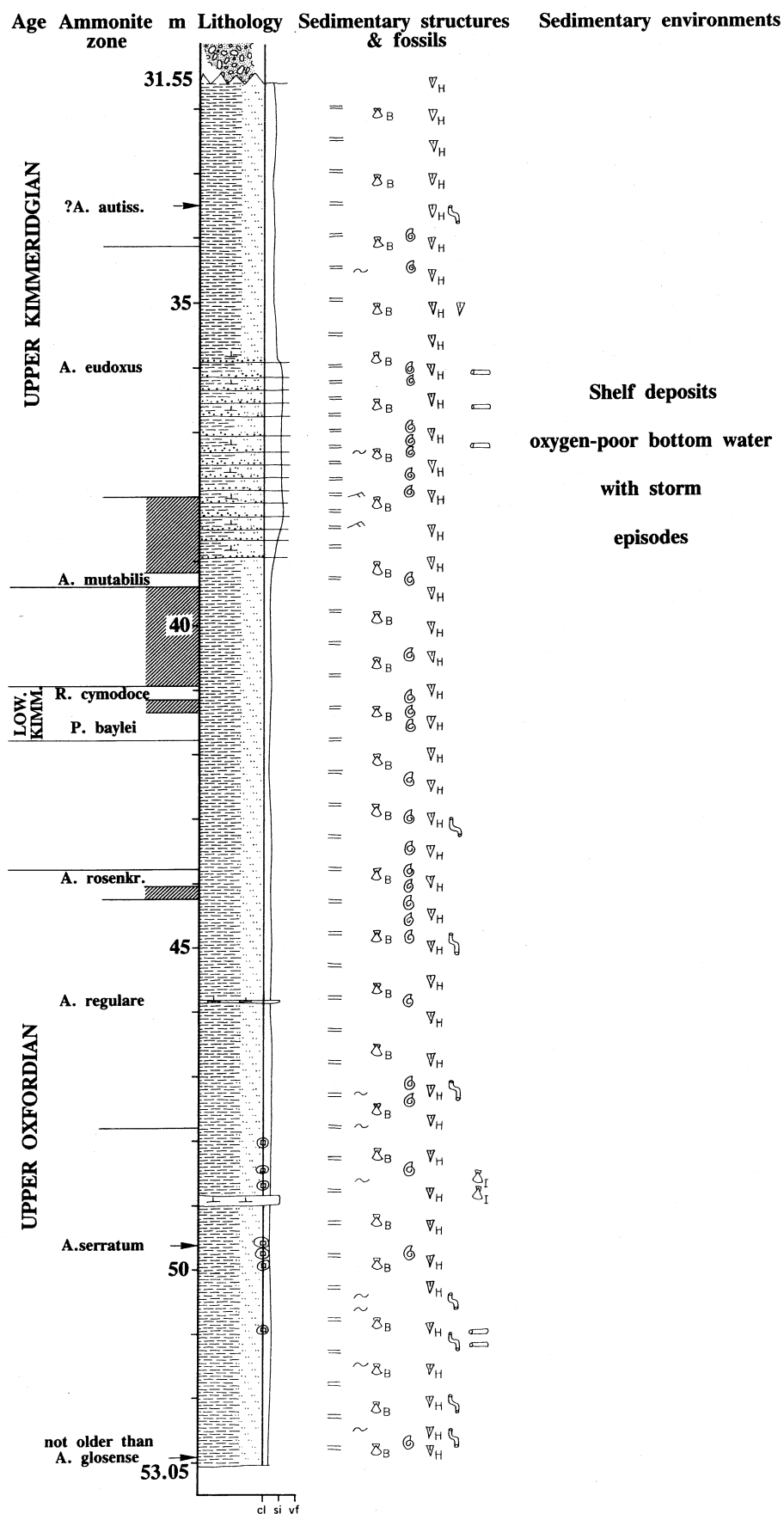
A.3.7 Organic geochemistry

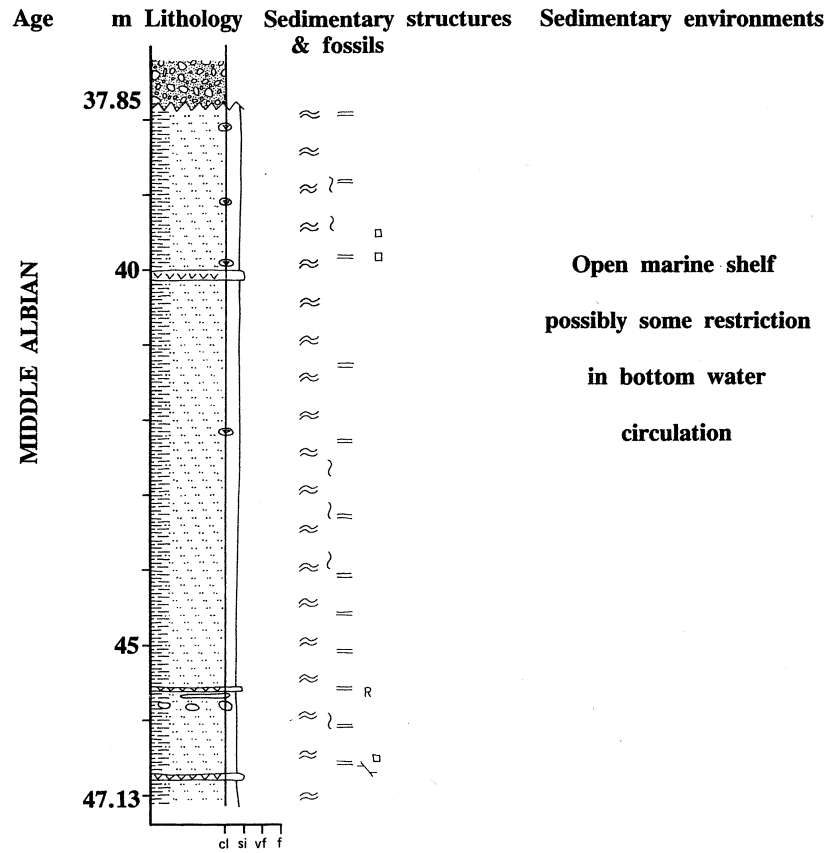
See the separate Appendix Volume.











Shallow Drilling Norfolk Basin 1986



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