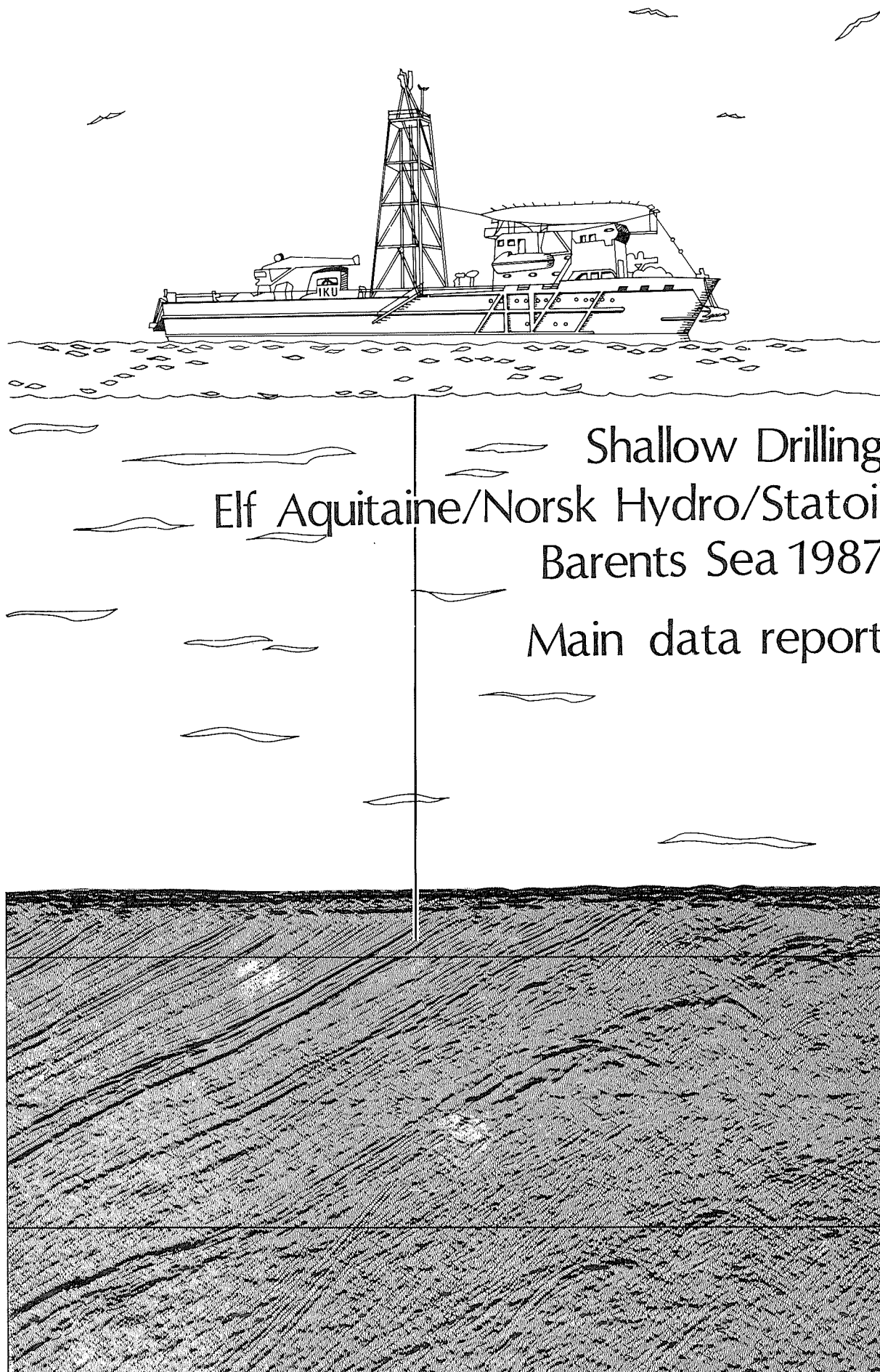




REPORT

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SHALLOW DRILLING
ELF AQUITAINE/NORSK HYDRO/STATOIL
BARENTS SEA 1987
Main Data Report

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CLIENT: Elf Aquitaine Norge a/s, Norsk Hydro a.s., Den norske stats oljeselskap a.s. (Statoil)				
SUMMARY: A total of 5 shallow drillings were carried out within this project in August/September 1987 in the Barents Sea. Two of the cores penetrated the youngest sedimentary units on the northeastern side of the Dia-Structure, one core penetrated the youngest sediments in the northeastern part of the Nordkapp Basin and two cores were from the top and base of a Lower Cretaceous unit further east in the same area. The main objective of the project was to provide cores and data to be used for reconstruction of the Cretaceous and Tertiary sedimentary and erosional history and its influence on the hydrocarbon potential in the area. The 5 cores all penetrated 50-60 m into bedrock, and 265 m of core were recovered, which is 94.5 % of the total cored length.				

KEY WORDS: Barents Sea	Shallow drilling
Dia-Structure	Source rock
Nordkapp Basin	Reservoir rock

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PREFACE

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1. INTRODUCTION

This report gives the result from bedrock drilling at five sites in the Barents Sea, three in the Nordkapp Basin and two close to the Dia-Structure. It is the main data report in the project "Shallow drilling Elf Aquitaine/Norsk Hydro/Statoil Barents Sea 1987". Previously one intermediate data report has been submitted ("Data report 1", 16 November 1987).

The project was originally split into two separate projects with Elf Aquitaine and Statoil in one project and Norsk Hydro and Statoil in the other. The first project comprised the two drillings at the Dia-Structure and one in the Nordkapp Basin and had as the primary objective to drill some of the youngest sedimentary bedrock in the area. Data should thereby be provided to studies of maturation etc. for subsequent use in the reconstruction of the thickness and erosional history of the Tertiary sediments in this part of the Barents Sea.

The other project comprised two shallow drillings in the northeastern part of the Nordkapp Basin where a Lower Cretaceous unit of up to about 500 msec thickness occurs. By coring the underlying Upper Jurassic source rock and compare the maturation parameters with those of a similar aged source rock further west, the influence on maturation of the sediment wedge could hopefully be stated. A core at the top of the unit should be used for dating of the wedge.

In November, two months after completion of the field work, the two projects were merged into one. Both projects were initiated by the participating companies. They were closely coordinated with another IKU drilling project, "Shallow drilling Barents Sea 1987". Except for a short shallow seismic line at the Dia-Structure, all the seismic data used here were collected during the latter project. All sites were selected on multi-channel seismic lines (720 m streamer, 96 channels, single air-gun).

Originally it was planned to drill 20 metres cores at three of the sites and 30-50 metres at the other two. The drilling operation was, however, so successful that it was drilled about 50-60 metres into bedrock at all sites. Total drilling in bedrock was 280 metres with an average core recovery of 94.5 %, while 238 metres of Quaternary overburden was penetrated. Some hammer samples of the overburden were also obtained, and analysis

results of these will be reported in another report scheduled for June 1988.

The present report is organized with the data presentation core by core in Chapter 3, starting with a short summary of each core and followed by a discussion of the local tie to the seismic data, core description, datings and organic geochemistry results. All organic geochemistry data and organic geochemical methods are presented in a separate appendix volume.

In the appendix part of the main volume we give a description of the field work, field work statistics, final positions and analytical methods. In particular we will mention the organic geochemical summary sheet and the detailed core logs (scales 1:100 and 1:50).

2. SUMMARY

During the late summer 1987 IKU drilled five shallow bedrock cores in two separate projects in the Barents Sea. During November the two projects were merged, and the five cores are all documented in the present data report.

Two cores were drilled at the Dia-Structure and three on the flanks of salt diapirs in the Nordkapp Basin (see Figure 2.1). Nearly 281 metres of bedrock were penetrated, with a core recovery of approximately 95 % (Table 2.1).

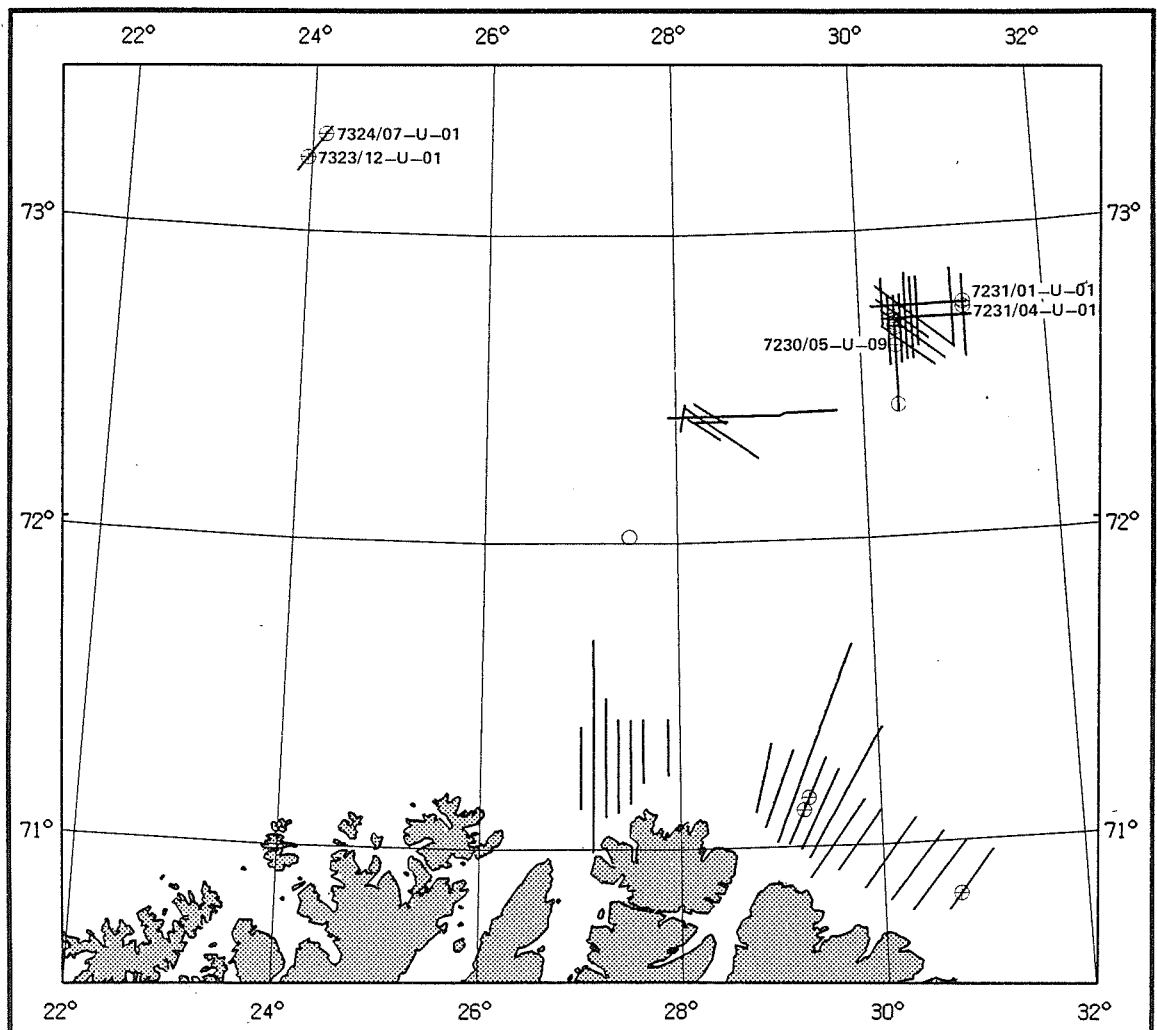


Figure 2.1 Map showing the locations of the three drill sites in the Nordkapp Basin and the two sites at the Dia-Structure. Other cores obtained by IKU in 1987 are also indicated.

Table 2.1 Technical data from the five sites.

Core no.	Seismic line	Shotp.	Quat. over- burden	Penetration in bedrock	Core recovery
7231/01-U-01	IKU-310730-87	2130.7	36.3 m	56.5 m	98.6 %
7231/04-U-01	IKU-310730-87	2246.3	37.7 m	59.7 m	97.3 %
7230/05-U-09	IKU-302230-87	1186.1	20.0 m	55.1 m	77.5 %
7324/07-U-01	IKU-21-87	1106.8	75.4 m	49.0 m	98.8 %
7323/12-U-01	IKU-21-87	411.1	69.2 m	60.6 m	100 %
			Σ238.4 m	Σ280.9 m	Av. 94.5 %

The main objectives were to collect data for maturity studies, to date seismic reflectors and document depositional environments. Sediments ranging in age from Late Oxfordian to Santonian were recovered, including potential hydrocarbon source rocks as well as potential reservoir rocks.

Core 7231/01-U-01 is 56.5 m long and contains three lithological units: Unit A (28.4 m) consists of black laminated shale with a high organic content and abundant ammonites. A nearly continuous succession was deposited from Late Oxfordian through latest Kimmeridgian - Early Volgian, and a major hiatus at the top of the unit is suggested. The shales contain 10-20 wt% organic material, which is thermally immature and consists of a largely amorphous type II/III kerogen. Artificial maturation experiments suggest that this material may be largely gas-prone. The sediment was deposited under oxygen depleted shelf conditions. Slightly more than the upper half of the about 50 m thick shale unit was cored at this site. The lower half of the same unit was cored by IKU 25 km to the southwest (at site 7230/05-U-02) this summer.

Unit B (4.5 m) is dominated by a limestone of wackestone/packstone. A green shale occurs in the lower and uppermost part and has gradational transitions to the limestone. Foraminiferal dating indicates the lower part of the unit to be of Early Hauterivian age while the upper part of the unit (and Unit C) shows latest Hauterivian - Early Barremian age inferred by

palynomorphs, foraminifera and nannofossils. The unit was deposited during well oxygenated open shelf conditions probably below the photic zone. The top of Unit B is recognized as a strong, regional seismic reflector.

Unit C (23.6 m) consists of dark grey mudstone with calcareous lamina of fossil debris throughout. Palynomorphs, foraminifera and nannofossils give the unit a latest Hauterivian - Early Barremian age. The unit contains moderate amounts of largely inert kerogen (type IV). The unit was deposited under open marine conditions.

Core 7231/04-U-01 is 59.7 m long and consists of silty and sandy mudstone. A marked seismic reflector was penetrated. Palynomorphs and foraminifera indicate a more or less continuous succession of Aptian to Middle Albian age. The organic material is immature, decreases in abundance upwards and is dominated by hydrogen-poor type IV kerogen. The core represents low sedimentation rates (glauconite, bioturbation) and was deposited under shelf conditions.

Core 7230/05-U-09 is 55.1 m long and contains claystones and sandstones, the latter with promising reservoir properties. Dinoflagellate cyst assemblages suggest more or less continuous deposition during latest Late Albian to earliest Middle Cenomanian. The core consists of two coarsening upward sequences which are overlain by a fining upwards sequence. The two lower sequences represent marginal marine sediments deposited in lower to upper shoreface. For the uppermost sequence a marginal marine and lagoonal setting is suggested. The core is very poor in organic material, which is hydrogen-poor and thermally immature.

Core 7324/07-U-01 is 49 m long and consists of silty claystone with silt and sandstone interbeds. Analyses of palynomorphs, foraminifera and nannofossils independently conclude with an age close to the Albian - Cenomanian boundary, however ammonites indicate Early - Middle Albian age. At present we emphasize the three datings that show good consistency, and conclude that the core is of latest Late Albian - earliest Early Cenomanian age. The lower part of the core consists of a coarsening upward succession and a seismic reflector is recognized near the top of this unit. The core contains fair to good organic richness, however of immature hydrogen poor type IV kerogen. The sediments were deposited under open shelf conditions.

The core is suggested to be time equivalent with the lower part of the youngest core from the Nordkapp Basin. Significant differences in depositional environment are, however, encountered.

Core 7323/12-U-01 is 60.6 m long and consists of calcareous claystones, glauconitic limestones and greenstones in the lower part, overlain by limestones and calcareous claystones. Palynomorphs, foraminifera and nanofossils indicate a more or less continuous sequence of Middle Turonian to Santonian age, and a seismic sequence boundary is located within the interval dated as Coniacian to Santonian. The core is extremely poor in organic material. The sediment was deposited on a well oxygenated open shelf, probably below the photic zone, and the very high glauconite content in the lower part of the core demonstrates low sedimentation rate.

The five cores yielded excellent opportunities to correlate core data to seismic reflectors, and major Cretaceous sediment wedges in the two areas are accurately dated. Cretaceous successions that never have been cored in the Barents Sea/Svalbard region before, are now documented by continuous cores. In addition information on maturation parameters is provided.

Finally it may be concluded that the project has been successful, in that twice the planned length of core was obtained permitting analyses that are presented in this report. Given the original objectives, however, the time and the budget, the present report must be regarded as a data report where the individual data are only brought up to a certain level of integration. The data and results obtained so far have a great potential of approaching, and of solving, major problems in the studied area. In particular we mention that correlation with the other cores obtained by IKU in the area in 1987 and 1986 probably will provide valuable stratigraphic, sedimentological and organic geochemical results. Further studies on maturation by means of organic geochemical analysis, isotope analysis, and further clay mineral analysis as well as other methods will be highly interesting for reconstruction of the sedimentation and erosion history of the Barents Sea during Cretaceous and Tertiary periods.

3. DATA PRESENTATION

3.1 Core 7231/01-U-01

3.1.1 Summary

In core 7231/01-U-01 56.5 m of bedrock was drilled in the interval between 36.3 m and 92.8 m below the sea floor, with 98.6 % core recovery. The core is divided into litho-units A, B and C, with boundaries at 64.4 and 59.9 m respectively (Figure 3.1.1). The latter correlates to a strong seismic reflector, while the Unit A/B boundary represents a sequence boundary. Another prominent reflector is correlated to the 78.3 m level.

The lower Unit A (28.4 m thick) consists of laminated black shales. A calcitic nodule band occurs at the 78.3 level, and at 66.22 m a thin lamina with glauconite is recognized.

Unit B (4.5 m thick) is dominated by a limestone of wackestone/packstone. A green shale occurs in the lower part. The carbonate content increases upwards into the limestone. The reverse situation is seen in the upper tens of centimetres.

Unit C (23.6 m thick) consists of dark grey mudstones with calcareous laminae of fossil debris throughout.

Deposition of Unit A took place in a deep shelf environment with oxygen depleted bottom water. However, well stratified water masses occurred as reflected by a distinct planktonic biota. A marked decrease in the number of ammonites and bivalves in the upper part of the unit may be explained by a higher rate of deposition.

Units B and C were deposited in a shelf position, probably below the photic zone, with well oxygenated water masses throughout.

7231/01-U-01
Age: Late Oxfordian
- Early Barremian

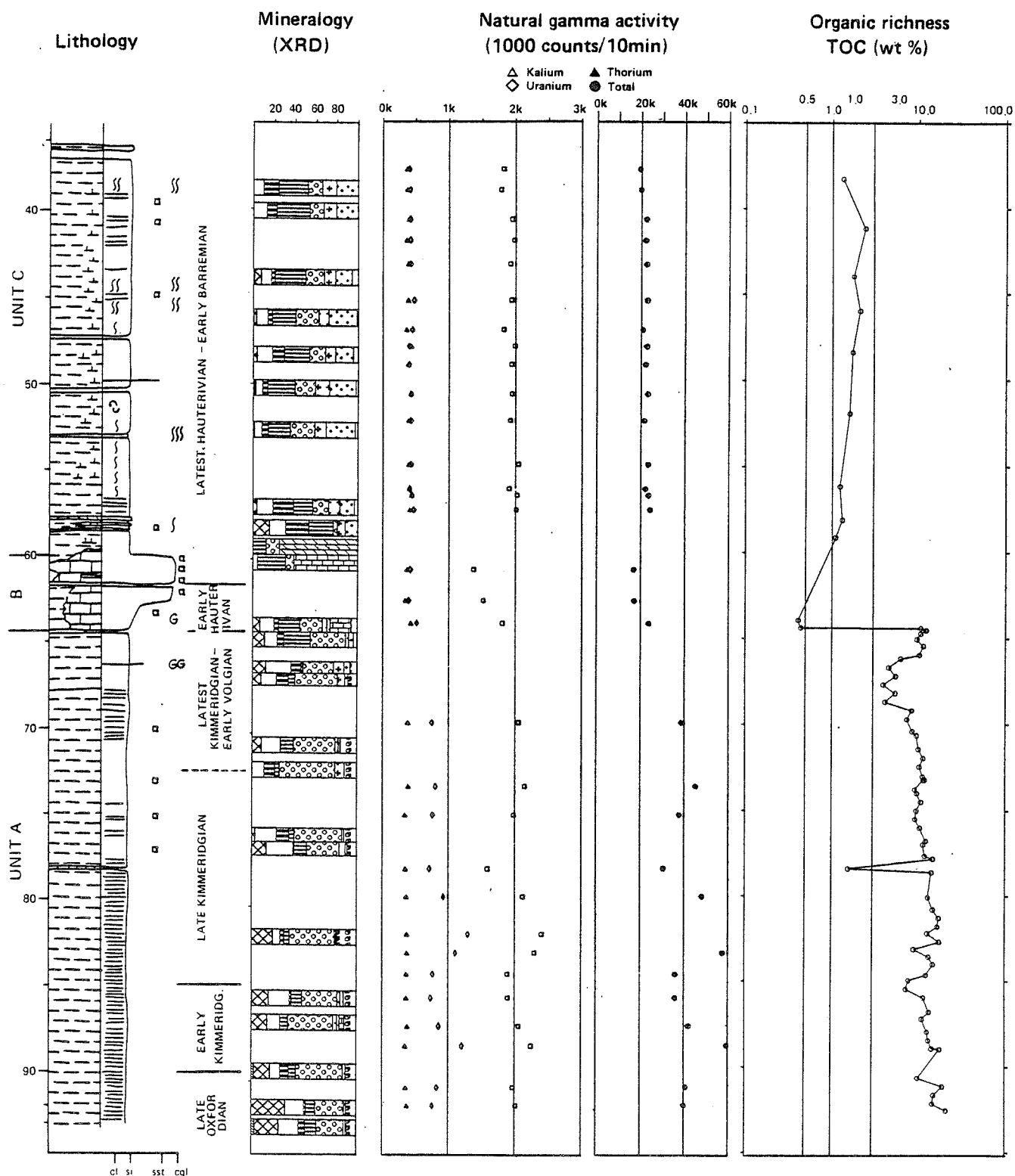


Figure 3.1.1 Summary figure of core 7231/01-U-01. Legend in Appendix A.3.

Ammonites and palynomorphs indicate a nearly continuous succession deposited from Late Oxfordian through latest Kimmeridgian - Early Volgian. Formaminiferal data suggest a major hiatus (at least some 15 million years) at the top of Unit A, as the lower part of Unit B is dated Early Hauterivian. The upper half of Unit B and the entire Unit C are of latest Hauterivian - Early Barremian age as inferred by palynomorphs, nannofossils and foraminifera.

The lithostratigraphical Units A, B and C are also reflected in the organic geochemical data. The shales of Unit A contain abundant (ca. 10-20 wt%), thermally immature (ca. 0.35 % Ro), largely amorphous, type II/III kerogen. This unit also contains appreciable amounts of immature bitumen which show some variation in composition. Artificial maturation experiments on material from Unit A suggest that these rocks may be largely gas-prone. Unit B is organic-lean, and the kerogen is largely inert. Non-indigenous hydrocarbons, probably representing seepage from Unit A, are present. The claystones of Unit C contain moderate amounts of largely inert kerogen (Type IV). Extractable hydrocarbons from this core show similarities with the hydrocarbons described from core 7231/04-U-01 below.

3.1.2 Seismic interpretation

The site is located on the southern flank of a salt structure in the northeastern part of the Nordkapp Basin. A sequence boundary was penetrated at the base of the limestone 59.9 m below seabed. Reflection from the top of this 4.5 m thick limestone is recognized as a strong regional seismic reflector (Figure 3.1.2). One minor unit boundary was penetrated above the limestone (50.5 m) and a more prominent one below (78.3 m), see also Table 3.1.1. The latter can be followed southwards into the basin as the only seismic reflector in the Upper Jurassic/Lower Cretaceous shale unit. The shale increases in thickness from about 50 m at the subcrop position to about 125 m in the basin. About 28 m or slightly more than half of it, was penetrated by this core.

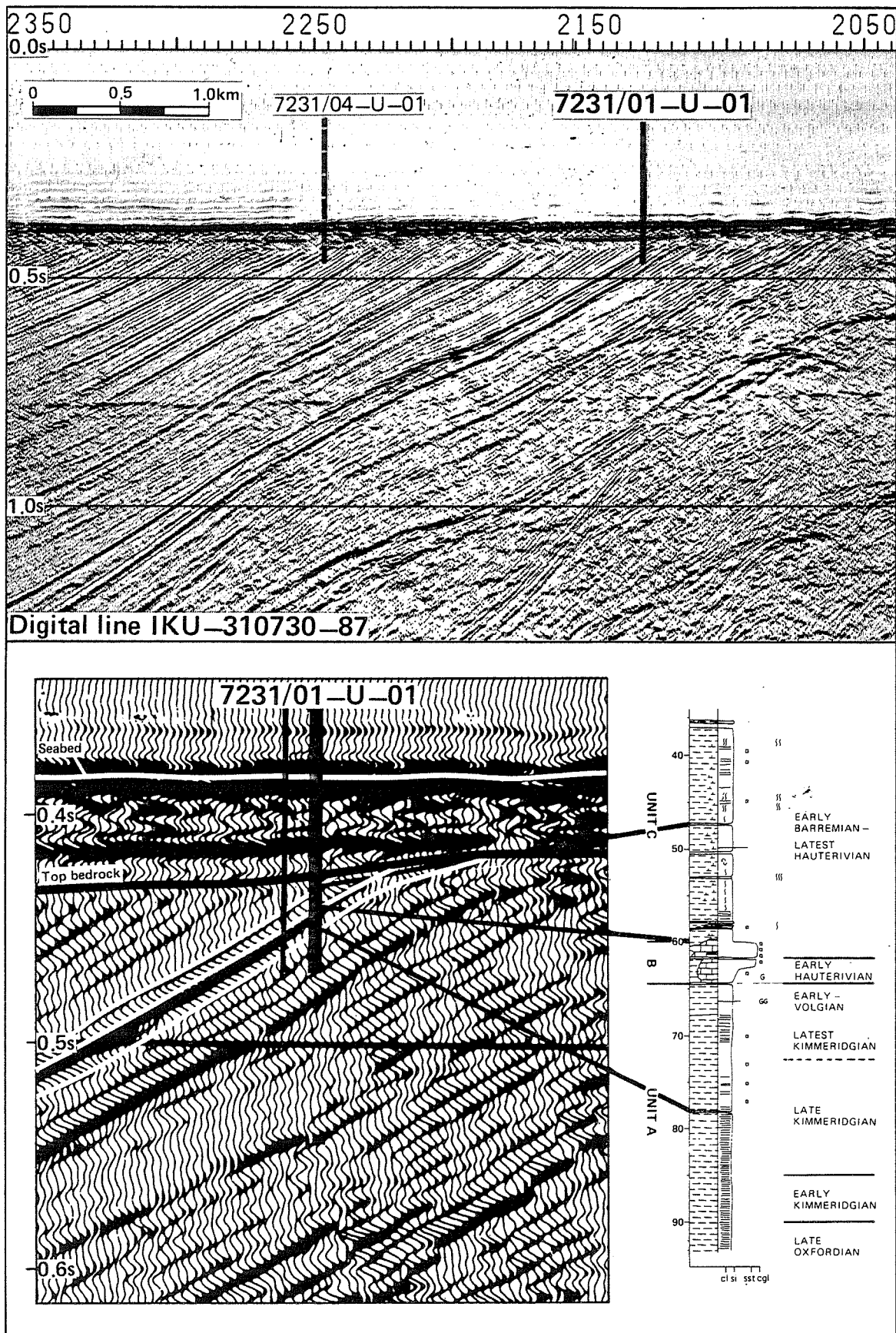


Figure 3.1.2 Correlation between core 7231/01-U-01 and seismic data. Because of the high dip angle all inclined reflections are uplifted about 5-6 msec. The "real" position of the core relative to the dipping beds is indicated by the thin vertical line on the lower seismic section.

Table 3.1.1 Key data of the correlation between core 7231/01-U-01 and seismic line IKU-310730-87.

Depth below seabed		Core unit	Thickness of seismic unit		Interval sound velocity
36.3 m	40.3 msec	Overburden	36.3 m	40.3 msec	1800 m/s
50.5 m	52.5 msec	C	14.2 m	12.2 msec	2330 m/s
59.9 m	60.5 msec	C	9.4 m	8.0 msec	2350 m/s
64.4 m	63.1 msec	B	4.5 m	2.6 msec	3460 m/s
78.3 m	73.1 msec	A	13.9 m	10.0 msec	2780 m/s
TD92.8 m	83.5 msec	A	14.5 m	10.4 msec	2780 m/s
Total TD below sea surface: 370.8 m / 463 msec					

3.1.3 Sedimentology

Core description

The core consists of three units (Figure 3.1.3). A lower black shale (Unit A) is overlain by a thin limestone and marl in Unit B and dark calcareous claystone in the upper part of the core (Unit C).

Unit A occurs from the base of the core up to 64.4 m and consists of thinly laminated black shale. In the lower part (up to ca. 75 m) ammonites are abundant as well as bivalves. Cephalopod hooks are also common. All these fossil remains represent a pelagic fauna and only a few traces of a benthic microfauna (foraminifera) are found, and no trace fossils. A calcitic nodule occurs at 78.40 m, and at 66.22 m a thin lamina with glauconite grains is present. The dark shale continues to the top of the unit and has a sharp boundary to the overlying unit.

Unit B is only 4.5 m thick and occurs between 64.4 and 59.9 m. In the lower two metres the unit is dominated by a green shale with small bivalve fragments. The carbonate content increases upwards and in the following one metre a light grey to white limestone dominates. The limestone mostly has a nodular appearance and seems to be strongly bioturbated. Further upwards the core consists of limestone with only a minor clay content, and in the upper 30 cm interfingering green claystone and limestone occur. The limestone content decreases over this short interval, and in the uppermost part of the unit it is dominated by the green shale. Limestone nodules and greenish shale are also found interfingered with the grey shale of the overlying unit.

Unit C occurs from level 59.9 m to the top of the core. The base of the unit is defined by the appearance of dark grey claystone overlying the green claystone on top of the limestone. Clasts of the limestone and claystone occur in the basal few centimetres of the unit. Carbonate nodules at 58 m consist of fine grained siderite. The whole unit consists of dark grey mudstone, with common thin calcareous laminae of fossil debris. Calcite cementation of the claystone is common, and probably reflects dissolved fossil remains. Sparse bioturbation occurs in part of the core, and some thin beds show intense burrowing. Lamination is present in most of the unit.

7231/01-U-01

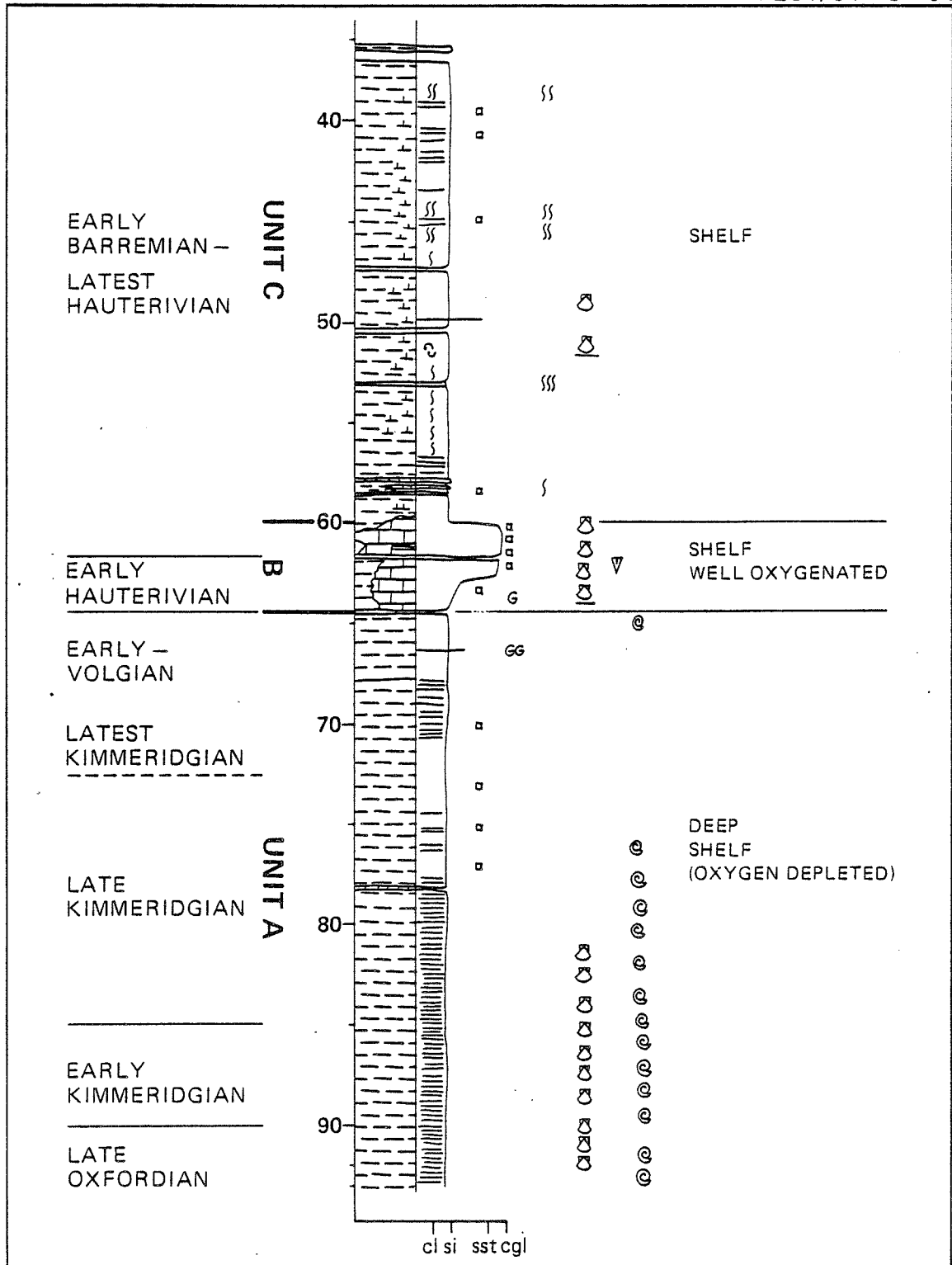


Figure 3.1.3 Simplified log of core 7231/01-U-01. Detailed log in scale 1:100 is found in Appendix A.5.

In the upper five metres some intervals are strongly tectonized.

Thin section description

The one thin section (78.45 m) that has been made from Unit A represents a limestone with micritic to microsparitic texture. The SEM analysis shows that the thin section represents mostly calcite. However, small patches of barite are present as well as a few grains of heavy minerals. The thin section contains abundant organic material and the drusy textures of the fine grained carbonate (micrite/microsparite) may indicate recrystallization from fecal pellets.

Eleven thin sections have been made from the limestone and marls of Unit B, and four of these have also been studied under the SEM.

The thin section at the base of the unit (64.4 m) shows presence of clayey peletoids. In the SEM little Ca (or calcite) is detected, but minor amounts of apatite and also pyrite are present. The clay is dominated by illite.

The remaining 10 thin sections from Unit B are wackestones and packstones, with clay matrix in the lower two samples. Bivalves are very abundant, both *Inoceramus* and more thin shelled forms. Other fossils that occur are ostracods, foraminifera and echinoderms, while calcareous algae, calcispheres and bryozoans are sparse. Many of the bivalve fragments show abundant boring, probably by sponges. Clear micritization is only occasionally observed.

Colouring of the thin sections show presence also of other carbonate minerals than calcite, and microprobe analysis at 62.21 m shows presence of a minor content of an iron rich dolomite (Figure 3.1.4). In one sample some clay matrix is also present between the bivalve shells.

In Unit C two thin sections are made from siderite beds. The lowermost (57.95 m) show presence of a drusy texture (Figure 3.1.5), and electron microprobe analysis shows presence of magnesium and calcium bearing siderite. The uppermost sample (53.18 m) shows micritic texture of the siderite, and this sample is burrowed by *Chondrites*.

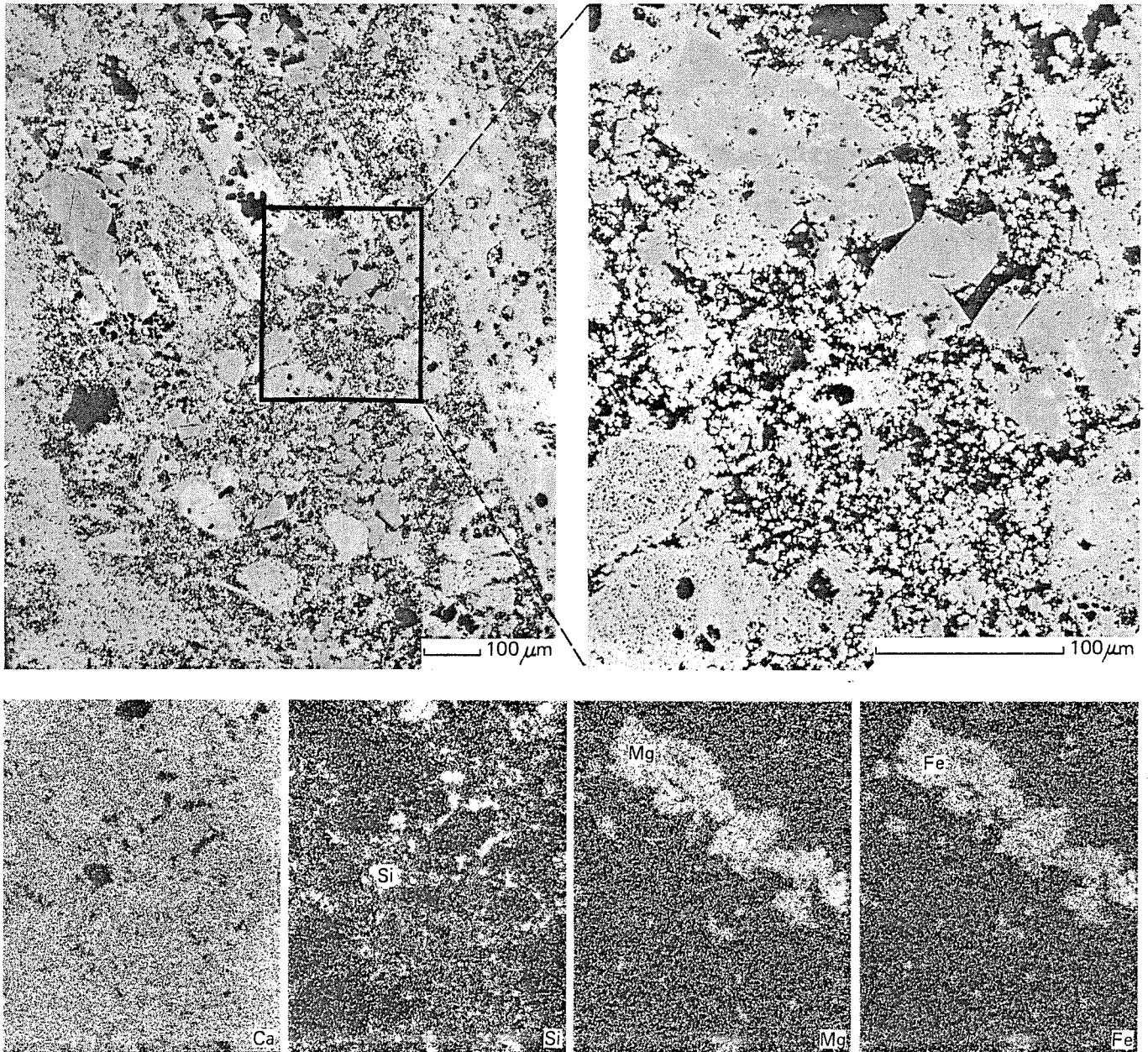


Figure 3.1.4 Backscatter electron microscope images (upper) and X-ray images (below) of a packstone from 62.21 m. The two backscatter images show bored bivalve fragments (mainly of *Inoceramus*) with a calcitic and slightly clayey matrix. The enlargement shows presence of diagenetic crystals of ferrous dolomite.

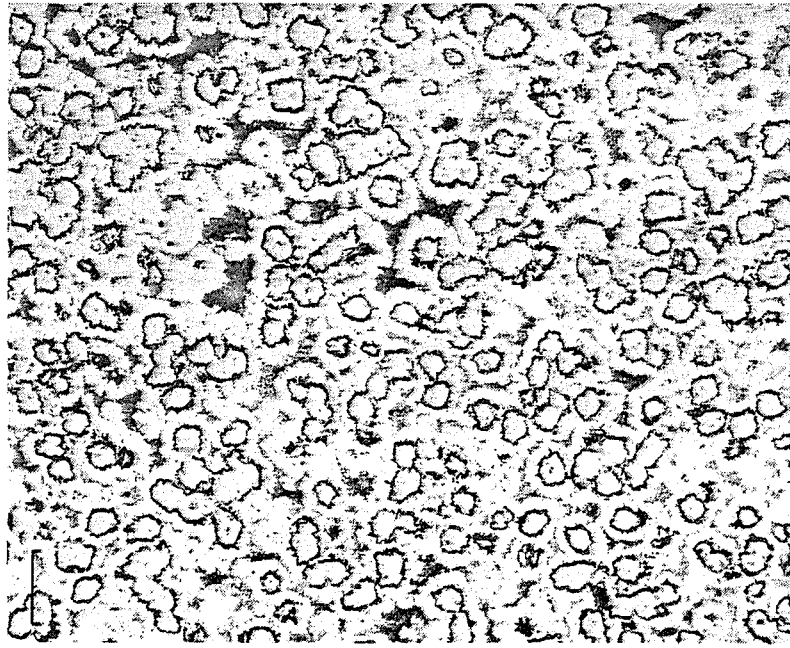


Figure 3.1.5 Backscatter electron microscope image of siderite from 57.95 m. The drusy texture occurs throughout the thin section, and minor amounts of clay occur in the central voids of the many druses.

X-ray diffraction

Twenty-five samples have been analyzed for bulk mineralogy by X-ray diffraction, and 12 clay samples have been separated for the < 4 micron fraction and analyzed. Marked differences are seen between the units (Figures 3.1.6 and 3.1.7, Tables 3.1.2 and 3.1.3).

Unit A contains abundant mixed layer clay minerals and has also a high content of pyrite. In the clay fraction the content of kaolinite and illite is increasing upwards, mainly at the expense of the mixed layer clays.

Unit B is only represented by a marl sample which is dominated by calcite and chlorite.

Unit C is represented by a sample of siderite in the lower part while the other bulk samples are rich in plagioclase and have a clay fraction dominated by illite and 7 Å minerals. While kaolinite is more abundant than chlorite in the bulk samples, the opposite is observed in the < 4 micron fraction.

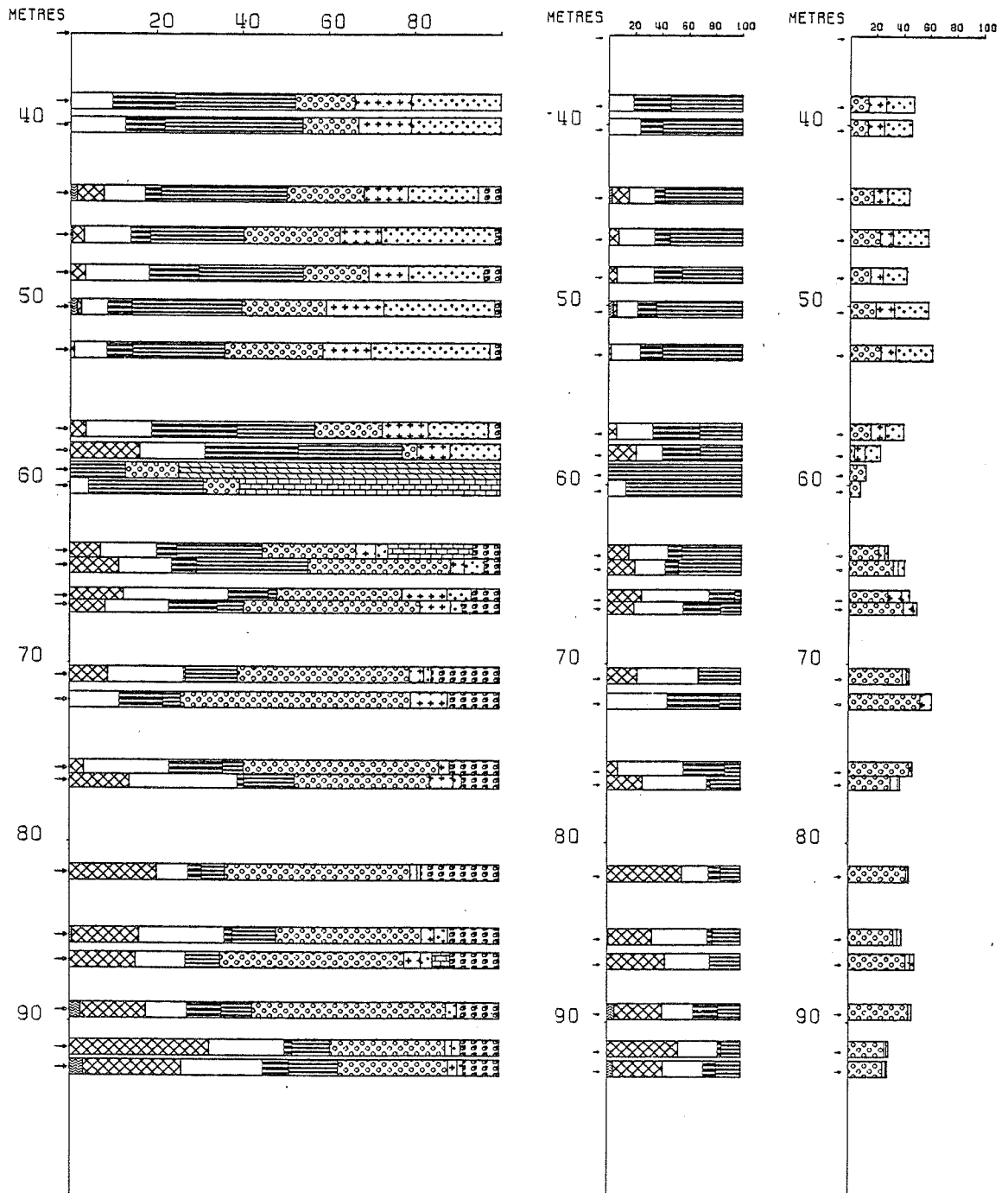


Figure 3.1.6 Whole rock mineralogy from core 7231/01-U-01 based on XRD analysis. Legend in Appendix A.3.

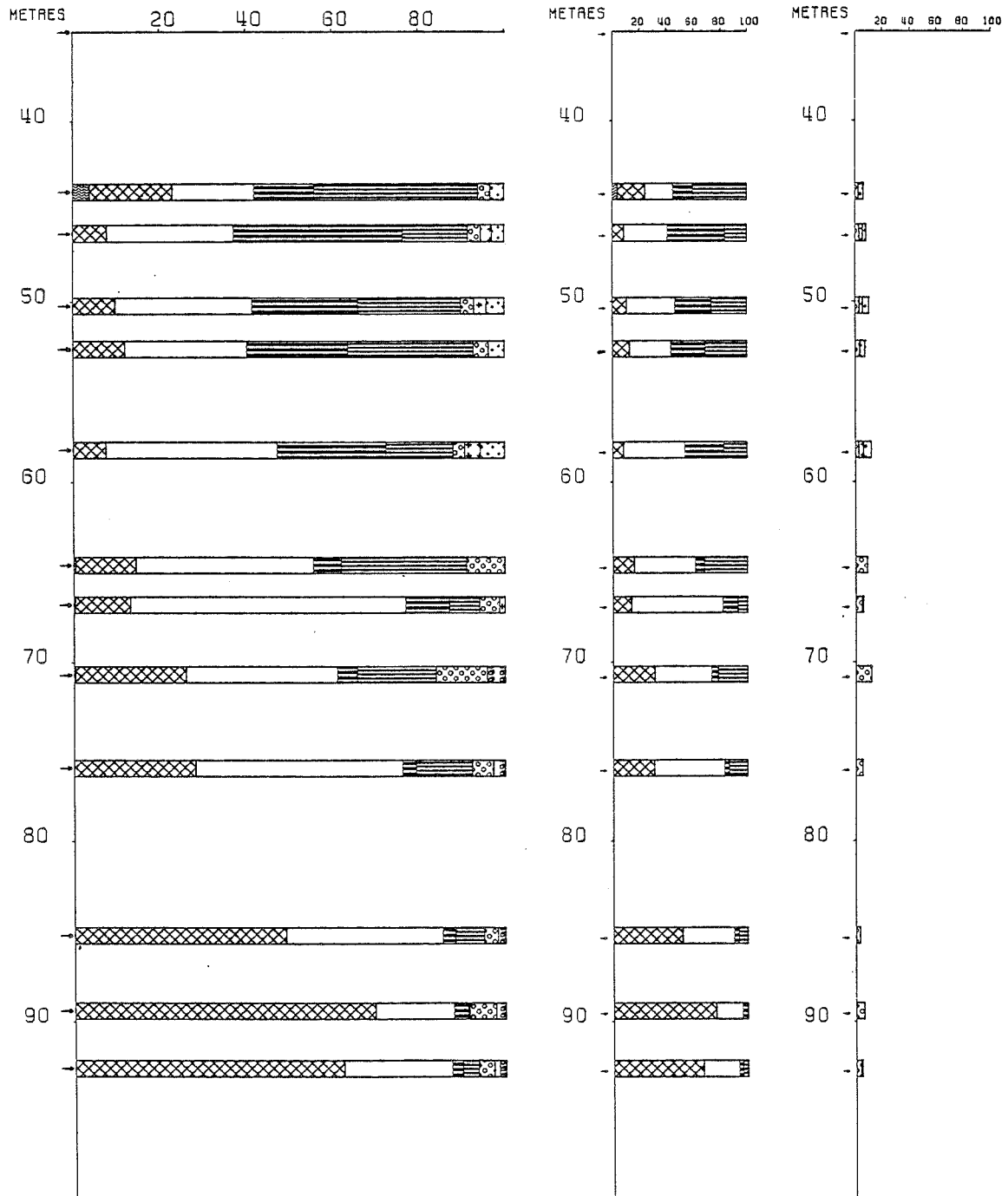


Figure 3.1.7 Clay mineralogy (<4 micron) from core 7231/01-U-01 based on XRD analysis. Legend in Appendix A.3.

Table 3.1.2 Tabulated values from XRD analysis of whole rock samples of core 7231/01-U-01. The values represent semiquantitative wt%. See Appendix A.3 for details.

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %
38.75	D-1253	0.0	9.7	14.6	27.8	13.9	13.1	20.8	0.0	0.0	0.0	0.0	0.0
40.11	D-1256	0.0	12.7	9.2	32.1	13.1	12.2	20.9	0.0	0.0	0.0	0.0	0.0
43.87	D-1262	1.5	9.6	3.7	29.3	17.8	10.2	16.4	0.0	0.0	0.0	0.0	5.2
46.24	D-1266	0.4	10.7	4.7	21.7	22.3	9.6	26.5	0.0	0.0	0.0	0.0	1.2
48.30	D-1269	0.0	14.8	11.6	24.2	15.3	9.1	17.6	0.0	0.0	0.0	0.0	3.9
50.16	D-1270	1.5	6.1	5.6	25.7	19.6	13.3	25.7	0.0	0.0	0.0	0.0	1.5
52.58	D-1273	0.0	7.5	6.0	21.4	22.9	11.1	27.7	0.0	0.0	0.0	0.0	2.5
56.95	D-1281	0.0	15.1	19.9	18.1	15.7	10.7	14.0	0.0	0.0	0.0	0.0	2.8
58.21	D-1283	0.0	15.1	21.7	24.1	3.5	7.7	11.7	0.0	0.0	0.0	0.0	0.0
59.29	D-1286	0.0	0.0	0.0	12.9	12.3	0.0	0.0	0.0	0.0	74.8	0.0	0.0
60.19	D-1287	0.0	4.2	0.0	26.8	8.3	0.0	0.0	60.7	0.0	0.0	0.0	0.0
63.79	D-1296	0.0	13.1	4.8	19.8	21.7	4.6	2.9	19.7	0.0	0.0	0.0	6.4
64.55	D-1295	0.0	12.2	5.9	25.9	33.3	3.2	4.5	0.0	0.0	0.0	0.0	3.7
66.25	D-1300	0.0	24.3	9.3	2.2	29.0	10.4	5.7	0.0	0.0	0.0	0.0	6.6
66.80	D-1301	0.0	14.7	11.4	6.2	40.9	7.0	2.8	0.0	0.0	0.0	0.0	8.7
70.66	D-1307	0.0	17.6	0.5	12.1	40.0	3.4	1.7	0.0	0.0	0.0	0.0	15.9
72.12	D-1311	0.0	11.6	10.1	4.1	53.6	8.6	0.0	0.0	0.0	0.0	0.0	12.0
75.92	D-1320	0.0	19.8	12.6	4.8	45.4	2.4	0.0	0.0	0.0	0.0	0.0	11.6
76.57	D-1319	0.0	25.2	1.5	11.8	31.5	5.6	1.8	0.0	0.0	0.0	0.0	8.8
81.65	D-1333	0.0	7.2	3.2	5.4	43.2	1.5	0.8	0.0	0.0	0.0	0.0	18.3
85.19	D-1340	0.6	19.8	2.0	10.2	33.7	3.1	3.1	0.0	0.0	0.0	0.0	12.0
86.59	D-1341	0.0	11.7	0.0	8.1	42.8	3.7	2.8	4.1	0.0	0.0	0.0	11.4
89.44	D-1347	2.5	9.6	8.1	7.2	45.0	0.0	2.5	0.0	0.0	0.0	0.0	9.9
91.51	D-1352	0.0	17.5	1.9	8.8	26.9	1.6	1.8	0.0	0.0	0.0	0.0	9.1
92.59	D-1353	3.1	18.9	6.1	11.4	25.6	2.3	1.2	0.0	0.0	0.0	0.0	8.4

Table 3.1.3 Tabulated values from XRD analysis of clay fraction (<4 micron) samples of core 7231/01-U-01. The values represent semiquantitative wt%. See Appendix A.3 for details.

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %
43.87	D-1262	3.9	18.9	14.0	37.9	2.8	0.0	3.2	0.0	0.0	0.0	0.0	0.0
46.24	D-1266	0.0	29.4	39.1	15.2	3.0	2.6	2.8	0.0	0.0	0.0	0.0	0.0
50.16	D-1270	0.0	31.7	24.6	23.8	3.0	2.8	4.2	0.0	0.0	0.0	0.0	0.0
52.58	D-1273	0.0	28.3	23.4	29.1	3.5	0.0	3.6	0.0	0.0	0.0	0.0	0.0
58.21	D-1283	0.0	39.7	25.3	15.6	2.7	3.6	5.6	0.0	0.0	0.0	0.0	0.0
64.55	D-1295	0.5	41.2	6.4	29.1	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
66.80	D-1301	0.3	63.7	10.3	6.9	4.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0
70.66	D-1307	0.3	35.1	4.5	18.4	11.9	0.0	0.0	0.0	0.0	0.0	0.0	4.1
75.92	D-1320	0.0	48.0	3.3	12.9	5.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7
85.19	D-1340	0.0	36.1	3.1	6.7	3.1	0.0	0.0	0.0	0.0	0.0	0.0	1.8
89.44	D-1347	0.0	18.1	3.3	0.4	6.2	0.0	0.0	0.0	0.0	0.0	0.0	2.2
92.59	D-1353	0.0	25.0	2.5	3.7	3.6	0.0	1.2	0.0	0.0	0.0	0.0	1.5

Petrophysics

Natural γ -radiation

The natural γ -activity from core 7231/01-U-01 shows a marked change at about 64 m (Figure 3.1.8). Thorium shows only very little variation. The uranium content increases below about 64 m. Above the carbonate (Unit C) the average radiation is 430 counts (per 10 minutes) while it is 860 counts below the carbonate (Unit A). Some layers show as high as 1200-1300 counts. The high content of uranium correlates with a change in lithology and also a higher content of organic carbon (TOC = 1.1-2.4 % above the carbonate and mainly 10-20 % below). Potassium shows only a small increase downwards, due to minor mineralogical changes. The marked increase in the total γ -activity is mainly due to the higher uranium content. Uranium has abundant radioactive daughter isotopes with γ -energies lower than that of potassium which are included in the "total" γ -log.

Sound velocity

Horizontal sound velocities have been measured at 37 levels along the core (Figure 3.1.8; Table 3.1.4). Some of the obtained values in Unit A are very low and are considered erratic due to expansion or fracturing of the core upon pressure release. The same effect is responsible for all the low values in the vertical sound velocity measurements, since fracturing mainly takes place along the lamination of the rock.

The two uppermost values in Unit B and all values in Unit C seem to be reliable. From correlation between the core and the seismic data, interval sound velocities have been calculated (see Table 3.1.1). The interval velocities are 2780 m/s, 3460 m/s and 2330 m/s for Units A, B and C, respectively, and are in good agreement with the above accepted values measured in the core.

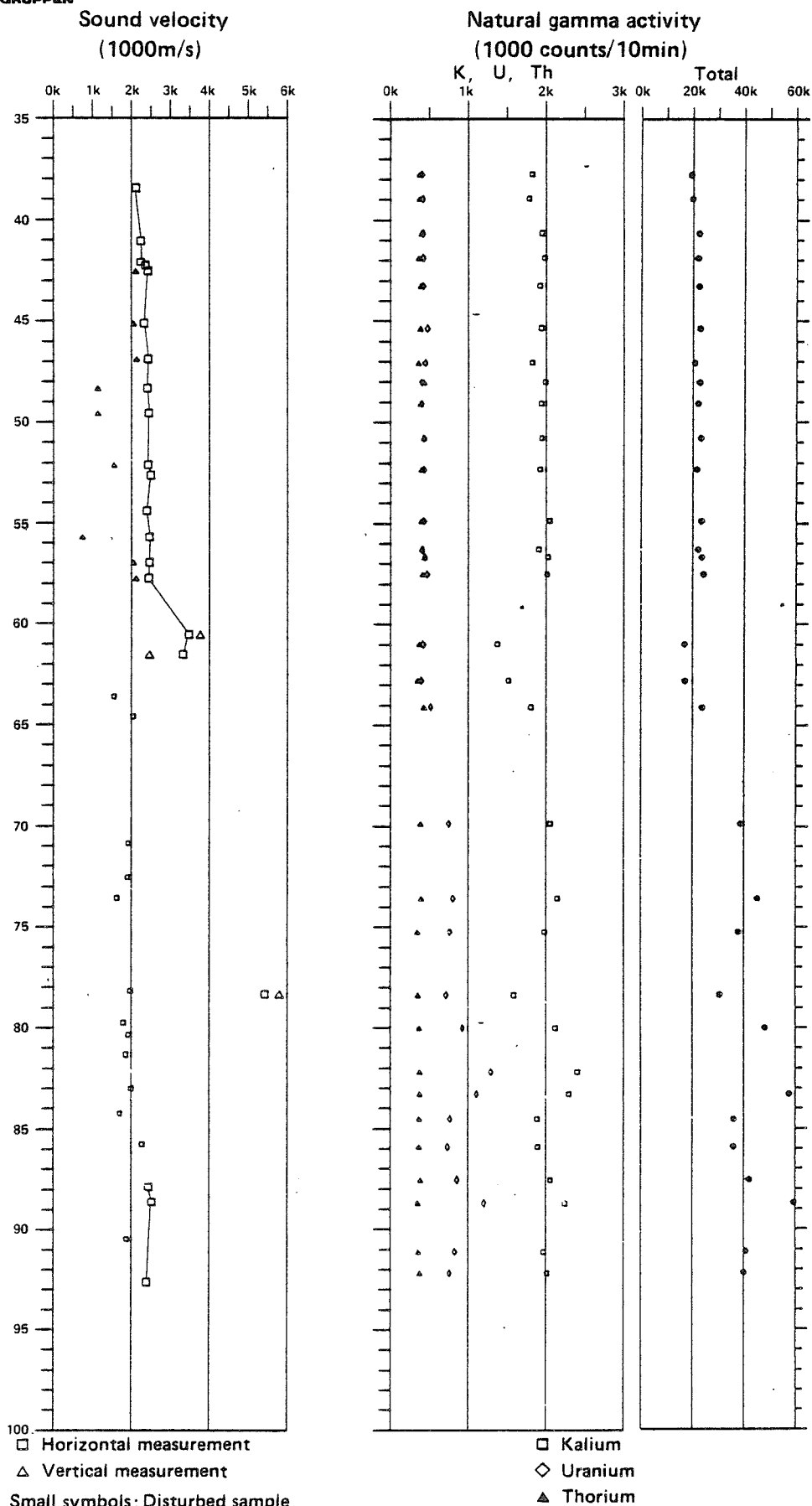


Figure 3.1.8 Natural γ -radiation (counts per 10 minutes) and sound velocity (m/s) in core 7231/01-U-01.

Table 3.1.4 Sound velocity (m/s) in core 7231/01-U-01.

Depth m	Horiz. velocity m/sec	Vert. velocity m/sec
38.46	2132	0
41.07	2253	0
42.12	2246	0
42.27	2368	0
42.57	2433	2112 *
45.14	2323	2054 *
46.91	2433	2136 *
48.34	2414	1137 *
49.59	2447	1138 *
52.11	2431	1554 *
52.66	2500	0
54.41	2396	0
55.72	2461	729 *
57.00	2455	2056 *
57.77	2449	2112 *
60.54	3484	3772
61.54	3326	2469
63.63	1553 *	0
64.63	2047 *	0
70.87	1921 *	0
72.57	1904 *	0
73.57	1630 *	0
78.15	1973 *	0
78.35	5432	5800
79.75	1789 *	0
80.35	1930 *	0
81.32	1869 *	0
83.00	1995 *	0
84.23	1705 *	0
85.74	2286 *	0
87.89	2453	0
88.63	2523	0
90.48	1880 *	0
92.63	2399	0

*) Velocities from samples marked by * represent disturbed samples.

3.1.4 Paleontology

92.8 - 90.0 m Late Oxfordian

Ammonites

A fauna consisting of the closely related forms *Amoeboceras* cf. *ilovaiskii*, *A.* cf. *transitorium* and *A.* ex gr. *ilovaiskii* - *transitorium* occurs between 92.77 and 91.92 m (Figure 3.1.9). The fauna characterizes the *A. ilovaiskii* Subzone of the *A. glosense* Zone, i.e. the lowermost part of the Upper Oxfordian after the definition of the substage by Sykes & Callomon (1979).

Amoeboceras serratum and *A.* cf. *serratum* are found between 91.04 and 90.75 m indicative of the *A. serratum* Zone.

In the interval from 90.60 to 90.27 m representatives of *Amoeboceras regulare*, *A.* cf. *regulare*, *A.* cf. *leucum* and *A.* cf. *freboldi* occur. This is a typical fauna of the *A. regulare* Zone. It may be noted that all these species, but associated with *A. serratum*, appear for the first time in the upper part of the *A. serratum* Zone (Sykes & Callomon 1979). *Amoeboceras* cf. *rosenkrantzi* indicative of the topmost Boreal Oxfordian *A. rosenkrantzi* Zone occurs at 90.04 m.

Palynology

The Boreal low diversity *Paragonyaulacysta borealis* dinoflagellate cyst assemblage is present in the two examined samples from this interval (Figures 3.1.10 and 3.1.11). A precise age assignation cannot be given on the basis of palynomorphs, but the recovery is consistent with a Late Oxfordian dating. *G. jurassica* is recorded in high numbers at 90.16 m. This is in good stratigraphic agreement with the common observation of this species

in the upper part of the *A. regulare* Zone in the IKU core 7227/8-U-3 from 1986.

Microfauna (see interval 72-64 m)

90.0 - 85 m Early Kimmeridgian sensu gallico

Ammonites

The ammonite fauna occurring between 89.87 m and 89.66 m is composed of forms close to *Amoeboceras bauhini* and referred to here as *A. aff. bauhini* (89.87 m) and *A. cf. bauhini* (89.66 m), as well as a single representative of *Amoeboceras schulginae* (89.84 m). The species *A. bauhini* and *A. schulginae* are known to occur in close proximity to the Oxfordian/Kimmeridgian boundary in the Boreal province. *A. bauhini* is considered as indicative of the lowermost Kimmeridgian (Birkelund & Callomon 1985). Hence, it is highly probable that at least parts of the deposits under question may belong to the lowermost Kimmeridgian.

A younger fauna occurs from 88.90 to 88.70 m and is composed entirely of *Amoeboceras (Amoebites) bayi*, but possibly also poorly preserved microconchs from 88.31 m and 88.51 m belong to the same assemblage. These tentatively may be referred to as ?*A. bayi*. The species *A. bayi* indicates the 14 horizon of the East Greenland succession (*Pictonia aff. normandiana* - *Amoeboceras bayi* horizon) which corresponds to the upper part of the *A. baylei* Zone (Birkelund & Callomon 1985), and it is clearly of Early Kimmeridgian age.

A still younger Kimmeridgian fauna with *Amoeboceras (Amoebites) subkitchini* and *A. cf. subkitchini* occurs from 88.06 to 87.77 m. The species, as well as some allied forms are known from horizons 15-17 of East Greenland, generally corresponding to the *R. cymodoce* Zone of the Lower Kimmeridgian. It is not excluded, that poorly preserved questionable perisphinctids from 86.22 m

and 86.38 m may also correspond to the same zone; it should be remembered that the perisphinctids are known to occur commonly exclusively in the *R. cymodoce* Zone in the neighbouring Spitsbergen succession. (A. Wierzbowski unpublished material). Moreover, a single microconch specimen at 85.33 m determined as *Amoeboceras* sp. ex gr. *subkitchini rasanense* may also be related to the *R. cymodoce* Zone.

Palynology

The low diversity age insignificant dinoflagellate cyst assemblage from the interval below continues throughout this interval. *Hystrihogonyaulax* (*Rhynchodiniopsis*) *cladophora* has been found up to 85.19 m and point to a middle Late Kimmeridgian (lower part of *A. eudoxus* Zone) or older age if data from 7227/8-U-3 are used.

Microfauna (see interval 72-64 m)

85 - 72 m Late Kimmeridgian sensu gallico

Ammonites

A poorly preserved specimen of *Amoeboceras* cf. *kochi* has been found at 84.80 m that eventually indicates ammonite horizon 20 from the East Greenland succession, placed by Birkelund & Callomon (1985) at the boundary of the *A. mutabilis* and *A. eudoxus* Zones in the standard Kimmeridgian subdivision.

The next *Amoeboceras* fauna in the core occurs between 82.81 and 77.10 m and is composed of *Amoeboceras* (*Amoebites*) *elegans* Spath and *A.* cf. *elegans* Spath. The beds containing the discussed species correspond approximately to the *A. eudoxus* Zone of NW Europe (Birkelund & Callomon 1985). Representatives of the genus *Aulacostephanus* at 79.05 m and possibly also at 79.13 and 76.48 m indicate that the corresponding beds still belong to the Kimmeridgian.

One specimen of *Amoeboceras* (*Hoplocardioceras*) *deciens* has been found at 72.52 m. Callomon & Birkelund (1985) distinguished between the *A. deciens* horizon below the *A. elegans* horizon in the middle Late Kimmeridgian *Aulacostephanus eudoxus* zone of East Greenland, but in Spitsbergen and the Barents Sea *A. elegans* and *A. deciens* occur together.

Palynology

The youngest occurrence of *Hystrihogonyaulax cladophora* somewhere between 85.19 and 82.10 m seems to be at about the same stratigraphic level as the youngest record of this species in the lower part of the *A. eudoxus* Zone in core 7227/8-U-3. If this is a good marker in the area, it ought to disappear between 82.81 and 82.10 m. The first poorly preserved representatives of *Cribroperidinium* sp. at 78.58 m in the *A. eudoxus* Zone also seems to be of some local stratigraphic value. In 7227/8-U-3 we recorded these from around the *A. mutabilis/eudoxus* Zone boundary.

72 - 64 m Latest Kimmeridgian sensu gallico-Early Volgian

Ammonites

The upper part of the black shales in this borehole contains very few, generally indeterminable ammonites. The one from 65.32 m is a small, very poorly preserved perisphinctid showing twofold division of ribs which may suggest a Volgian age.

Palynology

The presence of *Paragonyaulacysta capillosa* at 72.12 and 70.66 m suggests that these samples belong to the Upper Kimmeridgian *A. eudoxus* Zone, *A. autissiodorensis* Zone or lower part of the lowermost Lower Volgian *P. elegans* Zone (Piasecki 1980). High numbers of *Escharisphaeridia rudis* (at 72.12 m) were found in the

uppermost part of the *A. eudoxus* Zone and around the *A. eudoxus/autissiodorensis* Zone boundary in hole 7227/8-U-3.

A big tabulated variant of *Cribroperidinium longicornis* with a short median terminal projection occurs at 72.12 m and in higher numbers at 70.66 m.

Acanthaulax sp. occurs at 66.25 and 64.95 m. Piasecki (1980) recorded *Acanthaulax* sp. as *Trichodinium* aff. *ciliatum* from the middle Lower Volgian *P. scitulus* and *P. wheatleyensis* Zones in East Greenland. Tasmanitids are found at 68.55 and 64.95 m. It is more common to find representatives of this algal group in the Lower Volgian than in the Kimmeridgian in the Boreal realm.

Microfauna

Litho-unit A contained more or less homogeneous foraminiferal faunas (Figures 3.1.12 and 3.1.13), but a minor difference seems to occur at approximately 84 m (between 82 and 86.5 m). Below this level calcareous elements were present as *Lenticulina* spp., and the *Haplophragmoides* present could most likely be referred to *H. cf. goodenoughensis*. Above this level the most well preserved specimens may be referred to *H. cf. infracallovienensis*, co-occurring with questionable forms referred to *H. excavatus*. Rare specimens of *Trochammina depressa* are also recorded. In general all these forms are facies dependant, and from the Norwegian sector they are normally confined to the "hot shale" sequence of Kimmeridgian or younger age. Souaya (1976) recorded *H. goodenoughensis* in the Sverdrup Basin (Arctic Canada) in black shales of Lower Cretaceous and Late Jurassic age.

Fish debris, typically of black shale facies, was recorded throughout. One additional interesting feature was recorded in the sequence, namely the occurrence of common diatoms in the lowermost sample (91.51 m). Similar forms are recorded in the Heather Fm. in the North Sea.

64.4 m - 62 m: Early Hauterivian

Palynology

Palynological samples from this interval are practically barren with respect to dinoflagellate cysts.

Microfauna

Litho-unit B seems to be divided into two parts with respect to paleontology and age. The lower sequence, represented by sample 63.79 m, displayed a very rich fauna, dominated by bivalves and echinoderms. The foraminiferal fauna was mainly composed of calcareous, benthonic species, e.g. *Patellina subcretacea*, *Spirillina neocomiana*, *Trocholina infragranulata*, *Lagena hauteriviana hauteriviana*, *Spirillina minima*, *Lenticulina muensteri*, *Vaginulina kochii*, *Planularia umbonata* and *Tristix acutangula*. Last occurrences were noted for *Trocholina infragranulata*, *Planularia umbonata*, *Tristix acutangula* and *Pseudonodosaria* sp. Together with the occurrence of *Tritaxia pyramidata* and abundant *Marssonella oxycona* an Early Hauterivian age at this level is suggested (Bartenstein & Bettenstaedt 1962).

Calcareous nannoplankton

In a sample at 63.79 m, a few specimens of *Ellipsagelosphaera britannica* are present, with extremely rare *Biscutum salebrosum* and *Retecapsa crenulata* (Figure 3.1.14). This assemblage has no great diagnostic value and may indicate unfavourable conditions for nannoplankton life or nannofossil preservation. The co-occurrence of these species would suggest a correlation to nannofossil zones CC 2 to 4, that span the Late Berriasian to Hauterivian age interval. At 63.68 m, dominant *Ellipsagelosphaera fossacincta* is met in an association that is rich in specimens, but poor in species. The dominance of this taxon has been observed at several localities in Northwest Europe and the North Sea over restricted intervals in Upper Jurassic and Lower Cretaceous deposits. There is reason to assume that the dominance of this

species is related to an abnormal environment. In the North Sea basin, a similar dominance event is recorded in the Valanginian. One sample at 61.51 m yielded almost exclusively *Ellipsagelosphaera britannica* and cannot be dated with any precision.

The suggested datings in the lower and upper part of Unit B may infer a significant break within this sequence. Only a detailed sampling throughout this unit will give a proper answer to this interesting topic.

62 - 36.3 m Latest Hauterivian - Early Barremian

Palynology

Fairly diverse dinoflagellate cyst assemblages appear in the claystone above the limestone. The record of *Muderongia tetracantha* upwards from 56.09 m indicates a middle Late Hauterivian to Early Barremian age from this depth (Duxbury 1977, Davey 1979), but we have no reason to assume that the beds between 60.44 and 56.09 m are significantly older. *Hystrichosphaerina schindewolfi* has been recorded from 59.29 m and upwards indicating a latest Hauterivian or younger age (Duxbury 1977). *Nelchinopsis kostromiensis* which often occur consistently in the Hauterivian and does not range above this stage (Riley & Fenton 1984), has not been observed and may favour a Barremian dating for the whole interval.

The presence of *Batioladinium longicornutum* in most samples up to 38.75 m indicates that Upper Barremian has not been reached. *Subtilisphaera terrula* at 44.22 m and above may restrict the dating for the upper part of the core to late Early Barremian (Renéville & Raynaud 1981).

Microfauna

Litho-unit C and the upper half of Unit B contain common foraminifera of a Late Hauterivian - Early Barremian age, thus supporting the conclusions based on palynomorphs (in the upper part) and nannofossils (in the lower part).

Forms restricted to sample 60.19 m include *Marginulina acuticostata*, *Nodosaria sceptrum*, *Petelinella* sp., *Lingulina* cf. *lamellata*, *L. loryi* and *Citharina* cf. *harpa*. Species with first occurrence at this level and extinctions higher in the core include *Uvigerinammina* cf. *moesiana* (more triangular in outline than *U. moesiana* s.s., and more inflated chambers), *Gavelinopsis* sp., *Dentalina communis*, *Glomospirella gaultina* and *Gavelinella barremiana*.

Other first occurrences of significance higher in the core include *Verneuilinoides neocomiensis*, *Haplophragmoides concavus* and *U. moesiana* (s.s.) (58.27 m), *Pelosina* sp. (56.09 m), *Valvulineria gracillima* and *Epistomina caracolla* (52.58 m), *Saracenaria* cf. *bononiensis*, *Marginulina jonesi*, *Conorboides* sp. and *Astacolus schloenbachi* (50.16 m), *Conorotalites* cf. *bartensteini*, *M. cephalotes* and *S. cf. frankei* (48.30 m), and finally *Glandulina* cf. *mutabilis*, *S. cf. bronnii* and *Tristix globulifera* (40.11 m).

Some stratigraphical important forms occur at the top or close to the top, e.g. *G. barremiana*, *E. caracolla*, *S. minima*, *S. neocomiana* and *A. schloenbachi* (38.23 m), and *U. moesiana* (40.11 m). The presence of *E. caracolla*, *S. neocomiana* and *U. moesiana* near the top of the core support the conclusions based on palynomorphs and nannofossils, i.e. an age not younger than Early Barremian at this level.

Calcareous nannoplankton

In two samples (60.44 and 60.19 m) *Ellipsagelosphaera britannica* is very abundant. Of biostratigraphic importance is the relatively common occurrence of *Dodekapodorhabdus noellii* that according to Taylor (1982) is restricted to the latest Hauterivian *marginatus* and *variabilis* ammonite zones. Jakubovski (1986) observes that the sediments Taylor assumed to be part of the *variabilis* zone, actually are attributed to the earliest Barremian. We failed, however, to find the zonal markers used by Jakubovski to characterize his zones NLK 14 and NLK 15, above and below the Hauterivian - Barremian boundary. On the other hand, the common occurrence of *Micrantholithus* and *Braarudosphaera* as observed in this interval is also a characteristic of zones NLK 14 and 15. It is considered therefore that all evidence is in favour of a latest Hauterivian to earliest Barremian age for the base of this interval.

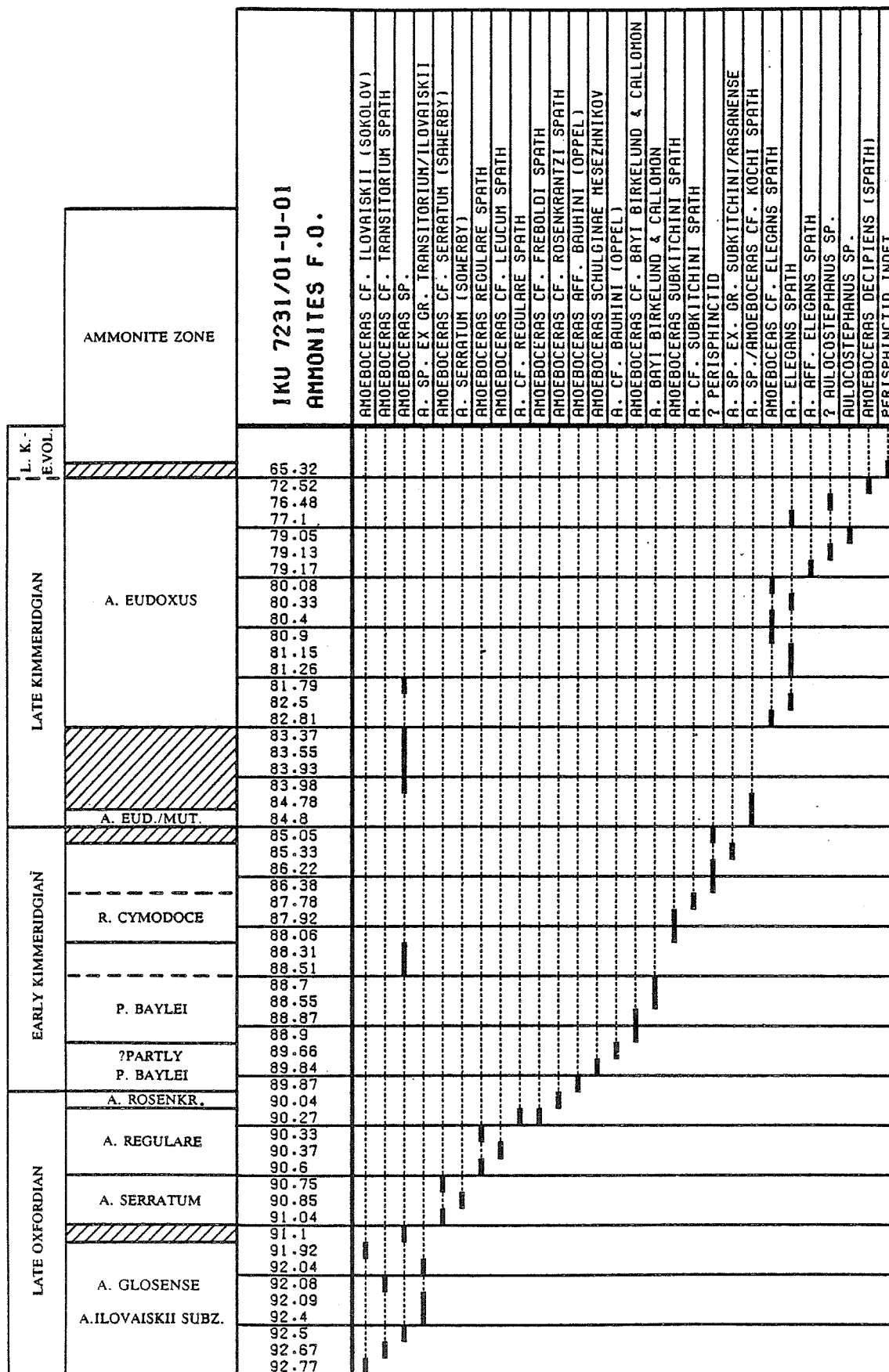


Figure 3.1.9 Ammonite range chart of core 7231/01-U-01.

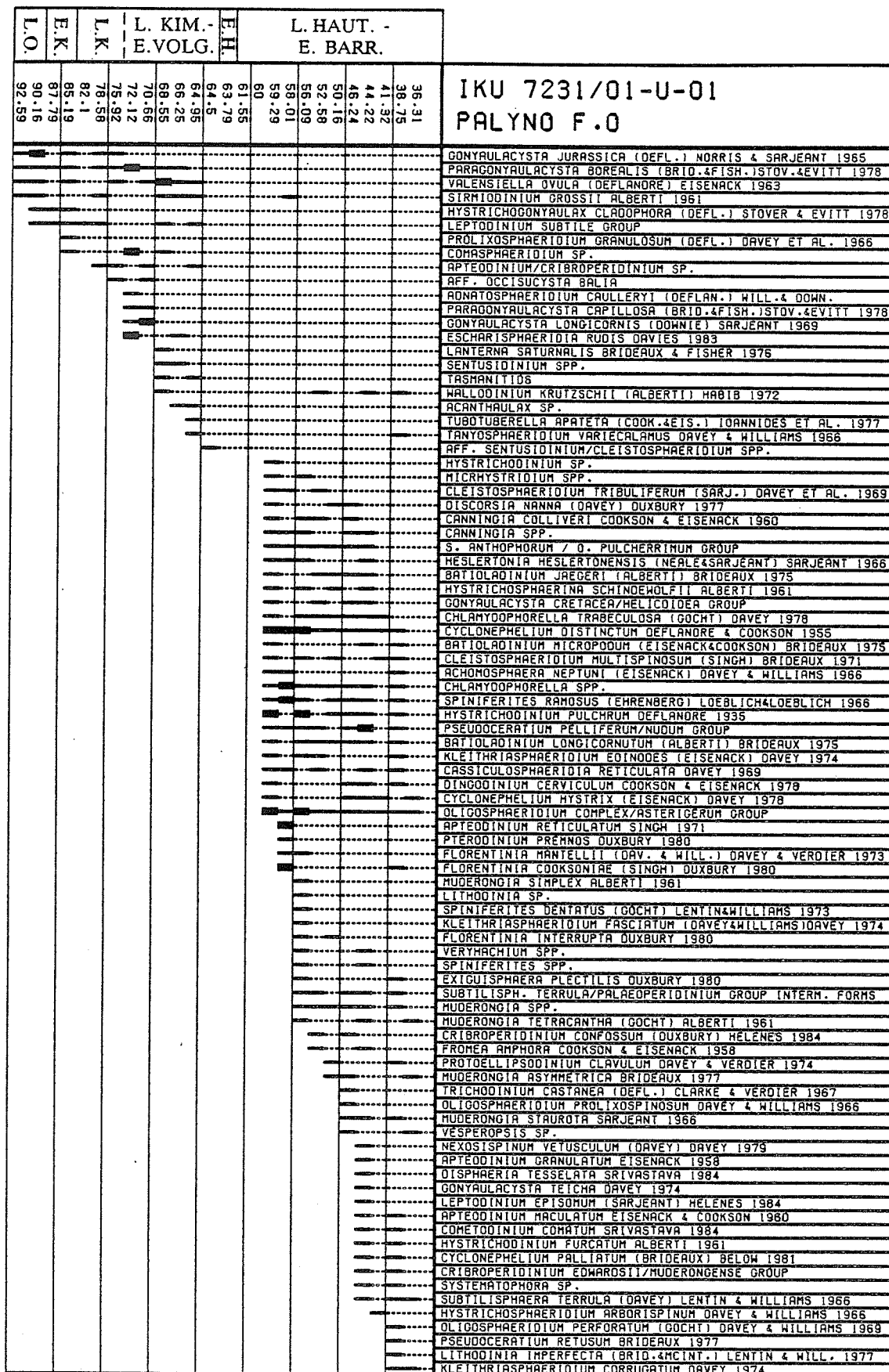


Figure 3.1.10 Palynological range chart of core 7231/01-U-01.
(Sorted according to first occurrence).

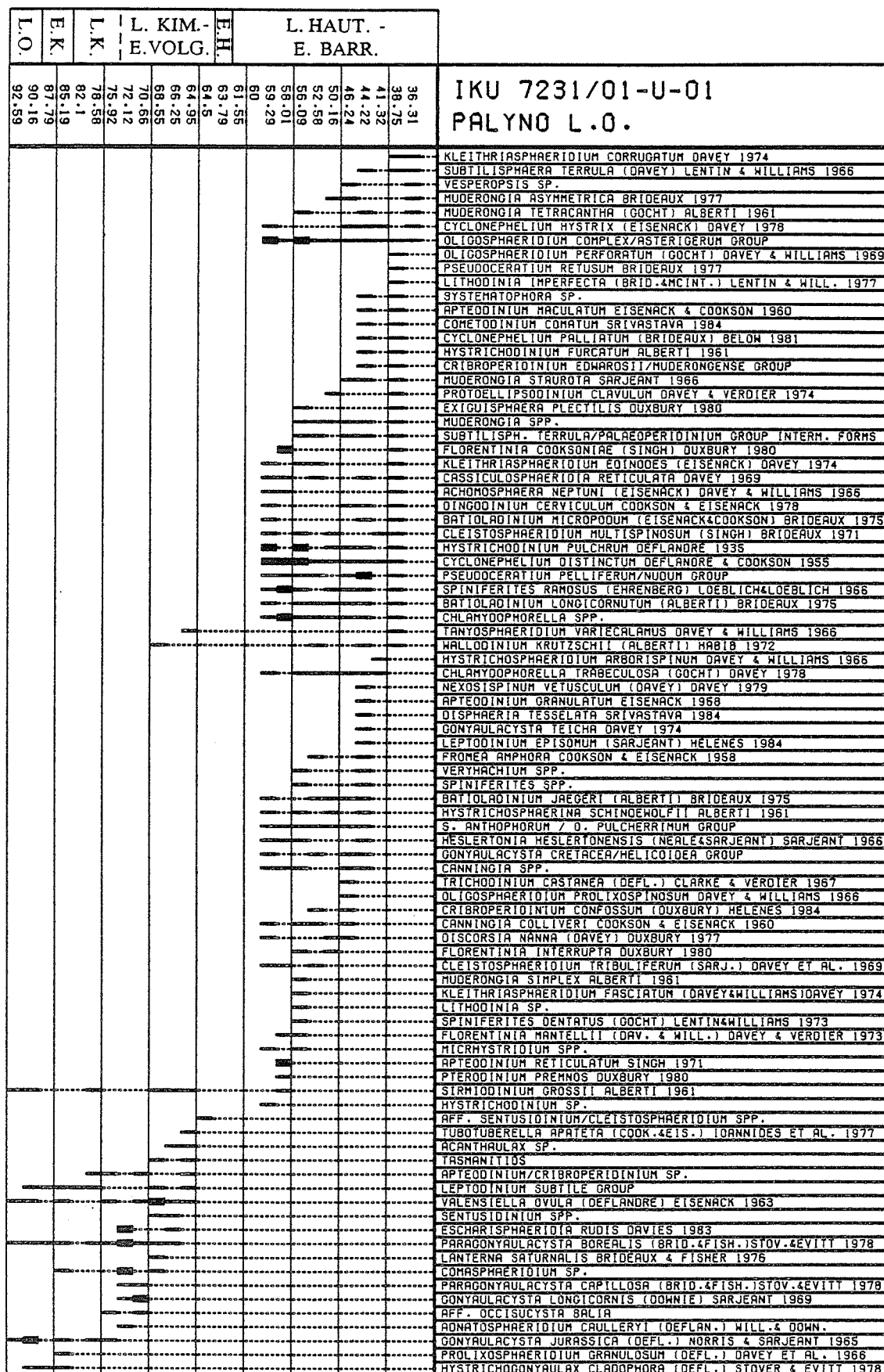


Figure 3.1.11 Palynological range chart of core 7231/01-U-01.
(Sorted according to last occurrence).

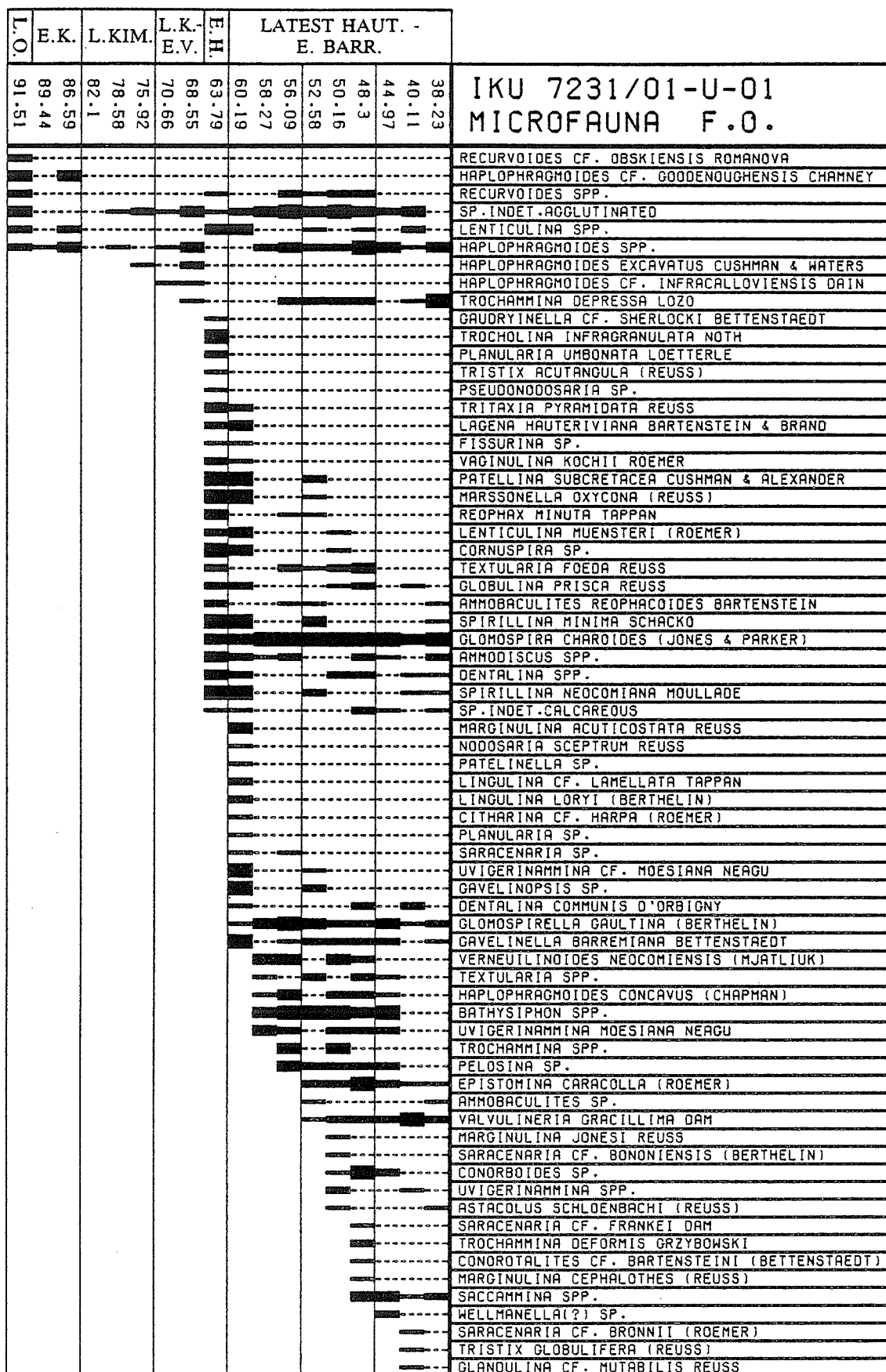


Figure 3.1.12 Foraminiferal range chart of core 7231/01-U-01.
(Sorted according to first occurrence).

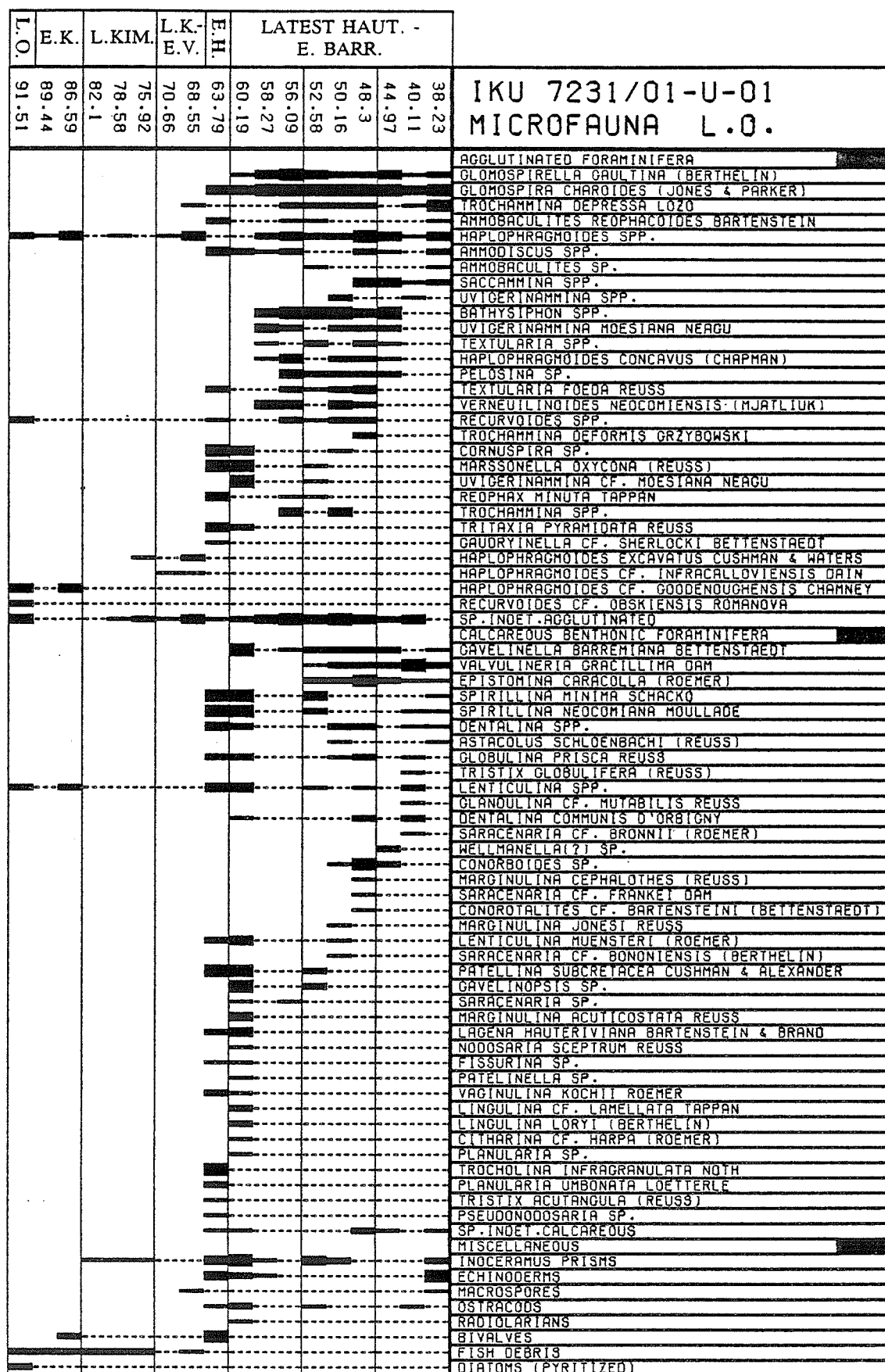


Figure 3.1.13 Foraminiferal range chart of core 7231/01-U-01.
(Sorted according to last occurrence).

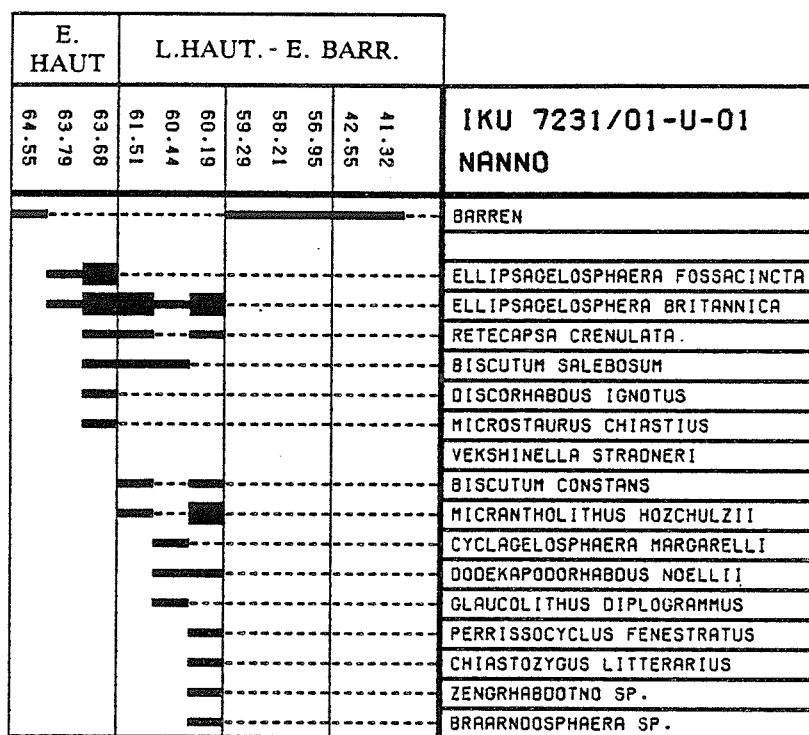


Figure 3.1.14 Calcareous nannoplankton range chart of core 7231/01-U-01.
(Sorted according to first occurrence).

3.1.5 Organic geochemistry

The organic geochemical data figures and tables are presented in a separate volume of the report. Only summary figures will be presented in this section.

A representative sample of the Unit A shales at 73.21 m was artificially matured using hydrous pyrolysis. This sample is discussed in the organic geochemical data volume. Sampling from this core was biased towards the lower, more organic-rich part of the core. This is reflected in the wide sampling interval used for the screening analyses above 64.40 m, and in the narrower sampling interval used below 64.4 m.

A total of 21 samples taken at approximately 3 m intervals, was analysed for C_1 - C_7 hydrocarbon composition of the headspace and occluded gas (Figure 3.1.15). The core can be divided into two distinct sections on the basis of these data.

The core interval below 67.21 m (Unit A) is characterised by generally high concentrations of methane (65,000 - 260,000 μ l gas/kg dry rock), together with appreciable concentrations of C_{2+} hydrocarbons (3,000 - 41,000 μ l gas/kg dry rock). The highest concentrations of methane occur in the headspace gas fraction, while the highest concentrations of C_{2+} components occur in the occluded gas fraction. Three intervals of relatively low gas hydrocarbon concentration can be identified at 88.93 m, 77.83 m and 67.21 m. These intervals of reduced gas concentration do not correlate with any obvious feature of the rocks. Low gas wetness values of between 1 % and 15 %, together with high iC_4/nC_4 values of 1 to 6, suggest that an immature assemblage of C_1 - C_7 hydrocarbons is present in the cores.

The core interval above 64.4 m is (Units B and C) characterised by a marked drop in the concentration of all gas components, and only trace amounts of the C_{2+} components (Total C_2 - C_5 = <300 μ l gas/kg dry rock). The highest methane contents are observed in the interval 50.08 m to 56.97 m. The low concentrations of gas components prevent any meaningful interpretation of the gas wetness and iC_4/nC_4 data.

Sixty-nine samples from this core were analysed for total organic carbon (TOC) content and Rock-Eval pyrolysis character (Figure 3.1.16).

The shales of the core interval below 64.4 m (Unit A) have high TOC contents of between 3.9 wt% and 21.2 wt%, with a mean value of 11.4 wt%. A thin carbonate horizon at ca. 78 m is characterised by a much lower TOC content of 1.6 wt%. The lowest TOC contents of 3.9 wt% to 6.3 wt% are observed in the interval 66.19 m - 68.70 m.

Above 64.4 m, a ca. 4 m claystone/carbonate horizon (Unit B) is characterised by TOC values of around 0.4 wt%. Above this horizon (Unit C), the dominantly-claystone interval typically has TOC values of between 1.1 wt% and 2.4 wt%.

The Rock-Eval data show similar variations to the TOC data. The hydrogen indices of the kerogen in the shales from Unit A are relatively constant, with values varying from 250 to 430 mg/g. These values are typically associated with mixed type II/III kerogen. Lower hydrogen index values of 149 mg/g TOC and 181 mg/g TOC, more typically associated with type III kerogen, occur in the shale sample from 70.4 m and from the carbonate sample at 78.41 m, respectively. Petroleum potential values typically in excess of 20-30 mg/g Rock suggest that these rocks may represent a significant source of hydrocarbons.

The microscopic composition of the kerogen from this interval is also relatively constant, with amorphous material accounting for 80-85 % of the isolated kerogen. Woody particles are the next most common component, accounting for 5-10 % of the kerogen. There is relatively little difference between the kerogen from Unit A, and the kerogen from Unit C.

The rocks from Units B and C are typified by low hydrogen indices of between 0 mg/g TOC (64.39 m) to 76 mg/g TOC (41.17 m), the highest values being found in the most organic-rich samples. Low petroleum potential values suggest that the kerogen in these rocks is largely inert.

In general, the pyrolysis-GC data reflect the Rock-Eval data. The pyrolysis-gas chromatograms of samples from Unit A are all broadly similar, with a range of alkene-alkane doublets extending beyond C₂₀. The xylene peaks are relatively prominent in all of the samples, as is toluene peak. Peaks identified as phenol and prist-1-ene are also present in some of the samples. The appearance of the pyrolysis-gas chromatograms suggests that the kerogen is influenced by more aromatic, possibly terrestrial material.

The two samples obtained from Unit C show a more abbreviated homology of alkenes-alkanes, with prominent benzene and toluene peaks. The pyrolysis-gas chromatogram of the lower sample at 51.95 m is very similar in appearance to the samples described from core 7231/04-U-01. The upper sample at 41.17 m appears to be intermediate between the Unit A shales and the 51.95 m sample in appearance. The pyrolysis-gas chromatograms are consistent with the low Hydrogen Indices observed from these samples.

Vitrinite reflectance, Rock-Eval T_{max} and thermal alteration index (TAI) were used to obtain maturation data from this core. The most reliable vitrinite reflectance data were obtained from samples in the upper part of the core at 41.17 m and 45.99 m, giving values of 0.36 % and 0.35 %, respectively. The vitrinite reflectance data from the lower part of the core tend to be lower, due in part to the general bituminite staining present in these samples. The TAI data indicate values of 3.0-3.5, which are largely consistent with the vitrinite reflectance data and which indicate thermal immaturity. The T_{max} data showed some variation due to changes in kerogen type. Higher values of 426°C to 436°C were observed from Unit C, while lower T_{max} values of between 400°C and 424°C were recorded from the more organic-rich Unit A. The variation in the values in the samples from Unit A does not appear to be related to variations in kerogen type.

A total of fourteen samples was extracted in order to examine the nature of the extractable hydrocarbons (EOM) present in the rocks (Figure 3.1.17). The lowest EOM concentration (427 ppm) was observed in the claystone sample at 56.16 m in Unit C. The highest EOM concentration was recorded from the base of the core at 92.56 m (15,844 ppm). With the exception of lower extractabilities at 56.16 m, 64.39 m (1,358 ppm), 67.21 m (1,944 ppm) and the carbonate horizon at 78.41 m (1,070 ppm), the majority of the samples had high extractabilities of between 4,000 ppm and 16,000 ppm, with an average of 8,816 ppm.

NSO and asphaltene compounds typically account for around 90% of the EOM in the samples. Saturated and aromatic hydrocarbon compounds are present in only small amounts. This type of EOM composition is often associated with thermally immature organic-rich rocks.

Gas chromatograms were obtained for the saturate fractions of the extracted

samples, the majority being obtained from the organic-rich Unit A. The gas chromatograms of the samples from 67.21 m, 70.40 m, 80.08 m, and 88.93 m show similar prominent pristane and phytane peaks and a slightly bimodal distribution of n-alkanes, with a prominent mode about the nC_{29} peak. The samples from 64.41 m, 64.53 m, 73.02 m, and 92.56 m also show a slightly bimodal distribution of n-alkanes and prominent pristane and phytane peaks, although in these samples the most prominent mode lies around the nC_{15} peak, with a less well-developed mode about the nC_{27} peak. The sample at 83.56 m differs from the above two groups in its relatively higher content of nC_{20} - nC_{24} compounds.

Both groups of samples have gas chromatograms with an immature distribution of n-alkane and isoprenoid peaks. The differences in the gas chromatograms may therefore reflect slightly different source inputs. The pristane/phytane ratios have values of between 0.8 and 1.0. Similar values have been associated with rocks deposited under fairly constant reducing or dysoxic conditions (Figure 3.1.18).

The gas chromatograms for the remaining samples, at 56.16 m, 64.39 m, and 78.41 m, vary from the previously described samples in both appearance and in the setting of the samples. The EOM from the first two samples was extracted from relatively organic-poor rocks, and the gas chromatograms of these extracts tend to show a largely unimodal n-alkane distribution.

The gas chromatogram of the 56.16 m sample is biased towards the lower molecular weight n-alkanes, although the marked odd-carbon number predominance in the nC_{23+} compounds suggests a low thermal maturity. The gas chromatogram of the 64.39 m sample bears more resemblance to the underlying samples from Unit A, with a bias towards the higher molecular weight nC_{25+} compounds. This extract is thought to represent migrated bitumen from the immediately underlying shales.

The gas chromatogram of the 78.41 m extract shows some similarities with the those of the immediately overlying and underlying samples. This sample is from a carbonate horizon which gave off a noticeable bituminous smell when struck with a hammer. It is possible therefore, that this extract represents material which has seeped in from the surrounding rocks, although an indigenous origin for this extract cannot be excluded.

Biomarker data were obtained for the saturate fractions discussed above.

With the exception of the sample at 64.39 m, all of the samples have biomarker distributions which are indicative of thermal immaturity.

The m/z 217 mass fragmentogram of the sample at 56.16m is dominated by a peak representing the C₂₉ 5 α 20R sterane, and is generally similar to the m/z 217 mass fragmentograms of the shales of Lower Cretaceous age from core 7231/04-U-01. The remaining m/z 217 mass fragmentograms, excluding that from 64.39 m, can be divided into two groups. One group, consisting of samples from between 64.41 m and 70.40 m, is characterised by prominent C₂₇, C₂₈ and C₂₉ 5 α 20R sterane peaks, together with an unidentified peak which is the last significant peak to elute out. The remaining samples also have prominent 5 α 20R sterane peaks, although only the C₂₇ and C₂₉ peaks are particularly prominent, and prominent re-arranged sterane peaks. The boundary between the two groups does not appear to correlate with any obvious features of the core.

Similar groupings can be recognized from the m/z 191 terpene mass fragmentograms, although in this case, the 56.16 m sample is not so similar to the Lower Cretaceous samples of core 7231/04-U-01. The upper group of Unit A, from 64.41 m to 70.40 m, is distinguished by the occurrence of prominent moretane peaks and an unidentified peak which elutes with the C₃₃ extended hopanes. The samples from the lower group generally lack the unidentified peak, with the exception of the sample at 73.02 m which appears to be intermediate between the two groups, and have relatively reduced moretane peaks.

Tricyclic terpenes are only well-developed in the sample at 64.39 m from Unit B. This sample differs from all the previously discussed samples. It is relatively mature in appearance with relatively well-developed re-arranged sterane peaks, and a 22S/22R extended hopane ratio which is at near-thermal maturity (i.e. 53%). However, the 5 α 20R sterane composition of this sample is typical of those observed in the underlying shales of Unit A. It is likely that the differences exhibited by this sample, relative to the underlying shales, reflect fractionation during small scale migration, as the bitumen is unlikely to have been sourced by the organic-lean rocks of Unit B. It is interesting to note that Seifert et al. (1978) attributed increased tricyclic terpene content to migration.

In conclusion, core 7231/01-U-01 can be divided into three zones on the basis of organic geochemical data which coincide with Units A, B and C. The

shales of Unit A contain abundant (ca. 10-20 wt%), thermally immature, largely amorphous, type II/III kerogen. This unit also contains appreciable amounts of immature bitumen which shows some variation in composition. Artificial maturation experiments on material from Unit A suggest that these rocks may be largely gas-prone.

Unit B is organic-lean, and the kerogen is largely inert. Non-indigenous hydrocarbons, probably representing seepage from Unit A, are present. The claystones of Unit C contain moderate amounts of largely inert kerogen (Type IV). Extractable hydrocarbons from this core show similarities with the hydrocarbons described from core 7231/04-U-01.

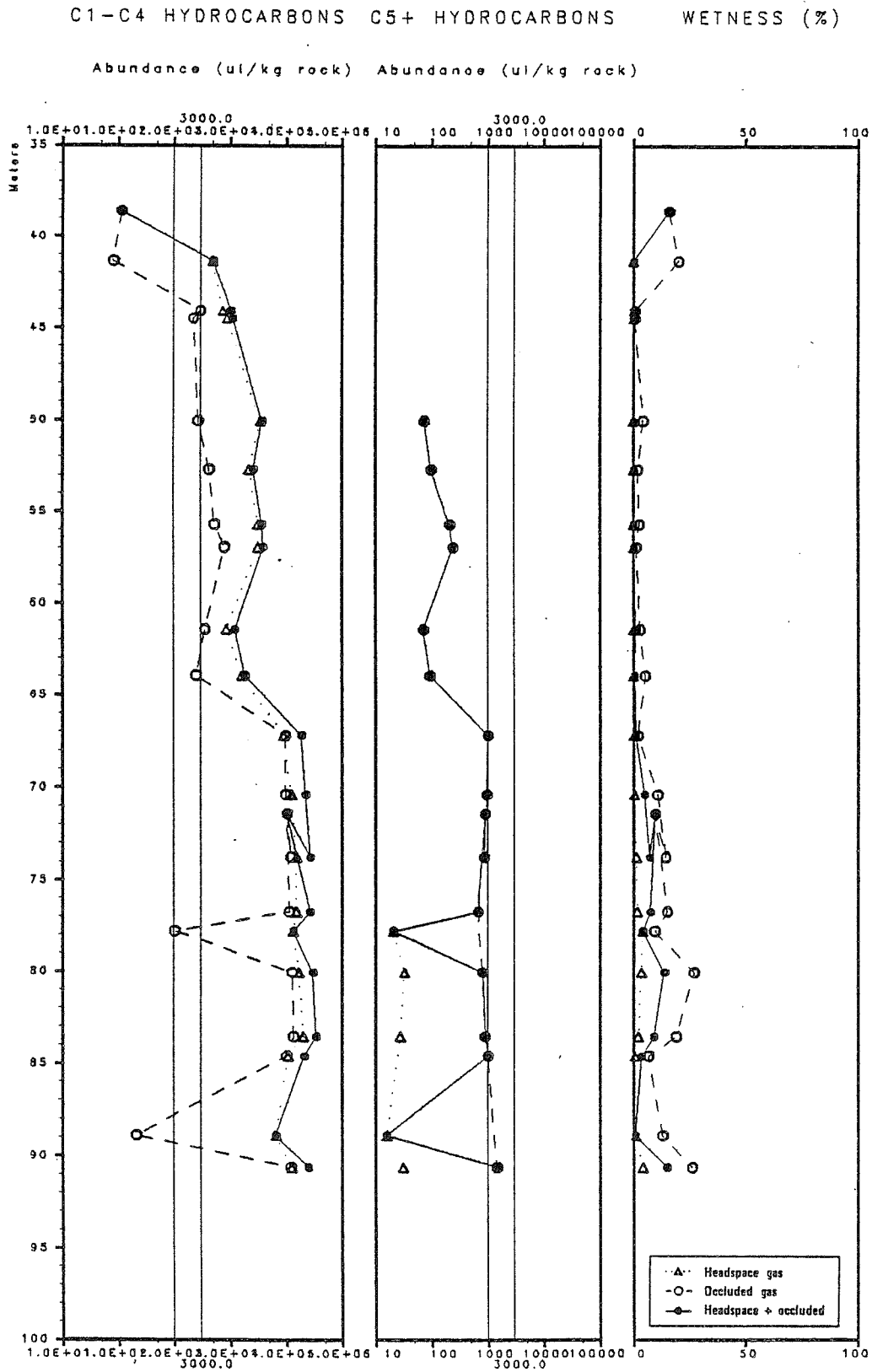


Figure 3.1.15 Yield and composition of headspace/occluded gas of core 7231/01-U-01.

ROCK-EVAL PYROLYSIS DATA

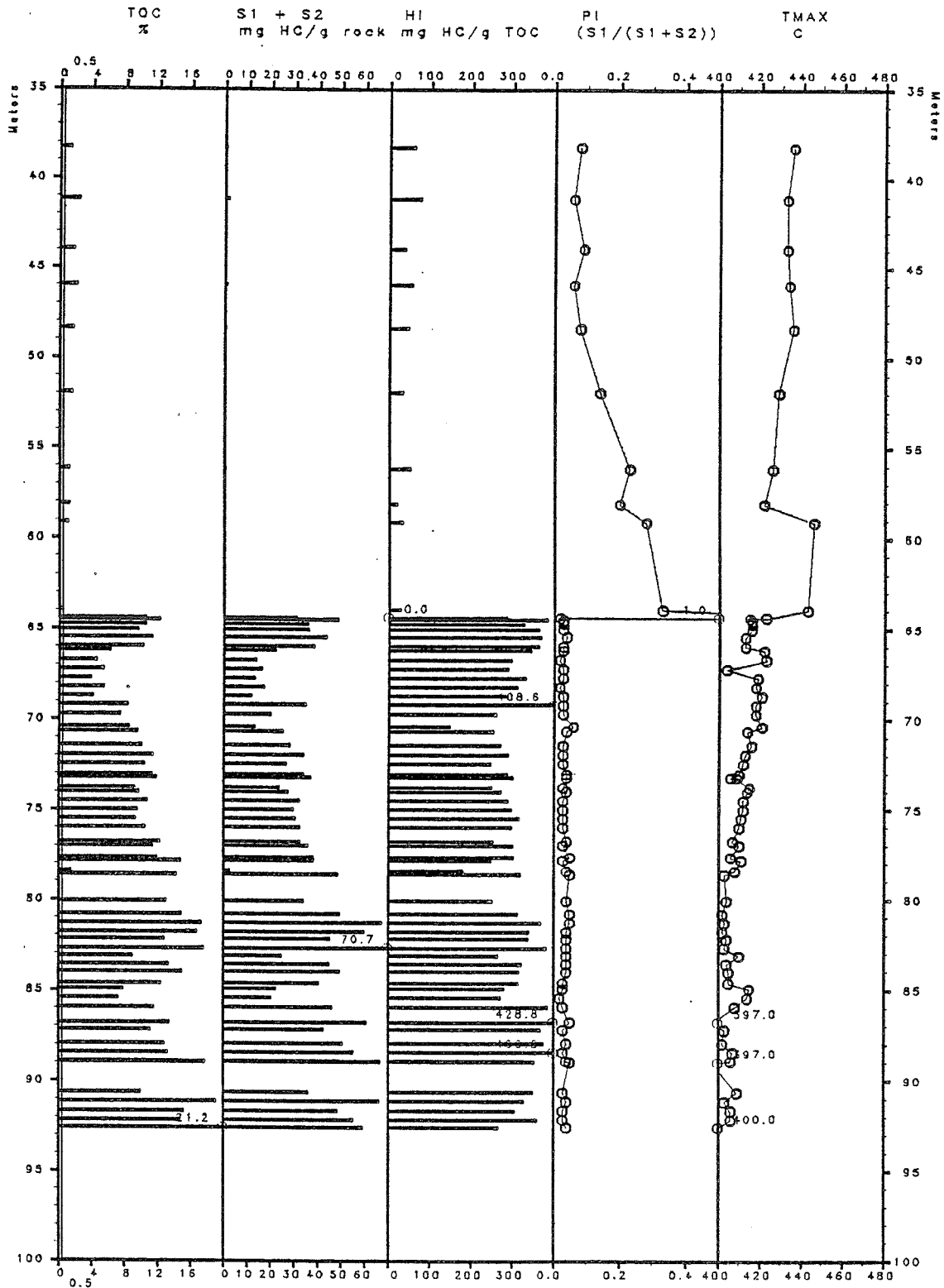


Figure 3.1.16 Total organic carbon content and Rock-Eval data of core 7231/01-U-01.

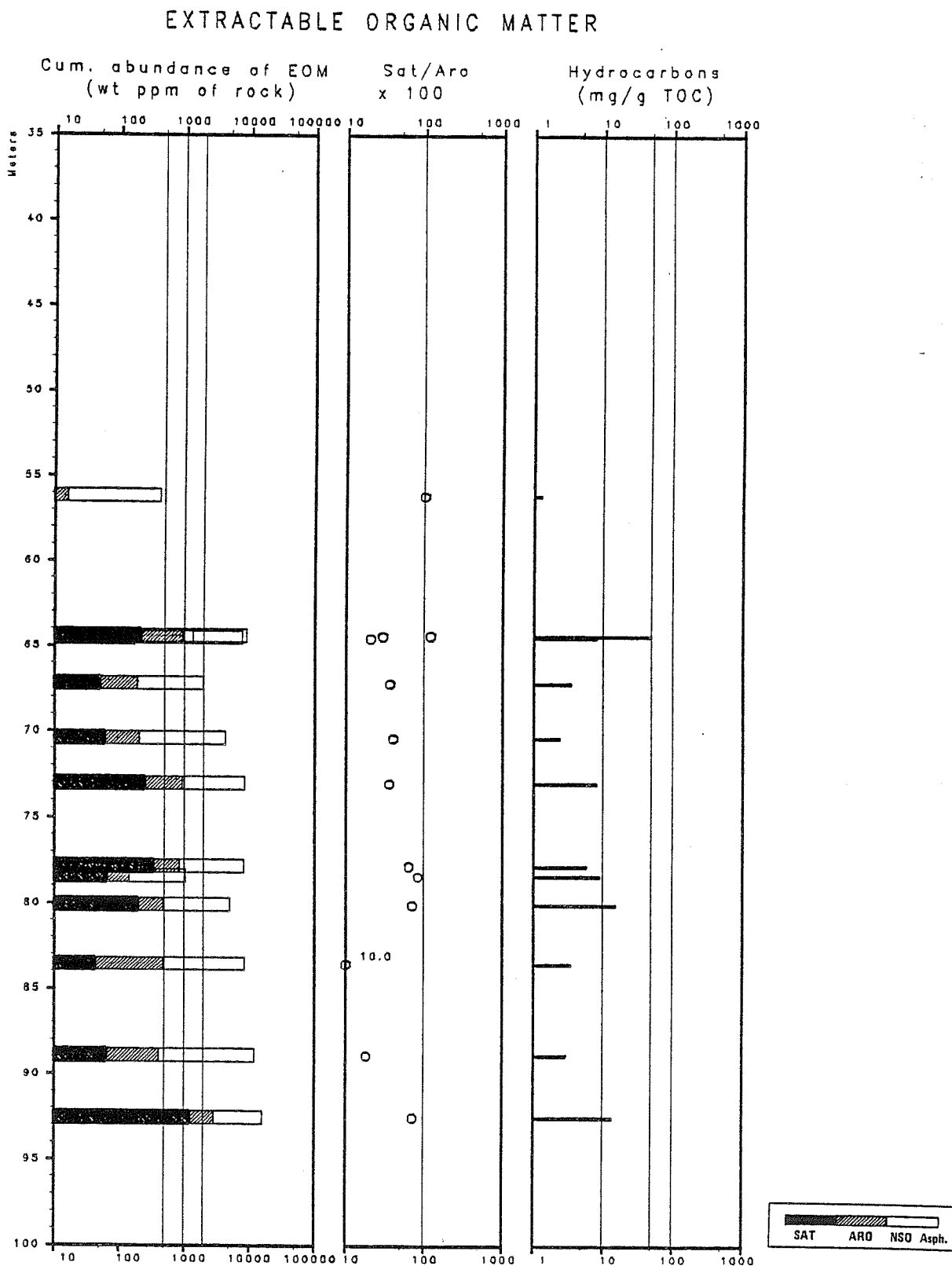


Figure 3.1.17 Extract data for core 7231/01-U-01.

GAS CHROMATOGRAPHIC RATIOS

CPI 2

Pristane/Phytane

Pristane/n-C17

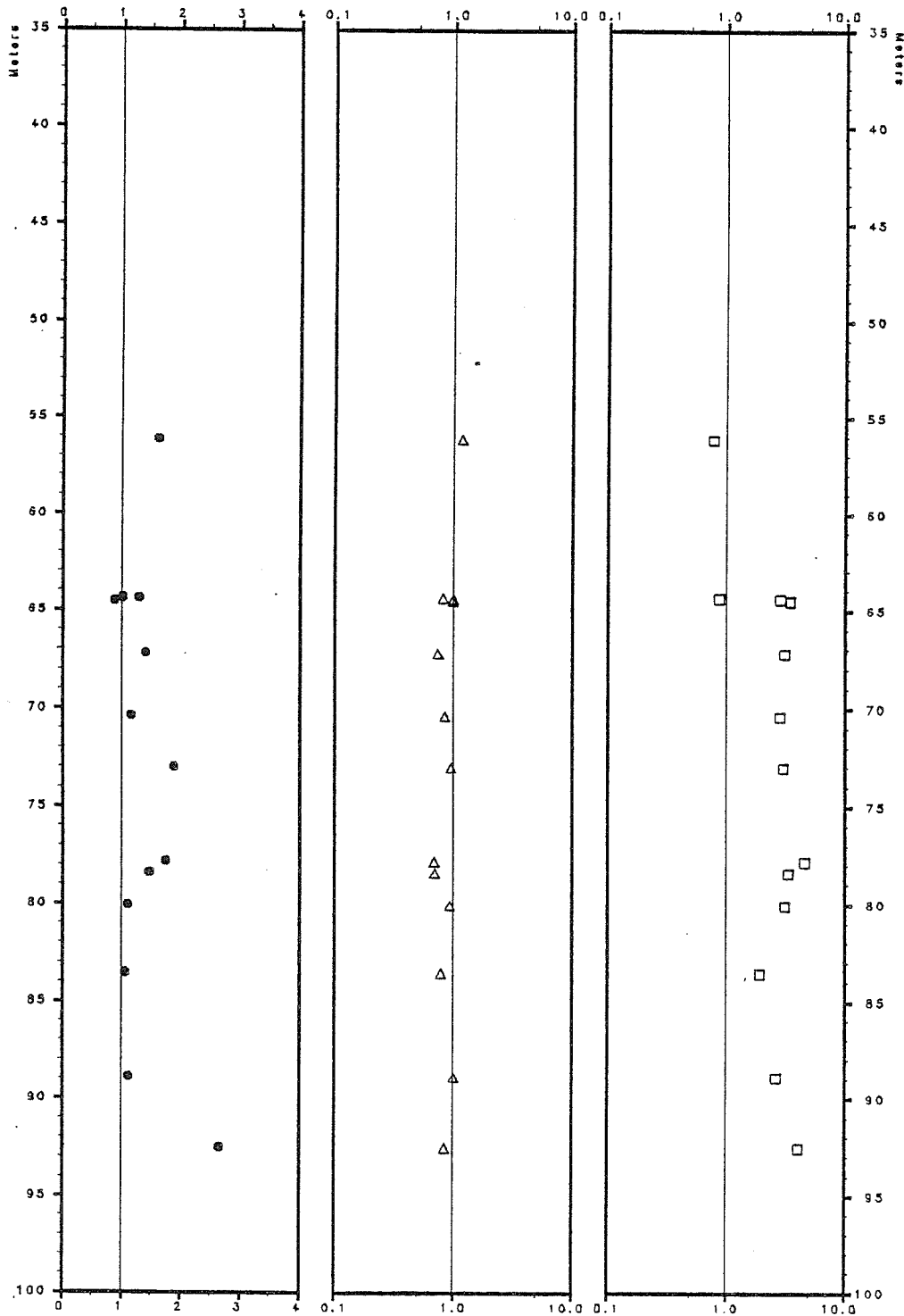


Figure 3.1.18 Compound ratios from gas chromatograms of saturated hydrocarbon fractions from core 7231/01-U-01.

3.1.6 Depositional environment

Unit A was deposited in an oxygen depleted environment below wave base, as suggested by the high content of amorphous organic material and the very sparse benthic fauna. The numerous ammonites and bivalves in the lower part of the core may be explained by very slow sedimentation rates. Above the 78.3 m level an increase in the sedimentation rates is thus inferred.

Unit B is also probably a relatively deep, but well oxygenated shelf deposit. Lack of, or sparse, micritization indicates deposition below the photic zone. Sedimentation was probably slow as boring sponges had time to attack most shell fragments. The deposition probably took place on a moderately deep shelf under good oxic conditions. The rich and diverse benthic fauna also suggests normal marine conditions.

Unit C contains bioturbated grey sediments with diverse dinoflagellate cyst assemblages typical of a shelf environment. Lack of current structures may indicate deposition below wave base. The high content of agglutinated foraminifera is explained by turbid water masses, resulting from a marked increase in the input of terrestrial fine grained debris compared to the unit below.

3.2 Core 7231/04-U-01

3.2.1 Summary

In core 7231/04-U-01 59.7 m of bedrock was drilled in the interval between 37.7 and 97.4 m below the sea floor, with 97.3 % core recovery. The core has been divided into litho-units A and B at the 62.7 m level (Figure 3.2.1), which is probably also represented by a strong seismic reflector. Another strong reflector is correlated to the 80.0 m level.

The lower Unit A (34.7 m thick) consists of a dark grey silty or partly sandy claystone. Beds of sandstone, which are partly carbonate cemented occur. The unit shows erosional features at its top surface.

Unit B (25.0 m thick) consists of dark to very dark claystone with some silt and glauconite. The middle part is more silty than the remaining part of the core.

Both units were deposited under shelf conditions, and intervals of intense bioturbation and abundant glauconite indicate low sedimentation rates. In the lowermost tens of metres reworking of early Jurassic fossils suggests that such sediments were eroded not too far away from the present site.

Palynomorphs and foraminifera indicate a more or less continuous succession of Aptian to Middle Albian age.

The organic geochemical analyses show that the core has an upwards-decreasing content of thermally immature (ca. 0.4 % Ro), hydrogen-poor type IV kerogen. Analysis of sample extracts from the base of the core indicates the presence of low concentrations of thermally immature, probably terrestrially sourced bitumen. This bitumen is unlikely to have migrated any significant distance, and may be of local origin.

3.2.2 Seismic interpretation

The core penetrated the upper boundary of a Lower Cretaceous unit which increases in thickness from the western part to the eastern part of the

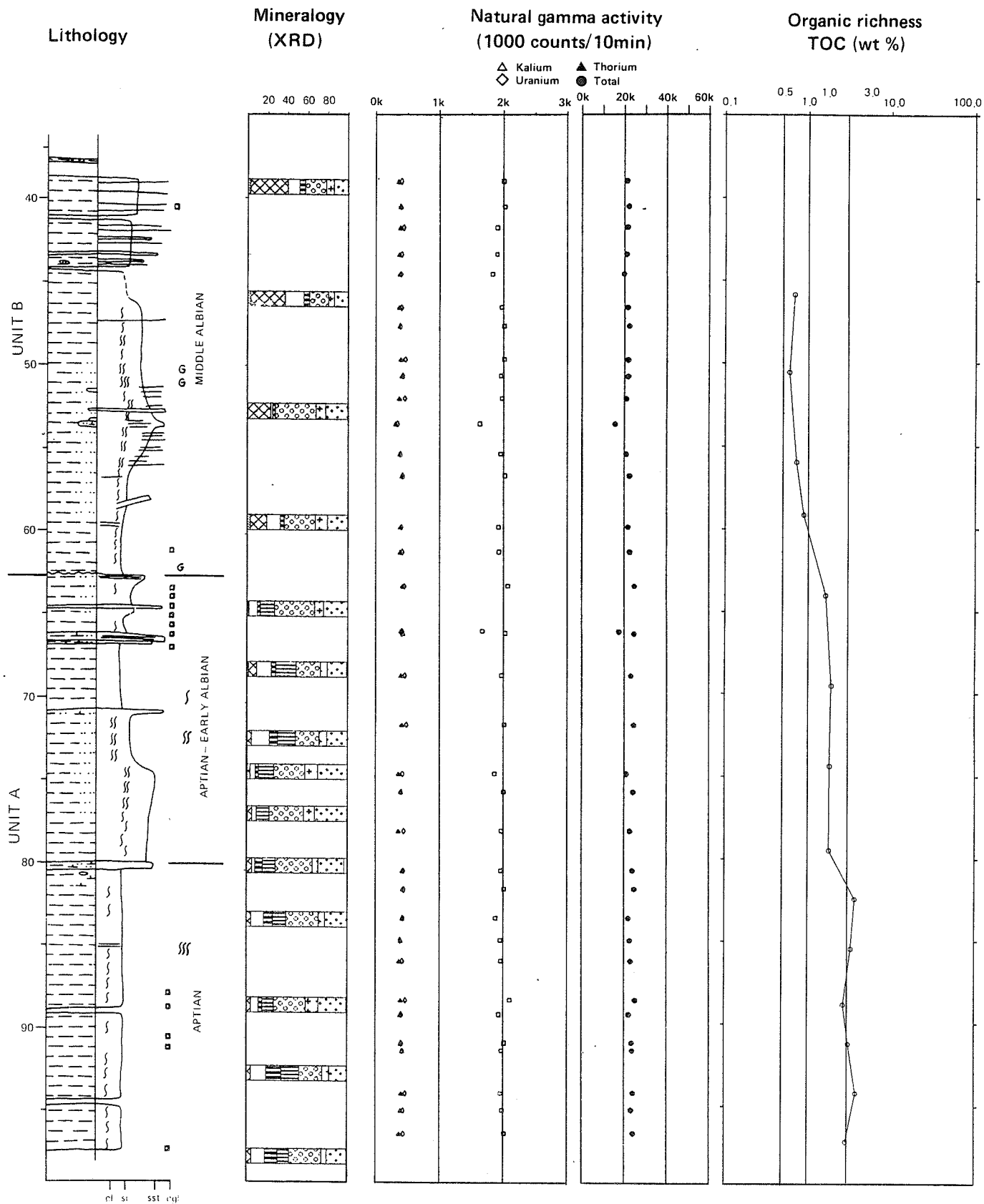


Figure 3.2.1 Summary figure of core 7231/04-U-01. Legend in Appendix A.3.

Nordkapp Basin. The unit has its maximum thickness in the area of the drill site. Core 7231/01-U-01 was drilled at the base of the unit.

Correlation between the core and the seismic data has not been straightforward at this site. A tentative correlation is shown in Figure 3.2.2 and Table 3.2.1. The core is sub-divided into two units with the boundary at 62.7 m. This boundary is correlated with a relatively strong seismic reflector. Another strong reflector is found below (80.0 m) and a weaker one above (appr. 50.5 m). The seismic unit between 62.7 m and 80 m seems to increase to twice the thickness going from the outcrop southwards into the basin, while the other units seem to be fairly constant in thickness.

Table 3.2.1 Key data of the tentative correlation between core 7231/04-U-01 and seismic line IKU-310730-87.

Depth below seabed		Core unit	Thickness of seismic unit		Interval sound velocity
37.7 m	41.9 msec	Overburden	37.7 m	41.9 msec	1800 m/s
ca 50.5 m	53.9 msec	B	ca 12.8 m	12 msec	ca 2130 m/s
62.7 m	64.9 msec	B	12.2 m	11 msec	ca 2280 m/s
80.0 m	78.4 msec	A	17.3 m	13.5 msec	2560 m/s
TD 97.4 m	92.9 msec	A	17.4 m	14.5 msec	2400 m/s (estimated)
Total TD below sea surface: 377.4 m / 475 msec					

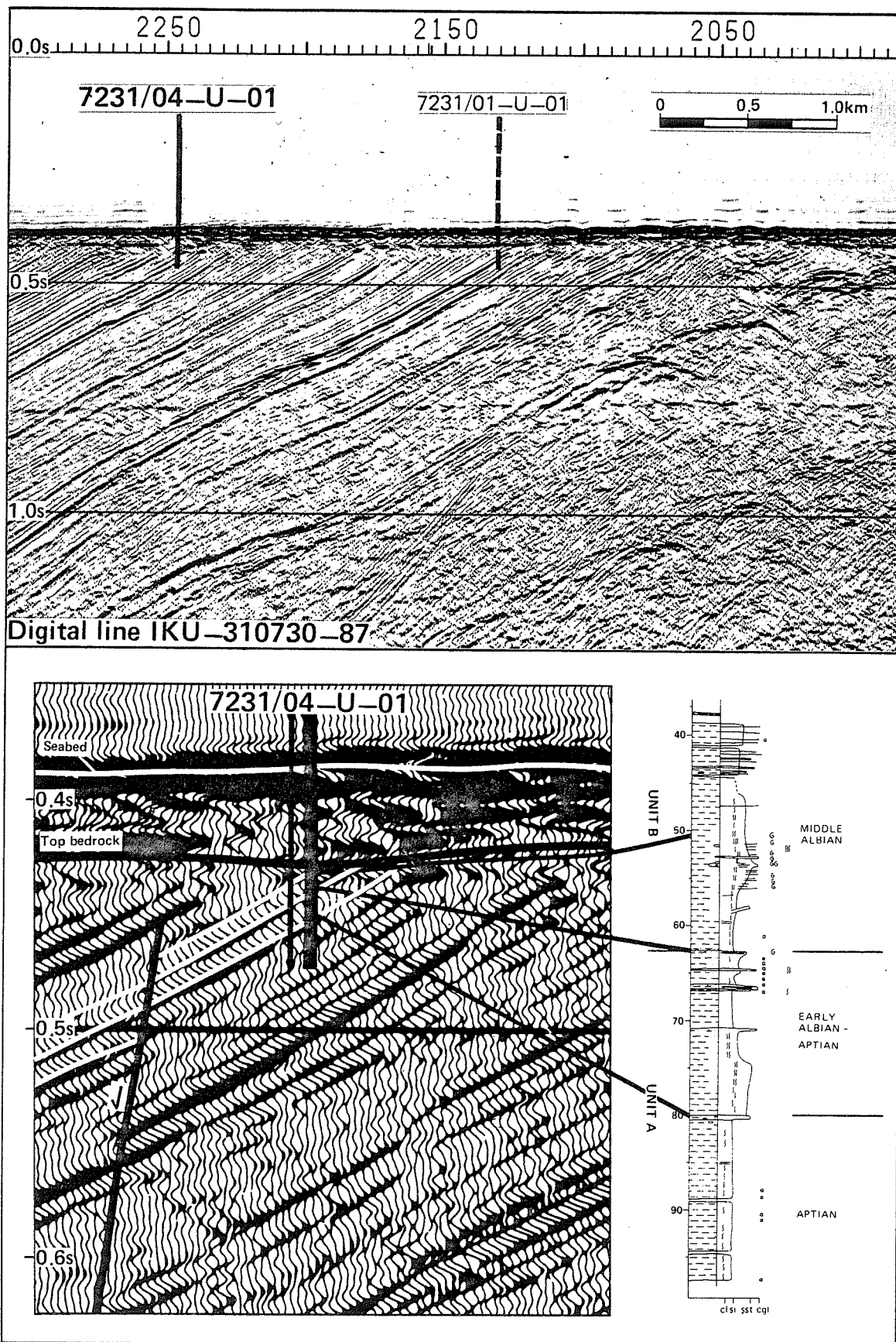


Figure 3.2.2 Tentative correlation between core 7231/04-U-01 and seismic data. Because of the high dip angle all inclined reflections are uplifted about 5-6 msec. The "real" position of the core relative to the dipping beds is indicated by the thin vertical line on the lower seismic section.

3.2.3 Sedimentology

Core description

The core is dominated by silty and sandy claystone. Some thin silt as well as sandstone beds also occur. The core may be subdivided in two lithological units with different clay mineralogy.

Unit A extends from the base of the core to 62.7 m (Figure 3.2.3). The unit consists of dark grey silty or partly sandy claystone. Most of the unit is weakly bioturbated, mainly by *Chondrites*. The more silty/sandy interval between 80 m and 71 m shows more intense bioturbation, obliterating all sedimentary structures. Beds of sandstone are mostly only a few centimetres thick. One carbonate cemented sandstone bed is 60 cm thick (at 66 m) and has faint lamination. The unit terminates with a thin (10 cm) very fine grained sandstone bed with an eroded top surface. In the upper part of the unit pyrite is abundant.

Unit B comprises the interval from 62.7 m to the top of the core. The unit consists of dark to very dark grey claystone with some silt and glauconite. A dark grey to black shale, at the base of the unit is only weakly bioturbated, however the bioturbation increases upwards, and in the silty middle part of the unit bioturbation is abundant. This part has also abundant glauconite. The upper part of the unit is less silty. However, intense tectonization (?Quaternary) of the upper 5 m makes further observation difficult.

Thin section description

The three thin sections made from siltstone beds in this core are also investigated in the electron microscope.

The lower sample, from 70.88 m, is dominated by quartz and albite in the grain size of silt to very fine sand. Some mica and clay are also present. The sand grains are mostly angular.

A sample from 64.71 m consists of silt grains in a carbonate matrix and

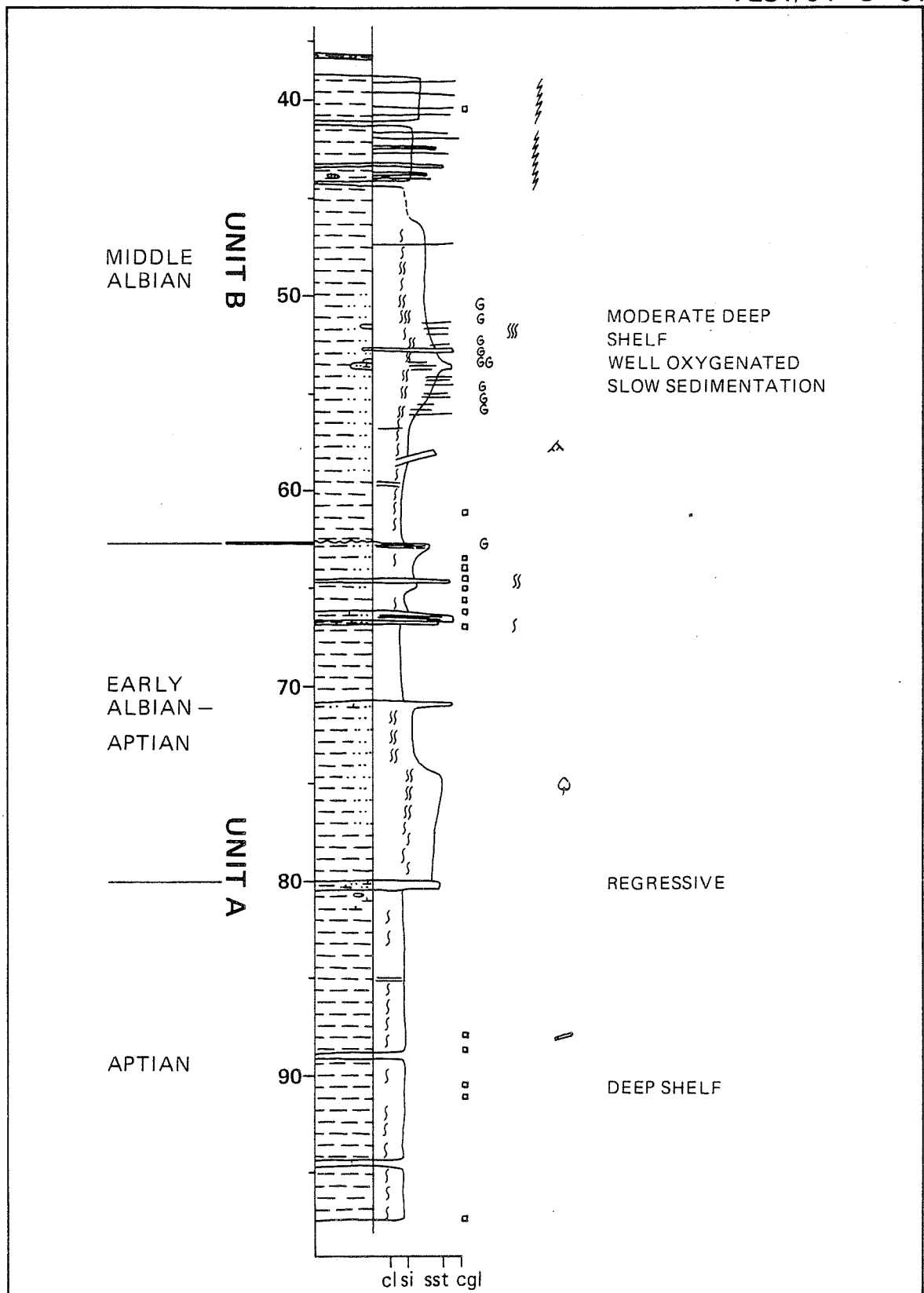


Figure 3.2.3 Simplified log of core 7231/04-U-01. Detailed log in scale 1:100 is found in Appendix A.5.

with abundant thin veins of pyrite.

The only sample from Unit B is from 53.49 m and consists of rounded very fine grained sand in a matrix of both Fe-rich calcite and siderite (Figure 3.2.4). Glauconite is also abundant, and the carbonate cement consists of rhombohedron shaped crystals.

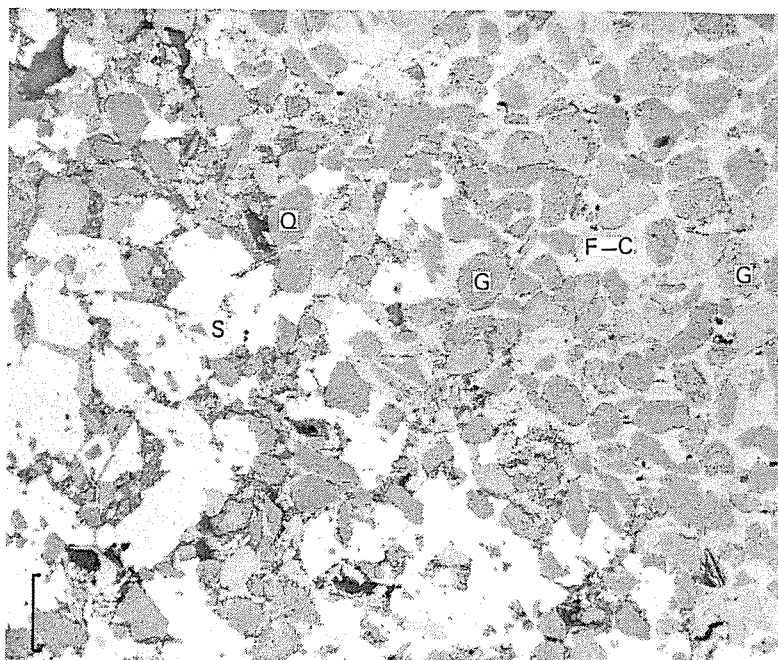


Figure 3.2.4 Backscatter electron microscope image of sand grains (Q) in a matrix of Fe-rich (F-C) calcite and siderite (S). Glauconite is also common (G). Sample 53.49 m.

X-ray diffraction

Fourteen samples have been analyzed by X-ray diffraction, both bulk samples and the fraction consisting of mineral grains < 4 micron are studied. (Figures 3.2.5 and 3.2.6, Tables 3.2.2 and 3.2.3).

Clear differences in mineralogy are seen between the two units, however, the sample at 64.36 m represent a transition between the units.

Unit A is dominated by quartz and plagioclase. Some K-feldspar is also present. The clay mineral fraction consists of illite, chlorite and kaolinite, while mixed layer clay minerals are only present in minor amounts. The lack of quartz and feldspars in the < 4 micron fraction indicates that these minerals are present only as sand and silt grains. In the clay fraction kaolinite dominates. Clay minerals expanding upon glycol

saturation are absent in Unit A. There are, however, minor amounts of interlayered chlorite-illite.

Unit B shows a similar distribution pattern as Unit A for quartz and feldspars, but the clay mineral pattern is clearly different. Mixed layer clay minerals are dominating and smectite is also present in minor amounts. The pronounced 10 Å reflection, which is plotted as illite in the figures, also reflects the abundant glauconite in this part of the core. In the < 4 micron fraction no quartz or feldspars are present and the fraction is totally dominated by the mixed layer clay minerals. When glycol saturated, the five samples from this unit show expansion of all the mixed layer clay minerals from 10-14 Å to nearly 17 Å (16.5-16.8 Å). This indicates randomly interlayered smectite - illite with smectite as the most abundant phase and only minor illite.

The sample at 64.36 m still contains high values of kaolinite and chlorite as found below. However, a higher content of mixed layer clays and the presence of smectite show similarities with the upper part of the core. This change in mineralogy may indicate that a gradational change between the two units takes place in the upper part of Unit A.

The presence of abundant smectite and randomly interlayered smectite-illite indicate immature diagenesis and a maximum burial temperature less than 70°C.

The marked change in clay mineralogy from Unit A to Unit B also indicates a change in either provenance or the weathering conditions.

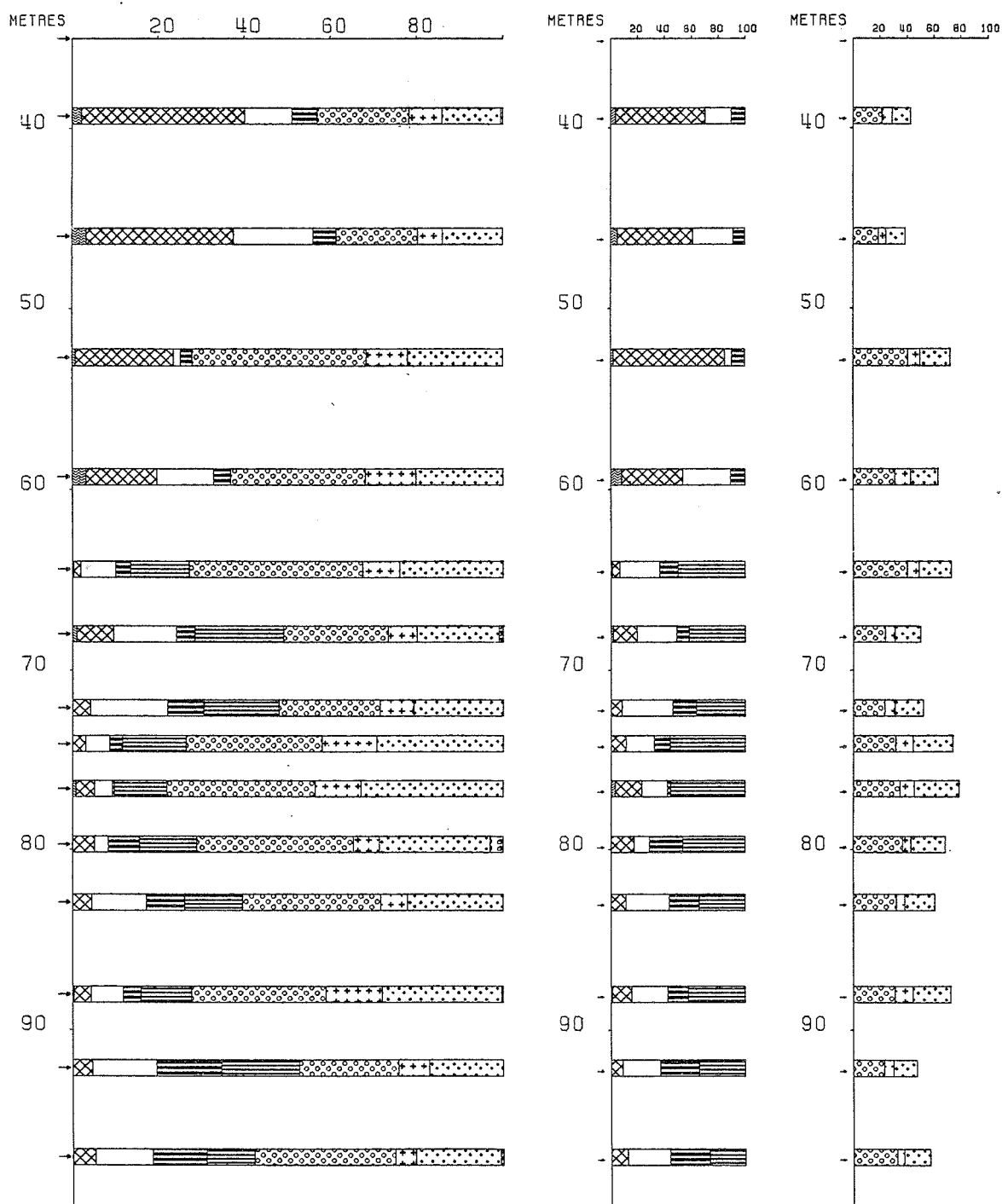


Figure 3.2.5 Whole rock mineralogy from core 7231/04-U-01 based on XRD analysis. Legend in Appendix A.3.

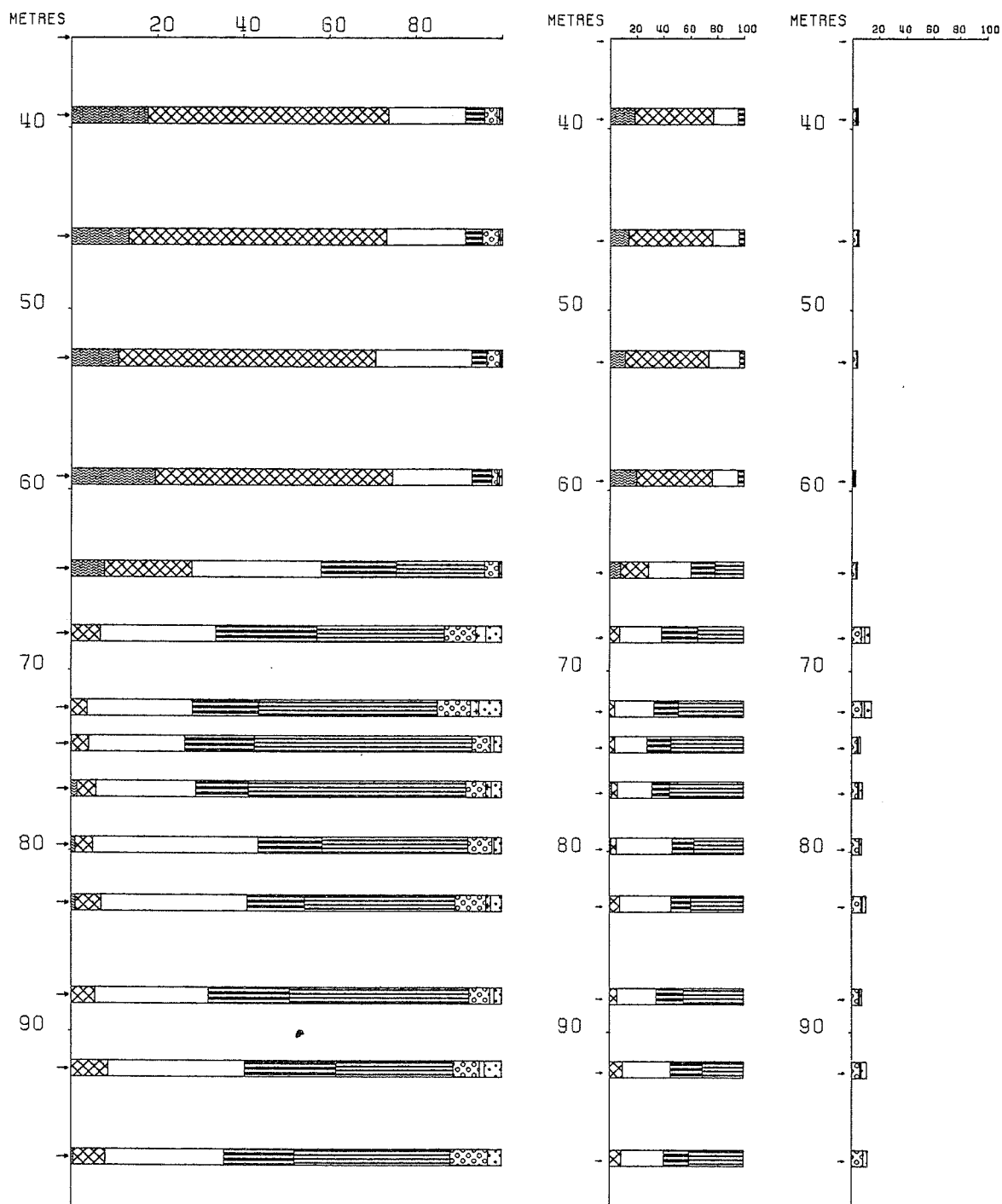


Figure 3.2.6 Clay mineralogy (<4 micron) from core 7231/04-U-01 based on XRD analysis. Legend in Appendix A.3.

Table 3.2.2 Tabulated values from XRD analysis of whole rock samples of core 7231/04-U-01. The values represent semiquantitative wt%. See Appendix A.3 for details.

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %
39.26	D-1138	2.2	11.0	5.8	0.0	21.4	7.6	13.6	0.5	0.0	0.0	0.0	0.0
45.97	D-1145	3.3	18.4	5.4	0.0	19.0	5.6	14.0	0.0	0.0	0.0	0.0	0.0
52.71	D-1154	0.7	1.5	2.7	0.0	40.5	9.6	22.1	0.0	0.0	0.0	0.0	0.0
59.32	D-1168	3.1	13.2	3.9	0.0	31.3	11.7	20.2	0.0	0.0	0.0	0.0	0.0
64.36	D-1179	0.3	8.0	3.6	13.6	40.3	8.5	24.0	0.0	0.0	0.0	0.0	0.0
67.96	D-1198	0.9	14.6	4.4	20.7	24.2	6.8	19.1	0.0	0.0	0.0	0.0	0.9
72.12	D-1202	0.0	18.0	8.4	17.5	23.4	7.8	20.8	0.0	0.0	0.0	0.0	0.0
74.12	D-1209	0.0	5.5	3.1	14.8	31.5	12.7	29.4	0.0	0.0	0.0	0.0	0.0
76.57	D-1210	0.7	4.1	0.5	12.2	34.4	10.7	33.0	0.0	0.0	0.0	0.0	0.0
79.67	D-1217	0.0	3.3	7.2	13.3	36.5	6.0	25.7	0.0	0.0	0.0	0.0	3.0
82.89	D-1222	0.0	12.6	8.9	13.6	32.1	6.2	22.2	0.0	0.0	0.0	0.0	0.0
88.02	D-1229	0.3	7.4	4.1	11.7	31.3	13.1	27.7	0.0	0.0	0.0	0.0	0.3
92.05	D-1236	0.0	14.9	15.1	18.1	22.9	7.1	17.2	0.0	0.0	0.0	0.0	0.0
97.01	D-1244	0.0	13.3	12.6	11.2	32.7	4.8	19.7	0.0	0.0	0.0	0.0	0.6

Table 3.2.3 Tabulated values from XRD analysis of clay fraction (<4 micron) samples of core 7231/04-U-01. The values represent semiquantitative wt%. See Appendix A.3 for details.

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %	Expand 14-17A
39.26	D-1138	17.7	17.8	4.5	0.0	2.8	0.6	0.7	0.0	0.0	0.0	0.0	0.0	Expands
45.97	D-1145	13.3	18.4	3.9	0.0	3.7	0.4	0.5	0.0	0.0	0.0	0.0	0.0	Expands
52.71	D-1154	10.9	22.1	3.6	0.0	2.9	0.3	0.4	0.0	0.0	0.0	0.0	0.0	Expands
59.32	D-1168	19.6	18.5	4.6	0.0	1.3	0.4	0.7	0.0	0.0	0.0	0.0	0.0	Expands
64.36	D-1179	7.8	29.9	17.5	20.4	3.2	0.3	0.5	0.0	0.0	0.0	0.0	0.0	Partly
67.96	D-1198	0.0	26.8	23.5	29.6	7.2	2.5	3.6	0.0	0.0	0.0	0.0	0.0	No Exp.
72.12	D-1202	0.0	24.5	15.4	41.4	7.8	1.8	5.3	0.0	0.0	0.0	0.0	0.0	No Exp.
74.12	D-1209	0.1	22.4	16.2	50.5	4.3	0.8	1.7	0.0	0.0	0.0	0.0	0.0	No Exp.
76.57	D-1210	1.4	23.2	12.2	50.6	4.6	1.2	2.4	0.0	0.0	0.0	0.0	0.0	No Exp.
79.67	D-1217	1.0	38.4	15.0	33.7	5.6	0.5	1.7	0.0	0.0	0.0	0.0	0.0	No Exp.
82.89	D-1222	0.9	33.9	13.4	34.9	7.2	1.1	2.5	0.0	0.0	0.0	0.0	0.0	No Exp.
88.02	D-1229	0.0	26.4	18.9	41.5	5.0	1.0	1.7	0.0	0.0	0.0	0.0	0.0	No Exp.
92.05	D-1236	0.0	31.7	21.3	27.2	6.1	1.2	3.9	0.0	0.0	0.0	0.0	0.0	No Exp.
97.01	D-1244	0.4	27.7	16.4	36.1	8.8	0.0	3.2	0.0	0.0	0.0	0.0	0.0	No Exp.

Petrophysics

Natural γ -radiation

The natural γ -activity along core 7231/04-U-01 varies slightly, due to varying sand content (Figure 3.2.7). The sandy layers are best reflected by the potassium log which shows low values where the sand content is high. The uranium content is slightly higher below about 66 m, which is also reflected by an increase of the total γ -activity. The higher γ -activity coincides with an increase of the total organic carbon content from less than 1 % to 2-4 %.

Sound velocity

The thirty-three measurements of horizontal sound velocity show very varying results (Figure 3.2.7, Table 3.2.4). All the measurements below 60 m are obviously erratic, except for the sandstone layer at 66 m. The low values are due to expansion and fracturing of the core upon pressure release. This effect is also responsible for the problems of measuring the vertical sound velocity, since fracturing takes place along the lamination of the rock.

The average measured velocity between 60 m and 45 m is 2340 m/s, while the calculated velocities from correlation between the seismic data and the core is 2280 m/s in the interval 62.7-50.5 m and 2130 m/s above 50.5 m. Taken into account that the seismic velocity is mainly vertical the seismic interval velocities should here be lower than the horizontally measured velocities because of the anisotropy of the sediments. The velocities measured on the core above 60 m seem therefore reliable. The interval velocity below 62.7 m is calculated to 2560-2400 m/s (see Table 3.2.1).

Sound velocity
(1000m/s)

Natural gamma activity
(1000 counts/10min)

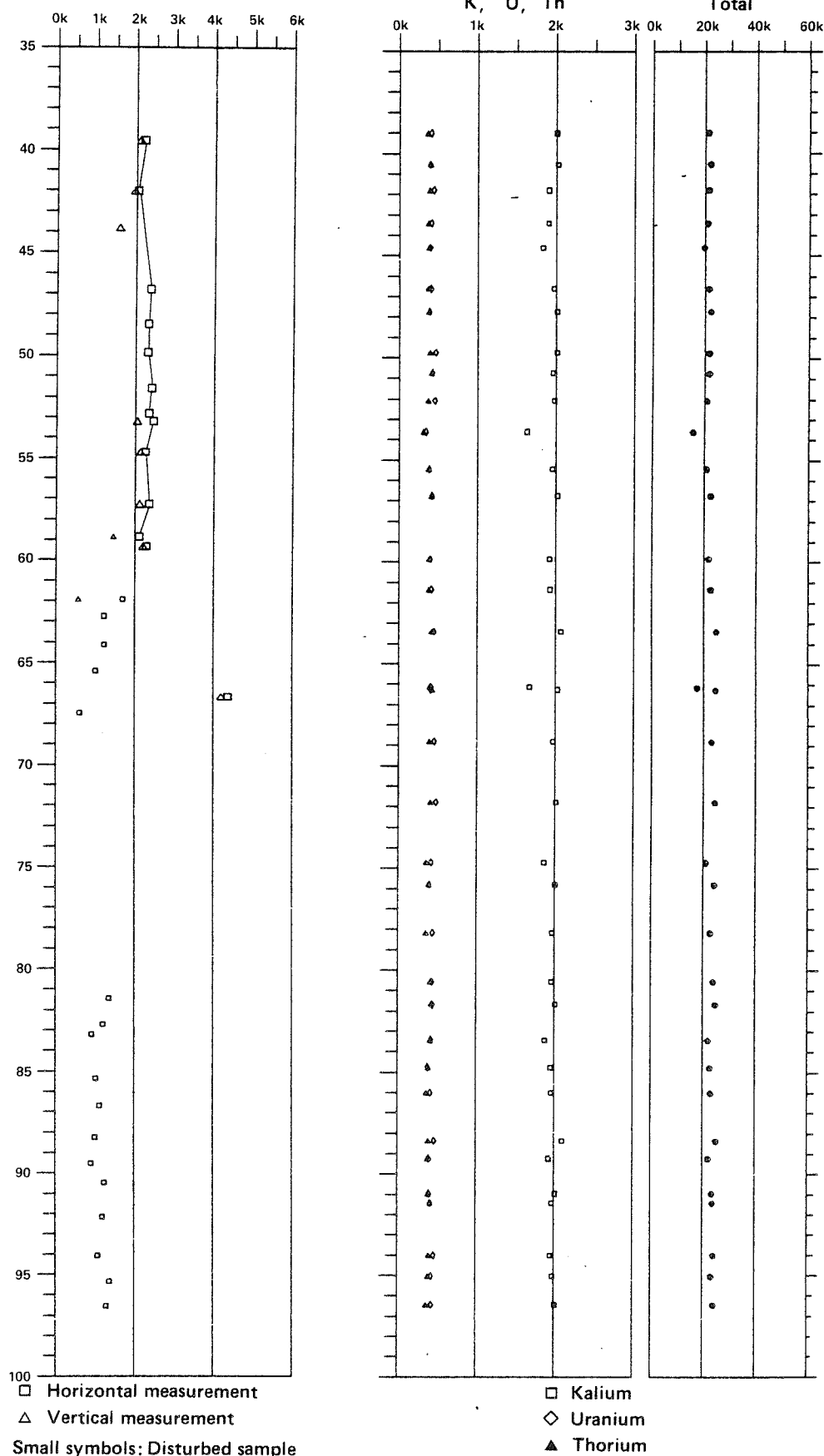


Figure 3.2.7 Natural γ -radiation (counts per 10 minutes) and sound velocity (m/s) in core 7231/04-U-01.

Table 3.2.4 Sound velocity (m/s) in core 7231/04-U-01.

Depth m	Horiz. velocity m/sec	Vert. velocity m/sec
39.57	2204	2102
42.03	2053	1966
43.81	0	1580
46.80	2374	0
48.49	2332	0
49.87	2313	0
51.59	2409	0
52.82	2339	0
53.21	2455	2047
54.71	2255	2137
57.26	2368	2124
58.86	2109	1456 *
59.34	2288	2208
61.94	1688 *	573 *
62.76	1232 *	0
64.16	1232 *	0
65.43	1004 *	0
66.68	4371	4207
67.48	603 *	0
81.45	1361 *	0
82.71	1218 *	0
83.23	933 *	0
85.37	1030 *	0
86.72	1131 *	0
88.26	1013 *	0
89.53	910 *	0
90.48	1247 *	0
92.19	1187 *	0
94.07	1073 *	0
95.37	1383 *	0
96.54	1300 *	0

* Velocities from samples marked by * represent disturbed samples.

3.2.4 Paleontology

Palynology

Low diversity dinoflagellate cyst assemblages occur in the dark shales below 80 m (Figures 3.2.8 and 3.2.9). *Canningia brevispinosa* is the most consistently occurring species; at 97.01 and 95.19 m in relatively high numbers. Scarce representatives of *Muderongia asymmetrica*, *Odontochitina operculata*, *Oligosphaeridium complex*, *Palaeoperidinium cretaceum*, *Cauca parva*, *Leptodinium cancellatum* and a few other species have also been found.

Brideaux & McIntyre (1975) recorded *C. brevispinosa* (as *Tenua* sp. A) in late Aptian to Middle Albian rocks from District of Mackenzie, Canada. The Aptian and Early Albian strata there contain low diversity palyno-assemblages in contrast to the Middle Albian, but the biostratigraphic control in the area is not the best. They also found that *M. asymmetrica* (recorded as *Muderongia* sp. A) was restricted to Late Aptian and Early Albian beds. The presence of *L. cancellatum* is supporting Late Aptian or younger evidence.

The diversity increases in the interval from 80 to 62 m. *Cauca parva* has been recorded consistently from 80.37 m to the top of the core and *Chlamydophorella nyei* less consistently from 76.88 m. A single specimen of *Chlamydophorella trabeculosa* has been observed at 71.07 m.

Transitional forms between *Palaeoperidinium cretaceum* and *P. pyrophorum* are present in the interval 65.13 to 50.55 m and point to changes in the *P. cretaceum* - *P. pyrophorum* evolutionary lineage during deposition of these probably partly condensed glauconitic beds.

The last record of *Muderongia asymmetrica* (although scarce in this hole) at 65.13 m and the first record of common *S. microreticulata* at 62.10 m confirms the impression from Tromsøflaket that these species are stratigraphic markers in the area and may be used for the approximate recognition of the Early/Middle Albian boundary in agreement with Brideaux & McIntyre (1975).

The sample at 62.10 m from a level about 0.5 m above a thin glauconitic sand bed also contains the first records of *Lithodinia imperfecta*, *Stephodinium australicum* sensu Singh 1983 and common representatives of *Canningia ringnesii* sensu Brideaux & McIntyre (1975).

Brideaux & McIntyre (1975) found *L. imperfecta* (as *Dictyopyxidia imperfecta*) in upper Lower and Middle Albian beds and *C. ringnesii* exclusively in what they interpreted as Middle Albian strata. Some of the published ranges from Brideaux & McIntyre's Horton River section conflict the ranges from western Europe.

Davey & Verdier (1971) found *Rhombodella paucispina* (as *R. natans*) in Middle and lower Upper Albian strata whereas Foucher (1981) recorded it from the Lower Albian *C. floridum* Zone to the top of the Albian. A single specimen of the species at 39.26 m, supports a Middle Albian or possibly late Early Albian dating for the upper part of the core.

We interpret three questionable specimens of *Sirmiodinium grossii* (Bathonian - Barremian) at 92.05, 83.27 and 80.37 m and also three *Nannoceratopsis gracilis* (Late Pliensbachian - Bajocian) at 95.19, 92.05 and 83.27 m as being reworked.

Microfauna

The lowermost interval (below 80 m) is composed of medium to fairly rich foraminiferal faunas of mixed calcareous and agglutinating forms (Figures 3.2.10 and 3.2.11). The calcareous element is partly red or brownish red stained.

Most of the agglutinating forms in this interval are long-ranging, but nearly consistant occurrences of *Textularia foeda* and *Glomospira charoides* may be noteworthy, in addition to the top occurrence of *Uvigerinammina* cf. *jankoi*. The latter is from our experience a stratigraphical index form in the region. The calcareous forms also include stratigraphical significant species, e.g. *Hoeglundina chapmani* (consistent), and top occurrences of *Citharina* (?) cf. *acuminata*, *Valvulineria gracillima*, *Lamarckina lamplugi*, *Saracenaria bronnii*, *Tristix globulifera*, *Oberhauserina morator* and *Lenticulina* cf. *heiermanni*. The co-occurrence of *L. lamplugi* and *S. bronnii* indicates vicinity of the Aptian - Albian boundary according to Bartenstein and Bettenstaedt (1962), who also indicate an acme of *V. gracillima* in the Late Aptian. The occurrence of *C. (?)* cf. *acuminata* and *L. cf. heiermanni* support an Aptian age for this interval (Hart et al. 1981). Reworking of Jurassic specimens are noted in sample 92.05 m.

The Early Albian interval (80-62 m) includes only sparse agglutinated faunas, except for the occurrence of *Hoeglundina chapmani* at the 65.13 m level. The top occurrence of *Verneulinoides subfusiliformis* (65.13 m) supports the palynological conclusion, but except for this only sparse records of long-ranging forms were obtained.

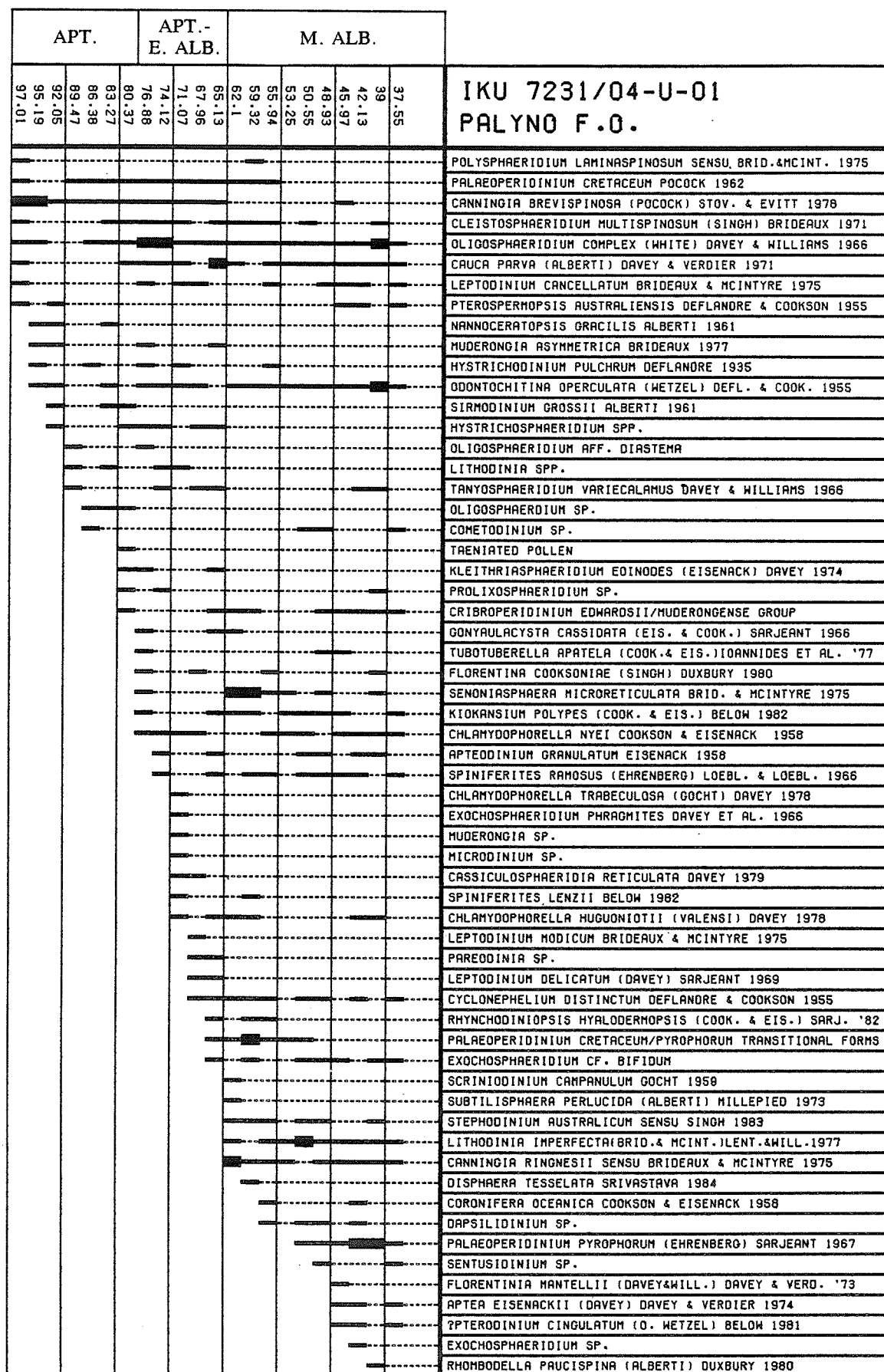


Figure 3.2.8 Palynological range chart of core 7231/04-U-01.
(Sorted according to first occurrence).

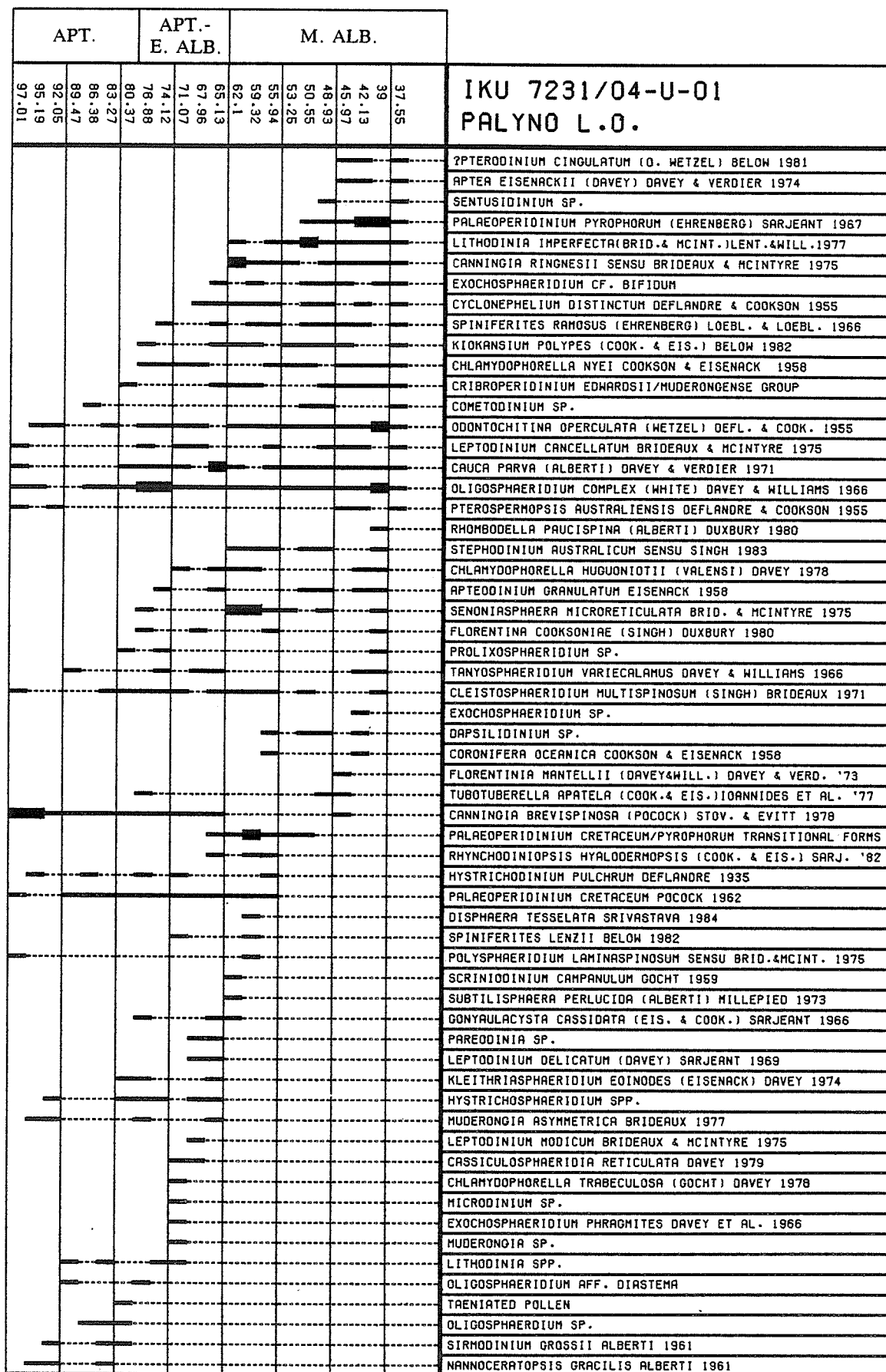


Figure 3.2.9 Palynological range chart of core 7231/04-U-01.
(Sorted according to last occurrence).

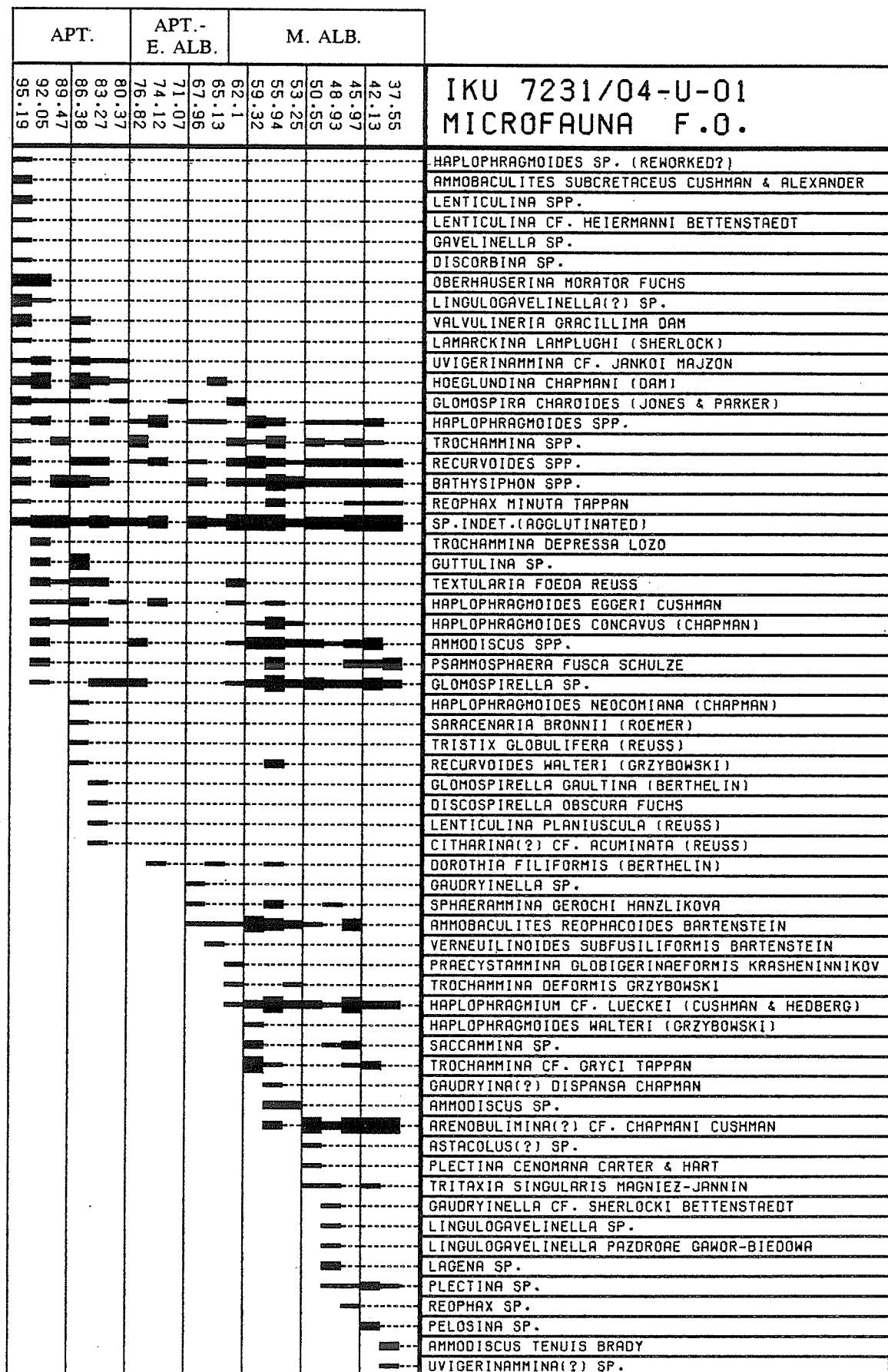


Figure 3.2.10 Foraminiferal range chart of core 7231/04-U-01.
(Sorted according to first occurrence).

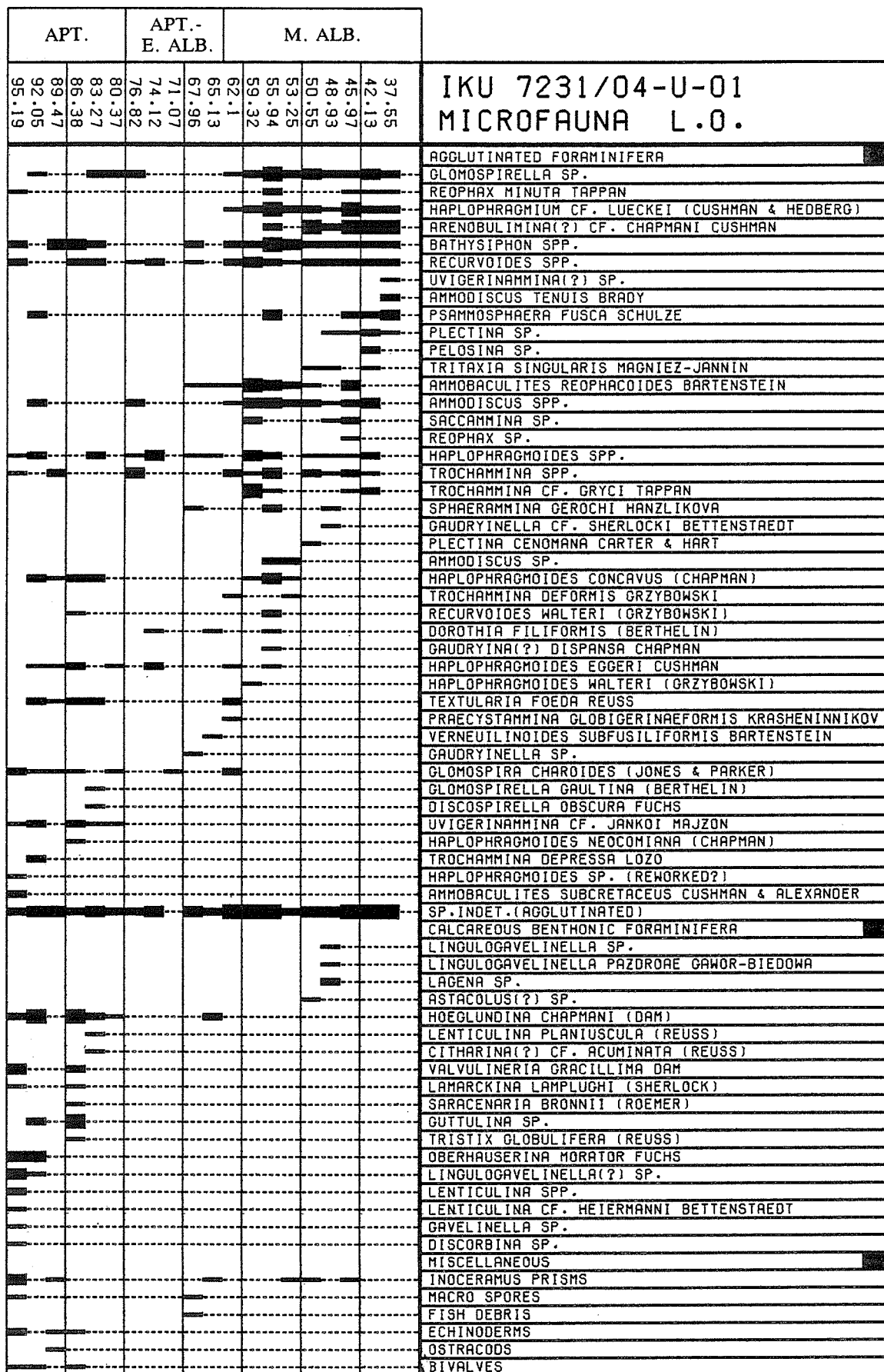


Figure 3.2.11 Foraminiferal range chart of core 7231/04-U-01.
(Sorted according to last occurrence).

The Middle Albian interval (above 62 m) contained fairly rich and diverse foraminiferal faunas of mainly agglutinating foraminifera. The interval is dated on palynomorphs, and none of the recorded foraminifera are known to allow a precise dating.

Some records are noteworthy, and may possess a potential for correlation purposes at a later stage, e.g. the consistent occurrences of *Glomospirella* sp. and *Haplophragmium* cf. *lueckei*, and occurrences of *Arenobulimina* (?) cf. *chapmani*, *Tritaxia singularis*, *Trochammina* cf. *gryci* and *Lingulagavelinella pazdroae* (the five latter with first occurrences within the interval).

3.2.5 Organic geochemistry

The organic geochemical data figures and tables are presented in a separate volume. Only summary figures will be presented in this section.

Nineteen canned core samples, taken at approximately 3 m intervals, were used to investigate the content of headspace and occluded gas associated with the cores (Figure 3.2.12). Methane is the dominant component in both the headspace and occluded gas, with concentrations normally one to two orders of magnitude higher than the C_{2+} components (i.e. ca. 20,000–50,000 μ l gas/kg dry rock for most samples).

C_{2+} gas components are only present in trace amounts of up to 350 μ l gas/kg dry rock. The highest concentrations of C_{2+} gas components are found in the four samples below ca. 85 m. The low concentrations of the C_{2+} components suggest that the gas wetness and iC_4/nC_4 ratios may not be reliable.

On the basis of total organic carbon (TOC) data, the core can be divided into three sections (Figure 3.2.13). The first section extends from the base of the core up to 80.0 m, and is characterised by high TOC values of between 2.7 wt% and 3.8 wt%. The rocks of the second section (62.7 m to 80.0 m) have a reduced TOC content (1.6 wt% to 1.9 wt%) relative to the underlying section. The uppermost section (45.87 m to 59.15 m) is characterised by the lowest TOC values observed in rocks from this core (0.6 wt% to 0.9 wt%).

Rock-Eval pyrolysis data indicate little change in the pyrolytic nature of the kerogen in the rocks from this core (Figure 3.2.13). The kerogen is characterised by low hydrogen indices, the maximum value being 58 mg/g TOC. The lowest hydrogen indices are observed in the four relatively organic-poor samples at the top of the cored bedrock section. Microscopic examination of the kerogen in four samples from the interval between 74.39 m and 97.13 m indicates that there is little variation in the composition of the kerogen. Most of the kerogen (60-80 %) consists of finely-divided amorphous material with embedded dark woody/coaly fragments.

The pyrolysis-gas chromatograms of three typical samples from this core, at 74.39 m, 88.84 m and 97.13 m, support the Rock-Eval data and suggest that the kerogen is largely inert. The pyro-chromatograms are all similar, with prominent benzene and toluene peaks, a prominent (m+p)-xylene peak, and an alkene-alkane homology which does not extend beyond the C₁₄ doublet.

Reliable Rock-Eval T_{max} values of 426°C to 434°C were only obtained from the lowest six samples of the core, due to poor S2 peaks in the majority of the samples. Mean vitrinite reflectance values of 0.36 % to 0.42 %, and greenish yellow to yellowish orange sporinite fluorescence colours are consistent with the T_{max} data. These data suggest that the kerogen in the rocks is thermally immature. The thermal alteration index (TAI) values of 3.5 to 4 suggest a slightly higher thermal maturity (i.e. early thermal maturity), but the influence of oxidation cannot be excluded given the nature of the kerogen.

Two samples (91.22 m and 97.13 m) with high C₂₊ gas component content were extracted in order to examine the character of any bitumen present (Figure 3.2.14). The samples yielded fair amounts (675 ppm and 1135 ppm) of extractable organic matter (EOM). Non-hydrocarbon compounds account for 70-90 % of the EOM. The upper sample at 91.22 m differs from the lower sample in its significantly increased content of saturated hydrocarbons. The reason for this difference is unclear. Aromatic hydrocarbons are present in only minor concentrations in both samples

The gas chromatograms of the saturate fractions of these two samples show similar distributions of n-alkanes. The extracts have a rather immature appearance with an odd-carbon number predominance, with carbon preference index (CPI) values of 1.2 to 1.3. The prominence of the higher molecular weight compounds (i.e. greater than nC₂₃) may suggest a contribution of

higher plant material. The moderately high pristane/phytane ratios suggest a dysoxic to oxic depositional environment for the source kerogen (Figure 3.2.15).

Biomarker data were obtained for the saturate fractions of the two samples in order to further evaluate the source and maturity relationships of the two sample extracts.

Both the sterane and terpane mass fragmentograms of the two samples show a similar distribution of compounds. The sterane (m/z 217) mass fragmentograms are dominated by a prominent C_{29} 5α 20R sterane peak, which is often associated with terrestrial organic matter input. In this respect, these samples are very similar to the uppermost extracted sample from core 7231/01-U-01, which is also of Lower Cretaceous age. The remaining sterane peaks are poorly developed, suggesting a rather immature bitumen of largely terrestrial origin.

The terpane (m/z 191) mass fragmentograms also have a strongly immature appearance with well-developed moretane peaks, and a prominent C_{27} 17α -trisnorhopane peak. In addition, the prominence of the R-isomer of the C_{32+} extended hopanes also suggests that the extracts are thermally immature (i.e. low %22S values of 21 % and 24 %, whereas values of 60 % are usually encountered in thermally mature extracts). A feature of the m/z 191 mass fragmentogram of both samples is a prominent unidentified peak.

In conclusion, the bedrock section represented by core 7231/04-U-01 can be described as containing an upwards decreasing content of thermally immature, hydrogen-poor type IV kerogen. Analysis of sample extracts from the base of the core indicates the presence of low concentrations of thermally immature, probably terrestrially sourced bitumen. This bitumen is unlikely to have migrated any significant distance, and may be of local origin.

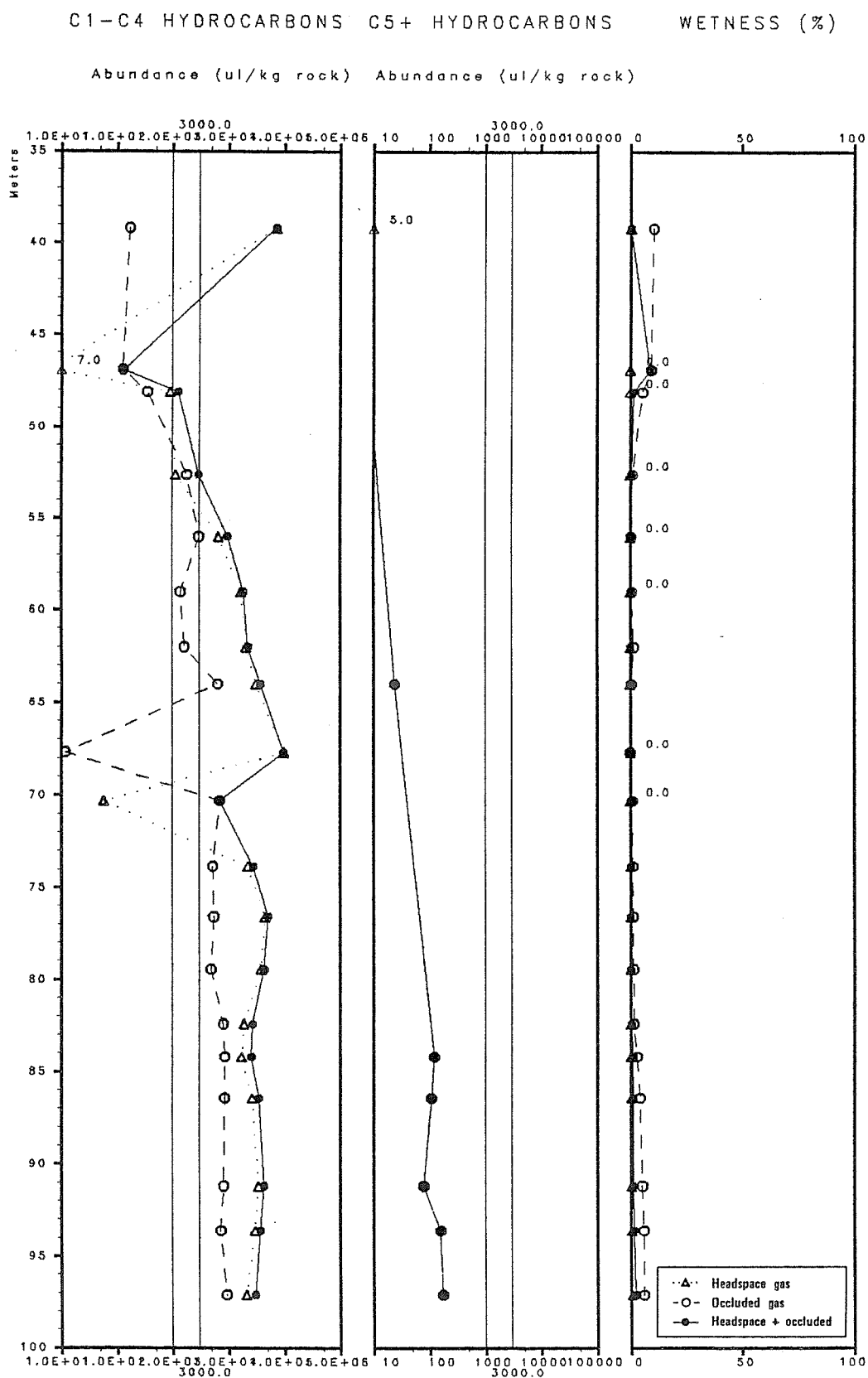


Figure 3.2.12 Yield and composition of headspace/occluded gas of core 7231/04-U-01.

ROCK-EVAL PYROLYSIS DATA

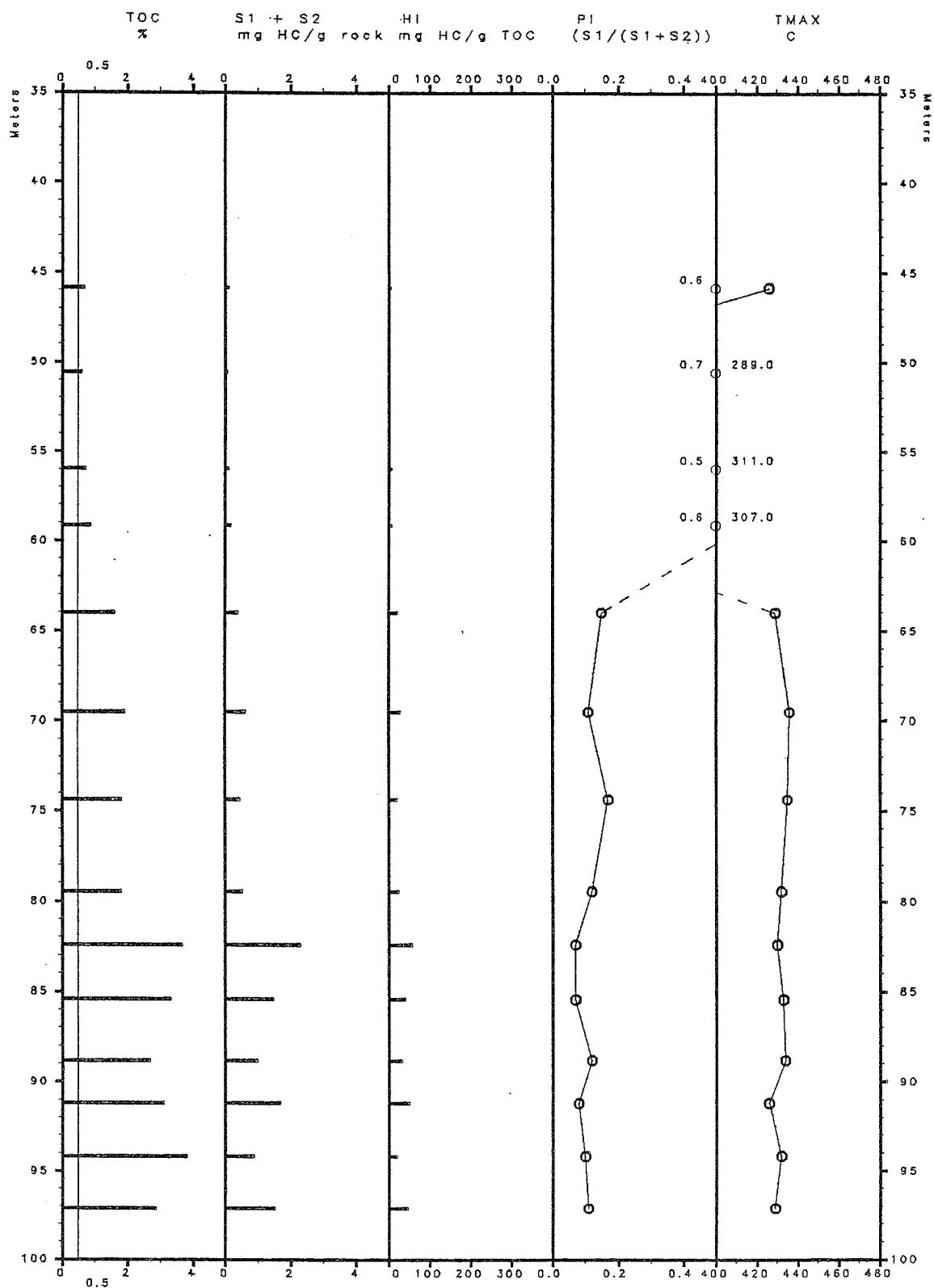


Figure 3.2.13 Total organic carbon content and Rock-Eval data of core 7231/04-U-01.

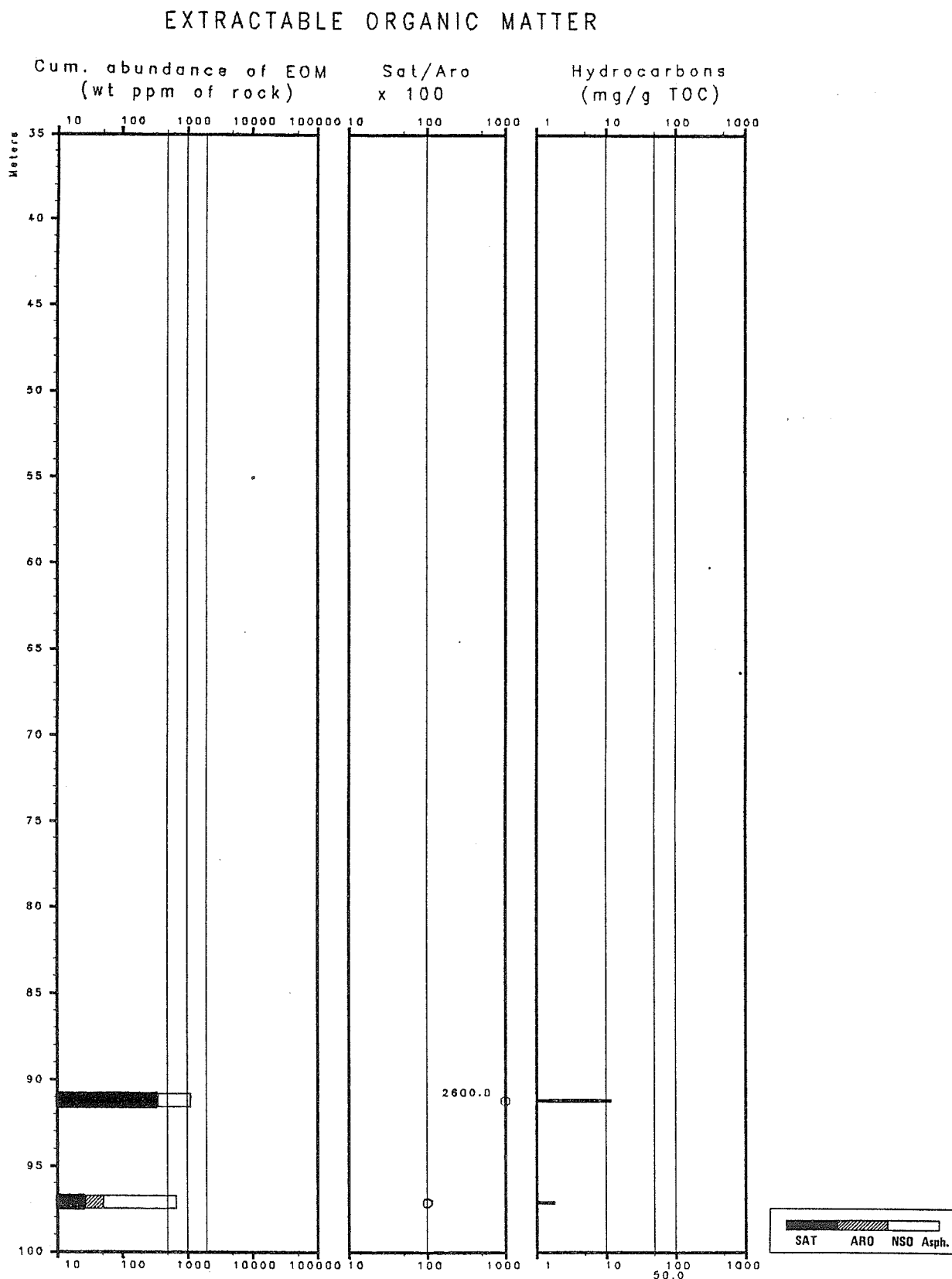


Figure 3.2.14 Extract data for core 7231/04-U-01.

GAS CHROMATOGRAPHIC RATIOS

CPI 2

Pristane/Phytane

Pristane/n-C17

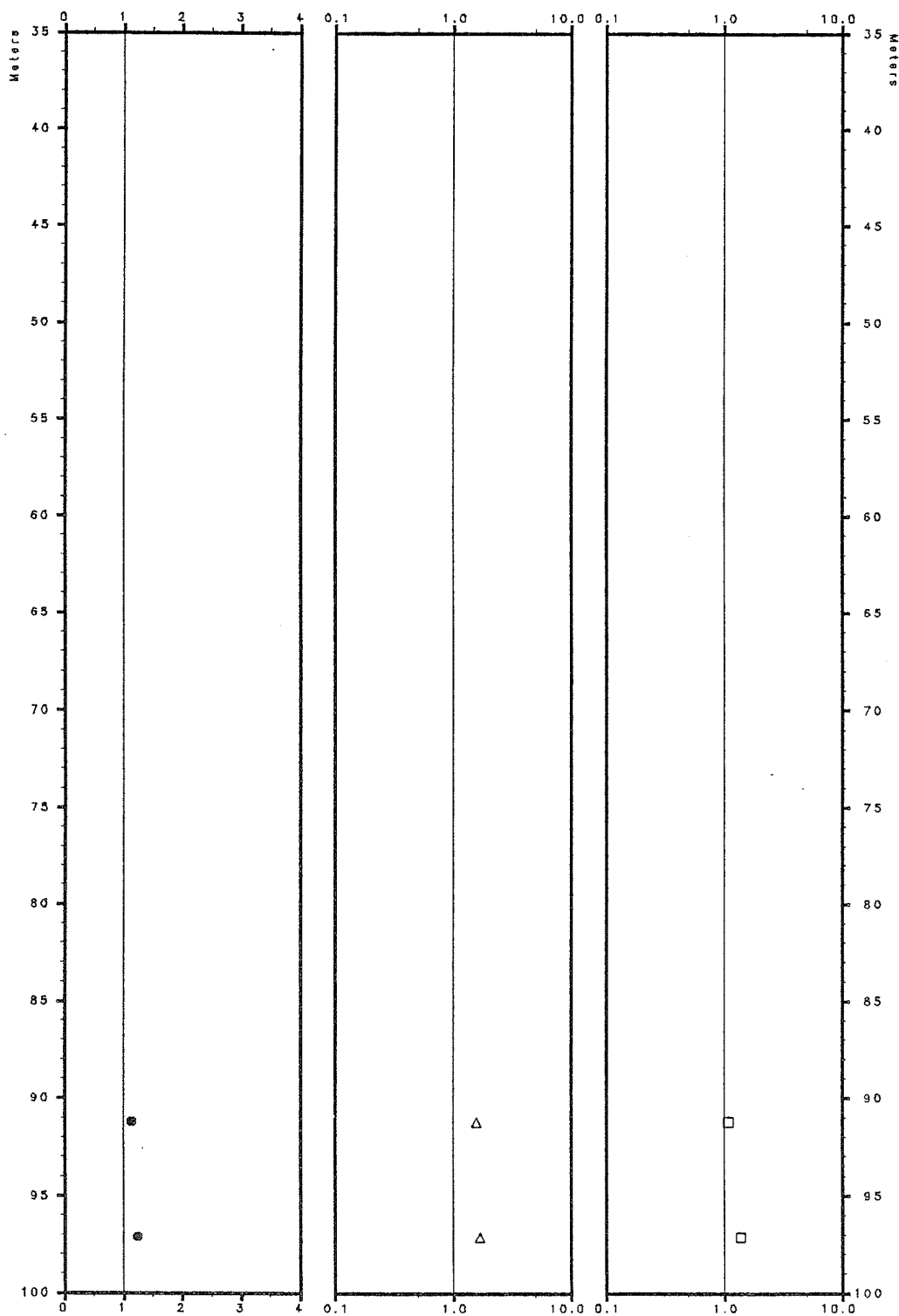


Figure 3.2.15 Compound ratios from gas chromatograms of saturated hydrocarbon fractions from core 7231/04-U-01.

3.2.6 Depositional environment

The core reflects sedimentation under shelf conditions. Lack of sedimentary structures suggests deposition below wave base, and the intense bioturbation in parts of the core indicates low sedimentation rates.

Some beds in Unit B contain abundant glauconite indicating a transition from a low oxic level during deposition of Unit A to oxic conditions and reduced sedimentation rate during deposition of Unit B.

Increased diversity in the dinoflagellate cyst assemblages from 80 m and upwards supports the impression of improved water circulation during deposition of these beds. The general upwards decreasing content of (type IV) kerogen supports this model.

3.3 Core 7230/05-U-09

3.3.1 Summary

In core 7230/05-U-09 55.1 m of bedrock was drilled in the interval between 20.0 and 75.1 m below the sea floor, with 77.5 % core recovery. In the lowermost 33 m the core recovery was nearly 100 %. The core is divided into litho-units A, B and C, with boundaries at 64.6 m and 46.5 m, respectively (Figure 3.3.1). None of the four seismic reflectors that are correlated to lithological boundaries are seismic sequence boundaries.

The lower Unit A (10.5 m thick) consists of a coarsening upward sequence of fine to medium grained sandstones with subordinate mudstone and intraformational conglomerate intervals.

Unit B (18.1 m thick) consists of a coarsening upward sequence of siltstones overlain by sandstones, with both coquina and siderite cemented beds.

The upper Unit C (26.5 m thick) consists of siltstones at the base overlain by fine grained sandstones and siltstones with abundant shell beds. The unit is complex, but represents a general fining upward succession.

The sediments are strongly bioturbated and were deposited in a marine (as shown by the many palynomorphs) barrier coastline of progradational stacked lower shoreface, upper shoreface and lagoonal setting in a generally shallow marine, regressive system.

Dinoflagellate cyst assemblages suggest more or less continuous deposition during latest Late Albian to earliest Middle Cenomanian.

The core contains very low concentrations of thermally immature and hydrogen-poor organic matter, which has no potential for generation of hydrocarbons. Vitrinite reflectance values of 0.36 - 0.39 % Ro and thermal alteration indices of 3.0 - 3.5 indicate that the organic material is thermally immature. The low concentrations of bitumen found in this core are thermally immature and probably derived from continental organic material. The core does not contain any significant amounts of non-indigenous hydrocarbons.

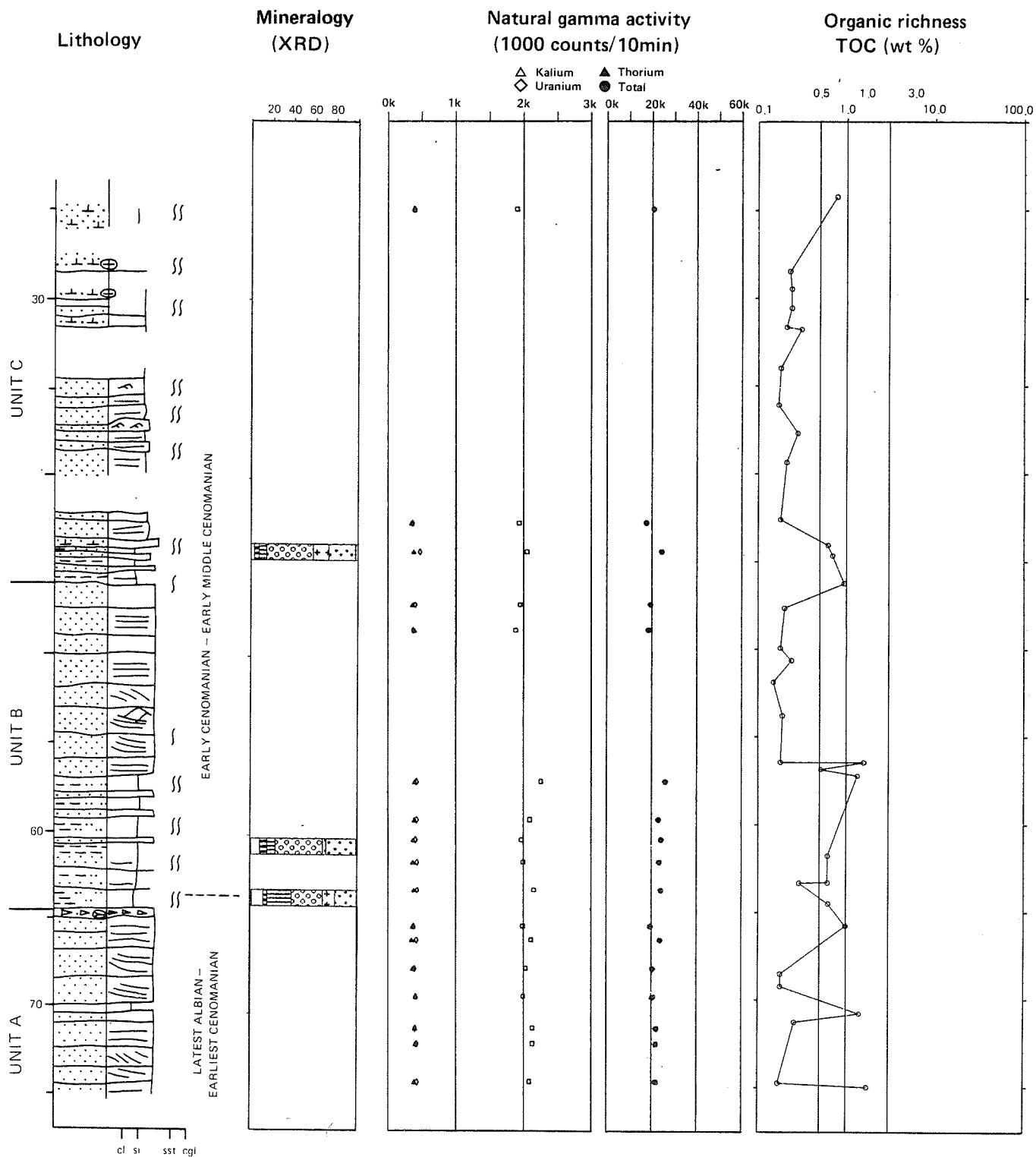


Figure 3.3.1 Summary figure of core 7230/05-U-09. Legend in Appendix A.3.

Porosity measurements range between 35 and 40 %, with a low (5 %) value in a calcite cemented sandstone. Horizontal permeability values vary between 500 and 1800 mD while vertical permeability in general is lower with values between 300 and 1000 mD. Low values are measured in the calcite cemented sandstone. The core thus shows presence of interesting reservoir rocks.

3.3.2 Seismic interpretation

The site is situated in a rim syncline to the south of the northeastern part of the Nordkapp Basin and was positioned at the base of the youngest bedrock unit in the area. About 12 m of this unit was penetrated as well as about 43 m of the unit below. A total of four seismic reflectors can be correlated with boundaries found in the core (see Figure 3.3.2 and Table 3.3.1). None of them seems to represent proper sequence boundaries. The boundary at approximately 32 m is probably the base of the upper, main unit. The reflector at 57 m is very strong and continuous and is probably the result of interfering reflection with the litho boundary at 64.6 m.

3.3.3 Sedimentology

About 55 m of sedimentary rocks were penetrated between 20 and 75.1 m, i.e. a recovery of about 77.5 %. The major core losses are in the following intervals: 20-24.8, 25.75-27.75, 28.85-29.35, 31.80-33.85, 36.70-37.10 and 40.05-41.95 m. Below 42 m the core recovery was almost 100 %. The core losses were from loose sandstones, particularly in the upper part. Because of the poor lithification some of the sandstones are difficult to describe.

The core has been divided into Units A, B and C as shown in the sedimentological column in Figure 3.3.3. Units A and B are coarsening upward units while Unit C is complex and displays in general a fining upward succession. The unit boundaries are defined at 64.6 and 46.6 m.

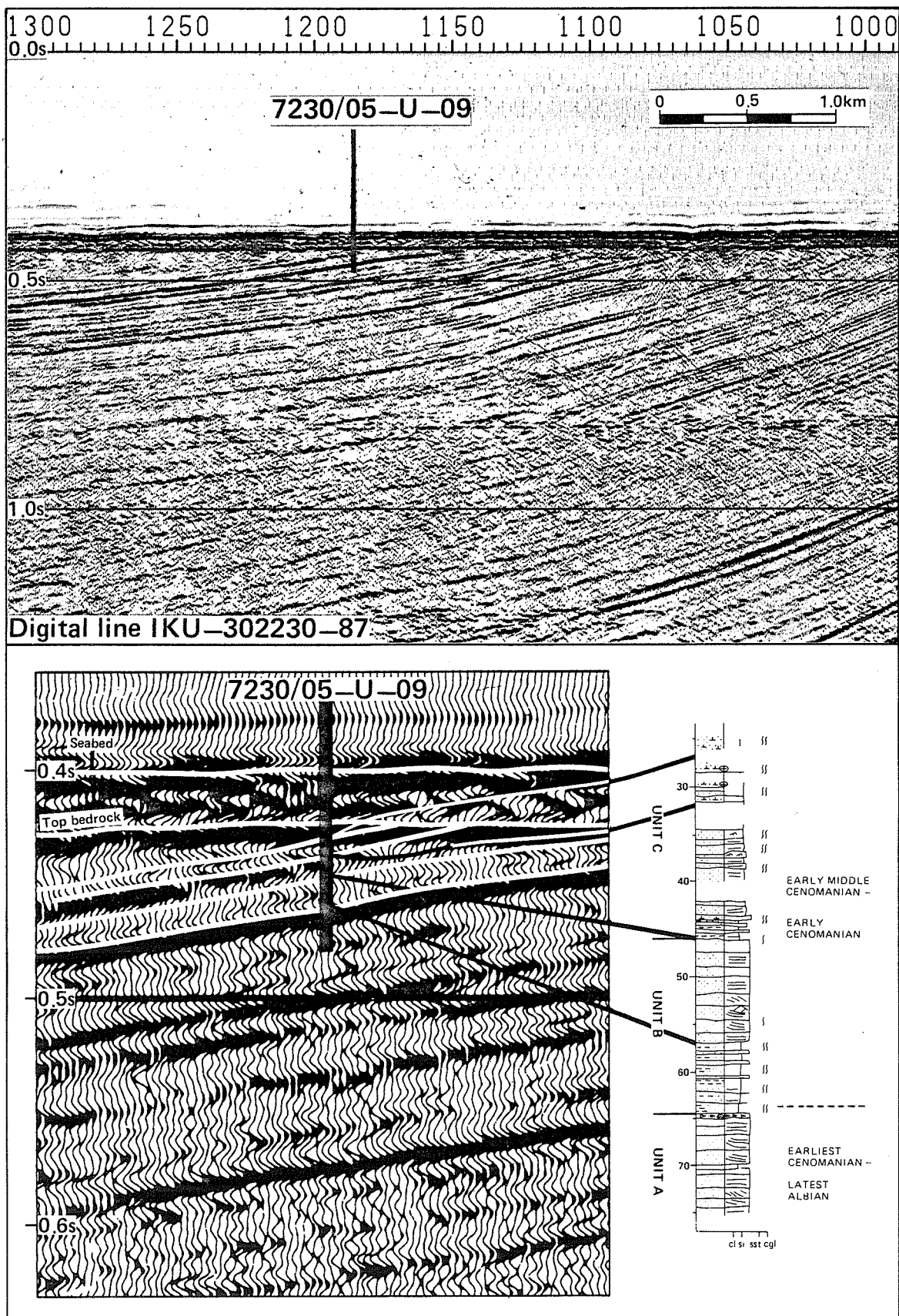


Figure 3.3.2 Correlation between core 7230/05-U-09 and seismic data.

Table 3.3.1 Key data of the correlation between
core 7230/05-U-09 and seismic line IKU-302230-87.

Depth below seabed		Core unit	Thickness of seismic unit		Interval sound velocity
20.0 m	22.2 msec	Overburden	20.0 m	22.2 msec	1800 m/s
26.0 m	28.7 msec	C	ca 6 m	6.5 msec	ca 1850 m/s
32.0 m	35.2 msec	C	6.0 m	6.5 msec	1850 m/s
46.5 m	48.7 msec	C	14.5 m	13.5 msec	2150 m/s
57.0 m	59.7 msec	B	10.5 m	11.0 msec	1910 m/s
TD 75.1 m	78.7 msec	B A	7.6 m 10.5 m	19 msec	1910 m/s (estimated)
Total TD below sea surface: 369.1 m / 480 msec					

Unit A (75.1–64.6 m) consists of medium grey, fine grained sandstones with subordinate mudstone and intraformational conglomerate intervals. The sandstones show hummocky bedding, trough cross lamination, ripple lamination or horizontal lamination. Hummocky beds are common below 69 m. They sometimes are separated with a few cms thick siltstone beds. Some beds show wave and current ripple and some have reworked tops.

7230/05-U-09

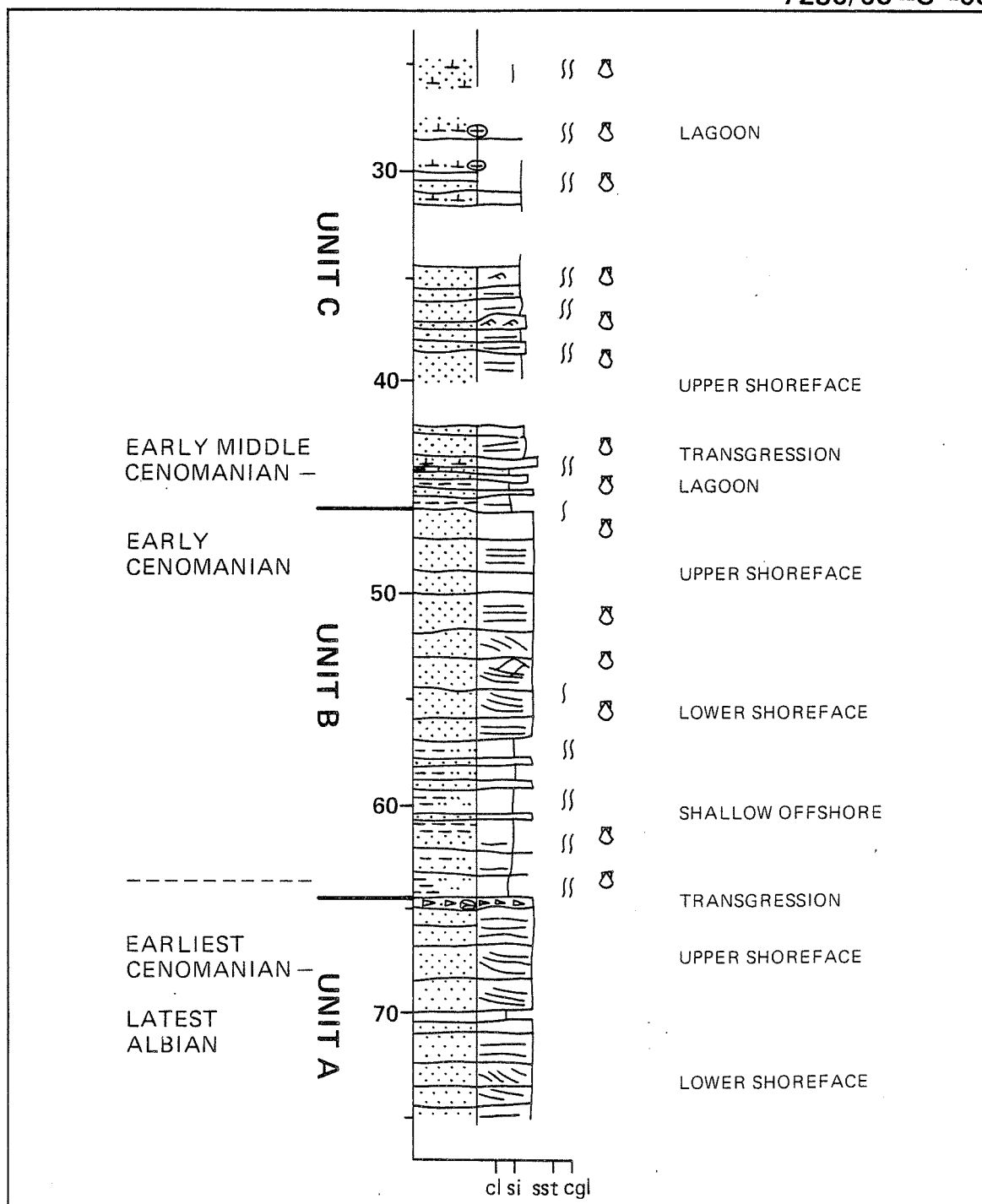


Figure 3.3.3 Simplified log of core 7230/05-U-09. Detailed log in scale 1:50 is found in Appendix A.5.

Trough cross laminated sandstone beds occur above the hummocky beds. They differ from the hummocky beds by an upward increase in dip angle of the cross lamination. Ripple laminated fine grained sandstones are restricted to the lower half of the unit, while horizontally laminated sandstones are more widespread above. Medium dark grey mudstones separate some of the sandstone beds. Some contains thin horizontal and/or ripple laminated, graded sandstone beds. Mudclast conglomerates (<1 cm diameter) with some siderite pebbles occur in the upper 75 cms of the unit.

Unit B is a coarsening upwards unit, grading from clayey siltstones below 57 m to sandstones dominating above. The medium dark grey clayey siltstones are moderately to strongly bioturbated, with burrows usually less than 1 cm in diameter. A few cms thick sandstone beds and lenses occur frequently in the clayey siltstone. They often show horizontal laminae and/or low angle ripple lamination. Siderite and pyrite concretions also occur in the unit. The sandstone shows hummocky beds up to about 54 m, overlain by trough and horizontal laminated sandstone in the upper part. Siderite cemented beds are present.

Fossils are common in both the clayey siltstones and the sandstones. Bivalves occur throughout most of the unit, and form coquina beds.

Unit C consists of medium dark grey siltstone in the lower 2.5 m, which is strongly bioturbated with both horizontal and vertical burrows. The lower metre of the siltstone contains up to 25 cm thick both ripple laminated fine grained sandstone beds and graded sandstone beds. The sandstone beds have horizontal lamination in the lower part and current ripple lamination in the upper part. One of the graded beds contains some mudstone clasts in the lower part. The overlying fine to very fine grained medium dark grey sandstone is moderately to strongly bioturbated. Horizontal laminae are recognized as well as ripple laminations and bivalve fragments. Above 31.75 m the rocks are very fine grained silty sandstones with abundant calcite cemented shell beds. The sand-/siltstones are moderately to strongly bioturbated.

Petrography

Twenty-nine thin sections and three XRD analysis have been studied. Four of the thin sections have been used for grain type determination and porosity

quantification in a scanning electron microscope (Table 3.3.2). The amount of cementing minerals is in general low with the exception of carbonate cemented beds where the calcite and siderite contribute with more than 30 % of the rock volume.

The quantification results (Table 3.3.2) show that quartz (18-32 %), alkalifeldspars (13-16 %), albite (7-17 %) and glaucony (3-7 %) are the major grain types. Micas (biotite and muscovite) and heavy minerals (zircon, tourmalins, apatite, rutile and titanite) occur in trace amounts in the sandstones. The sandstones are classified as arkosic arenites.

Compaction has only reduced some of the primary porosity of these sandstones. Evidences of compaction are squeezing of glaucony grains, breaking of elongated grains and some reorientation of grains. Pressure solution is uncommon in these rocks.

Silicates

Quartz is a major grain-type in the sandstone. The sandgrains are mostly subangular to angular. Most grains show undulatory extinction, but non-undulating grains and grains rich in inclusions of Fe-Ti-minerals also occur.

Quartz cement (Figure 3.3.5) is recognized as both syntaxial and epitaxial cement in the rocks. It postdates chlorite cement as shown in Figure 3.3.6. The cement is distinguished from the clastic core by its lack of luminescence.

Feldspars often show various stages of dissolution and alteration. Alkalifeldspars are in general less altered during diagenesis than albites. Chemical analysis of altered feldspar grains is shown in Table 3.3.4, measurements I to XIII. Our chemical analysis shows that feldspars were depleted in SiO_2 , K_2O , Na_2O while Al_2O_3 was in general enriched during the alteration reactions. In addition FeO , MgO , TiO , and some MnO were added to the degraded feldspars, probably during later chloritization reactions.

Alkali feldspar cement is recognized in small amounts in samples from this core. Alkali feldspar cement most commonly occurs as syntaxial cement on alkali feldspar grains (Figure 3.3.4 and 3.3.5). It postdates chlorite cement (Figure 3.3.6).

Table 3.3.2 Quantitative composition (%) of four sandstones based on image analysis of thin sections in the SEM.

Depth	42.15m	48.80m	65.50m	74.85m
Quartz	31.5	25.8	17.9	27.8
Alkalifeldspars	15.1	15.1	15.5	12.8
Albite	6.5	16.7	11.0	10.0
Mica	0.3	tr	tr	tr
Heavy minerals	1.1	tr	1.2	1.3
Glauconite	3.2	3.0	7.2	3.0
TOTAL GRAINS	57.7	60.6	52.8	54.9
Calcite	-	21.5	-	-
Siderite	-	9.8	tr	-
Chlorite	3.7	3.0	3.9	4.8
TOTAL DAGENETIC	3.7	34.3	3.9	4.8
POROSITY	38.9	5.0	39.6	38.9

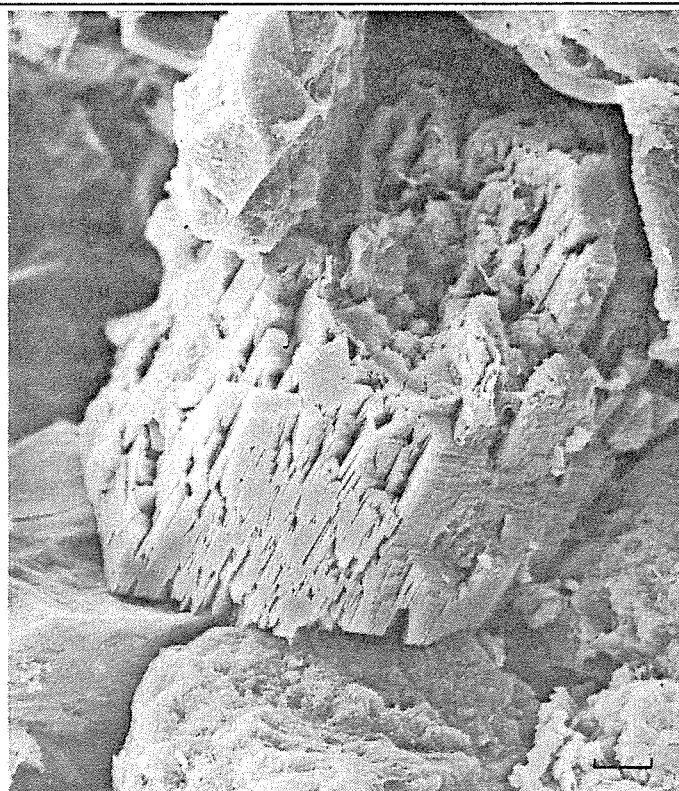


Figure 3.3.4 SEM image of authigenic alkali-feldspar cement on chloritized feldspar grain. Sample 28.25 m. Scale bar is 10 microns.

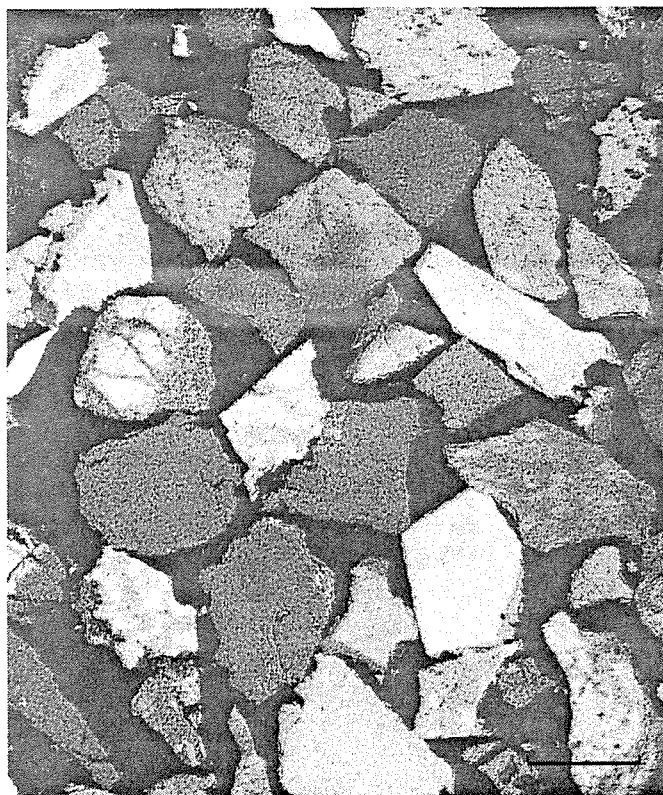


Figure 3.3.5 Combined backscatter and cathodoluminescence image of a feldspar and quartz cemented sandstone. Black is porosity, darkest grey is quartz grains, lightest grey is alkali-feldspars and albite. Notice the corrosion of the alkali-feldspar cement (dark grey coating on alkali-feldspar grains). Sample 42.15 m. Bar is 100 μm .

Biotites often show expansion due to recrystallization along cleavage planes, fringing rims and growth of illitic minerals perpendicular to the cleavage. Pyrite and siderite are sometimes recognized along cleavage planes. Electron microprobe analysis of altered biotites is shown in Table 3.3.3, measurements XIV and XV. The analysis shows that the alteration caused a depletion of SiO_2 , FeO , MgO and K_2O , while Al_2O_3 and possibly also TiO_2 are enriched.

Chlorite cement is often recognized in the sandstone, but it contributes with less than 5 % of the rock volume (Table 3.3.2). It occurs as pore lining cement on clastic grains and glaucony and as replacements of partially altered feldspars. The cement clearly predates quartz and feldspar cements (Figure 3.3.6).

Table 3.3.3 Electron microprobe analysis (wt %) from altered terrigenous grains. Measurements I-XIII are from altered feldspars, while XIV and XV are from altered biotites. The analytical results are overprinted by later chloritization.

Depth (m)	74.85										65.90		48.80		65.90		48.80
Measurements	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV		
SiO ₂	66.82	17.08	59.03	66.67	49.78	43.29	75.31	53.88	48.67	51.22	45.12	38.92	47.73	35.61	29.84		
Al ₂ O ₃	19.61	8.30	10.74	4.71	12.31	24.91	8.47	14.41	21.50	10.18	20.45	19.94	18.53	24.13	22.05		
FeO	.00	16.58	6.65	.32	4.39	1.46	.09	7.75	2.00	9.20	8.10	9.17	8.06	10.70	11.12		
MgO	.07	2.38	1.61	.14	2.33	.58	.01	1.39	.57	1.81	2.02	2.46	2.61	1.49	3.32		
MnO	.01	-	.10	-	.04	.02	.01	.10	.08	.07	.04	.01	.10	-	.06		
TiO	.01	.04	.11	.01	.31	.05	.01	.17	.08	.13	.07	8.08	.11	.19	.56		
Na ₂ O	11.55	.01	1.14	.04	.63	6.06	.07	.64	.07	.09	-	.61	.24	.02	.23		
K ₂ O	.19	.06	1.47	1.10	4.13	5.31	.66	2.64	2.05	1.42	6.36	5.51	7.99	.43	2.45		
CaO	.20	.06	.11	.02	.15	.69	.02	.19	.25	.14	.11	.46	.33	.27	5.4		
Tot	98.46	44.51	80.96	73.01	74.07	82.37	84.65	81.71	75.20	74.26	82.27	85.16	85.70	72.84	75.09		

Chemical analysis (Table 3.3.4) show that the chlorites are iron rich with a high content of calcium, sodium and potassium indicating a chlorite-dominated chlorite-illite-smectite mixed layer mineral. Such mixed layer minerals are indicated from X-ray diffraction (XRD) analyses of adjacent clayey siltstones.

Table 3.3.4 Electron microprobe analyses (wt %) of chlorite cement.

SiO ₂	29.36	28.61	28.06	30.52	42.37
Al ₂ O ₃	18.59	19.96	14.48	12.39	19.35
FeO	30.71	30.27	27.15	28.97	21.49
MgO	3.56	3.85	5.65	2.95	2.84
MnO	.11	.17	.02	.03	.12
TiO	.41	.05	.11	.11	.20
K ₂ O	1.09	.65	2.31	.92	2.65
CaO	.12	.07	.42	.88	.59
Na ₂ O	.23	.23	.04	.14	-

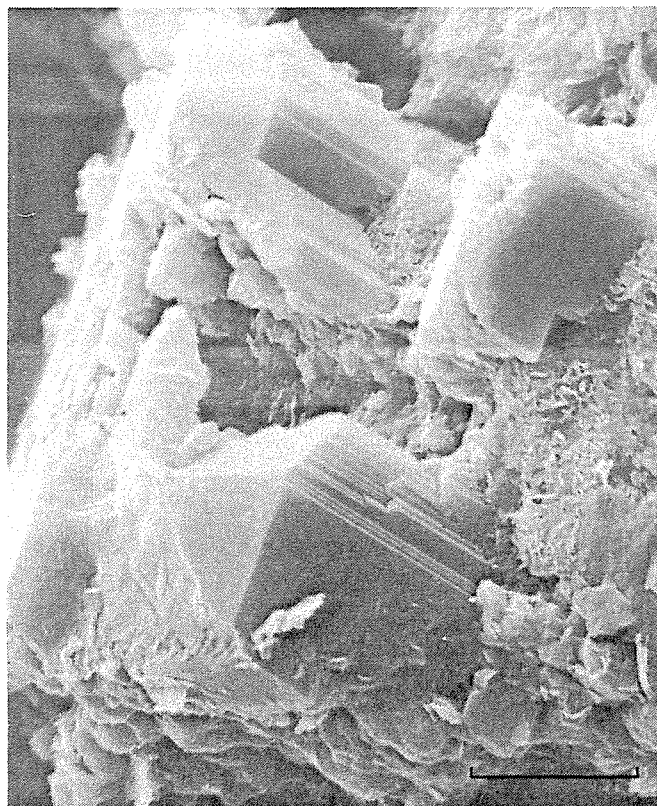


Figure 3.3.6 SEM image of epitaxial quartz cement growth on chloritized feldspar grain. Sample 73.35 m. Bar is 0.01 mm.

Carbonates

Carbonates occurs only as calcite and siderite cement.

Calcite cement occurs in association with shell beds. The cement contributes with 21.5 % of the rock volume in beds at 48.30 m (Table 3.3.2). The cement occurs as sparry cement with crystals upto 200 μm . It commonly contains inclusions that locally may give the cement a dirty appearance. Other characteristic features of the cement are that it often shows undulatory extinction and very strong corrosion of grains and older cements.

Chemical analysis shows that in addition to CaO , the calcite cement contains between 3 and 4 % FeO , 0.5 to 3 % MgO and about 0.5 % MnO .

Siderite cement occur in low amounts in the sandstones, but locally it may contribute with up to 10 % of the rocks (Table 3.3.2, Figure 3.3.7).



Figure 3.3.7 Combined cathodoluminescence and back scatter image showing siderite (white) occurring as inclusions in calcite (light grey). Clastic grains (various shades of white to dark grey) show syntaxial quartz and feldspar cement predating calcite cement. Sample 48.80 m. Bar is 0.1 mm.

Both thin section and SEM images show that the siderite consists of up to 100 μm crystal aggregates. The chemical analyses (Table 3.3.5) also show that the FeO content of the siderites varies between 40 and 49 %, MgO between about 2 and 4 %, CaO between about 5 and 11 % and MnO varies between 0.5 and 1.2 %. Corrosion of clastic grains, but never of quartz and alkali feldspar cement, is commonly observed and indicates an early diagenetic formation of the siderite cement.

Pyrite cement is recognized in trace amounts in most thin sections. It occurs as aggregates of crystals between grains and as inclusions in glaucony grains. SEM studies show presence of some pyrite framboids. Some burrows are filled by pyrite.

Late-diagenetic secondary porosity is common in the sandstones. The strongest evidences are common dissolution of alkali feldspar and quartz cement.

Table 3.3.5 Electron microprobe analysis of siderite (wt%). Measurement I-III and IV-V are profiles from core to rim of two zoned siderites. Sample 48.80 m.

	I	II	III	IV	V
FeO	44.07	43.43	48.54	39.87	41.38
MgO	4.26	3.41	1.93	1.63	2.58
CaO	6.38	7.28	5.44	6.44	10.92
MnO	1.12	.49	.84	1.22	.64

Discussion of diagenetic processes

The rocks were deposited in regressive, marginal marine environments. The oldest cements in the sandstones are pyrite and calcian siderite. Both cements occur as scattered intergrain cement, particularly in burrows. Pyrite was probably formed by bacterial reduction of sulphate to sulphide in a marine porewater, at or close to the sea floor.

The calcium content in the siderites points toward a calcium-rich porewater. Matsumoto and Iijima (1981) indicated that calcian siderites formed from marine/brackish type of porewater or from siderite replacements of calcium carbonate. The investigated siderites show no evidences of replacement of calcium carbonates and therefore may have precipitated from a marine/brackish porewater at shallow burial. Iron necessary for the formation of pyrite and siderite may have been supplied from ironoxides/hydroxides adsorbed on grains or from alteration of iron bearing minerals.

Compaction is indicated by reorientation of grains, breaking and bending of elongated grains and squeezing of some glauconies. The processes reduced some of the porosity of the sandstones. The compaction most likely took place during moderate burial before major cementation commenced.

Feldspar and biotite grains show alteration and partial dissolution. Chemical analysis of altered parts of grains shows that feldspar grains were depleted in potassium, sodium, and silica, while aluminium were enriched relative to fresh grains. Biotites were depleted in silica, magnesium and potassium, and enriched in aluminium and iron. Alteration of these mineral grains shows that the porewater was undersaturated with

respect to these minerals. Such porewater may be supplied as meteoric water penetrating down from nearby land areas.

Ironrich chlorite occurs as pore lining cement on grains and as intragrain cement in feldspar grains. The cement therefore precipitated after alteration/dissolution of clastic grains. The needed elements as iron, aluminium, magnesium and silica probably were sourced from alteration of feldspar with abundant inclusions containing these elements and from biotite grains.

Alkalifeldspar cement grew on fresh and chloritized feldspar grains. The cement therefore grew after chlorite cementation. The ions liberated from alteration/dissolution of feldspars and biotites were probably the major sources for the feldspar cement. The ions may have been 'stored' in the porewater untill the burial temperature was high enough for feldspar to crystallize.

Quartz cement grew both as syntaxial cement and epitaxial cement on chloritized feldspar grains. The age relationship relative to feldspar cement is not well documented. It is, however, likely that excess silica from alteration/dissolution of the unstable silicate grains was precipitated as quartz cement. Additional silica may have been supplied from percolating meteoric water. Growth of feldspar cements requires high silica activities. It is therefore likely that feldspar cementation predates quartz cementation.

Sparry Fe-calcite cement shows embedded corroded clastic grains as well as corroded older cement generations, indicating that it is a late diagenetic cement. It is characterized by undulatory extinction, abundant inclusions and strong corrosion on older grains and cements. It also occurs in proximity to shellrich beds. The cement was probably sourced from dissolution of bivalve shells (consisting of aragonite and/or Mg-calcite) causing a strong super-saturation and consequently rapid growth of calcite. It is likely that such cement formed during shallow burial. Saigal and Bjørlykke (1987) indicated calcite cementation from dissolution of shell beds to take place at temperatures between 15 and 40°C in the Haltenbanken and North Sea areas.

The last diagenetic phase recognized is corrosion on both quartz and feldspar cement. It is unlikely that the late diagenetic sparry calcite

cement should cause the dissolution of the cements as the corrosion occurs in all parts of the core. The corrosion may be caused by introduction of fresh water after the Paleogene uplift and later erosion, possibly during Quaternary glaciations.

X-ray diffraction

Three whole rock samples and their $<4 \mu\text{m}$ fractions are analysed by use of XRD to reveal the mineralogical composition of the finest grained layers in this core (Figures 3.3.9 and 3.3.10, Tables 3.3.6 and 3.3.7).

The diffraction profiles of the whole rock samples show a dominance of detrital components as quartz, albite and alkalifeldspar in order of decreasing abundance. The clay minerals are not very prominent in the whole rock diffraction profiles. The reflection at about $7 \text{ \AA}$, i.e. kaolinite and chlorite, is the most intense in all the diagrams. A reflection at $10 \text{ \AA}$ (illite) is also seen in the whole rock diffraction profiles.

The diffraction profiles of the $<4 \mu\text{m}$ fractions are dominated by the clay mineral components, while quartz and feldspars are minor or trace constituents only. The most prominent reflection is that of chlorite and kaolinite at $7.2 \text{ \AA}$. The presence of both minerals are indicated by other characteristic basal reflections. In addition, there are reflections from illite and chlorite ($10 \text{ \AA}$ and $14.4 \text{ \AA}$), both with shoulders on their low angle sides.

The result of glycol saturation of the $<4 \mu\text{m}$ fractions is expansion of the broad accumulation from between $10\text{--}14 \text{ \AA}$ to poorly defined reflections at about $17 \text{ \AA}$ and above. Heating at 550°C for 2 hours does not add anything to the $10 \text{ \AA}$ reflection, the $14.4 \text{ \AA}$ reflection contracts to about $13.8 \text{ \AA}$ with a lower intensity than the original peak. The broad band of reflections from $10\text{--}14 \text{ \AA}$ remains. The $7 \text{ \AA}$ reflection of kaolinite, including the kaolinite layers of the chlorite structure, disappear.

The behaviour of the clay minerals upon these treatments indicate that kaolinite, chlorite, illite and smectite are present. In addition there are mixed layers of illite-chlorite (expandable chlorite ?) and possibly chlorite-smectite.

The presence of smectite and randomly interlayered clay minerals indicate an immature diagenesis and a maximum burial temperature less than 70°C .

SEA FLOOR

DEPOSITION AND
EARLY CEMENTATION

METEORIC DIAGENESIS

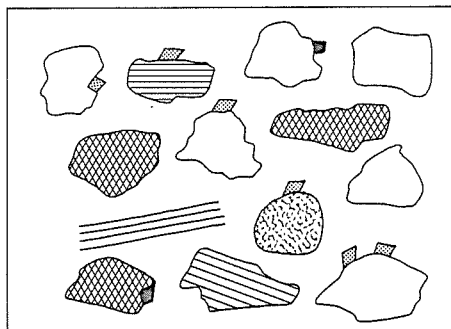
COMPACTION AND
FELDSPAR ALTERATION/
DISSOLUTION

CHLORITE, QUARTZ
AND K-FELDSPAR
CEMENTATION

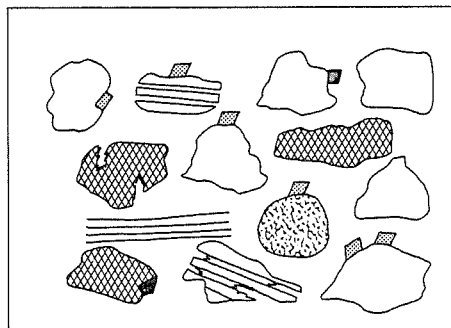
SPARRY CALCITE CEMENTATION
AND CORROSION

<40°C

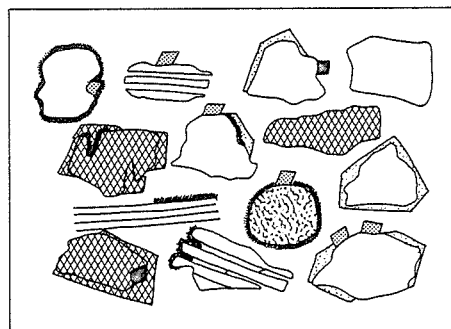
A



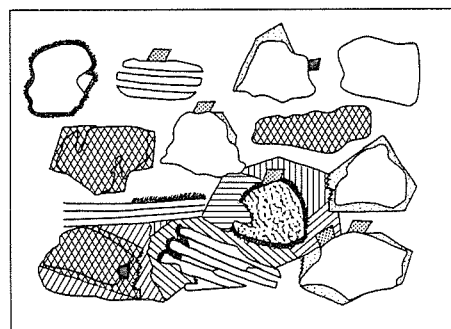
B



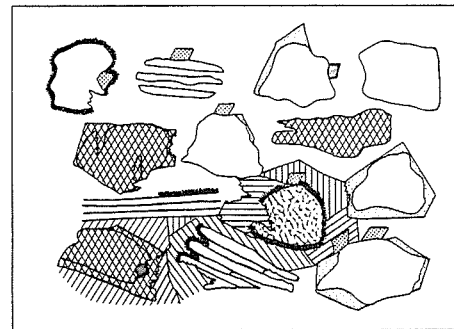
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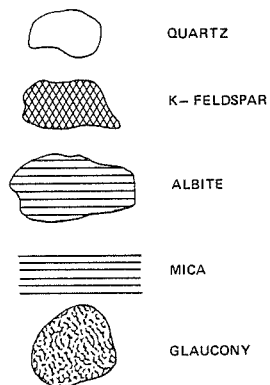


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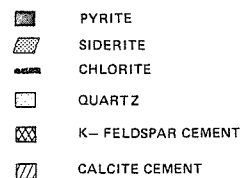


TERTIARY UPLIFT AND
EROSION FRESH WATER
CORROSION, PROBABLY
IN QUATERNARY TIME

GRAINS



CEMENT



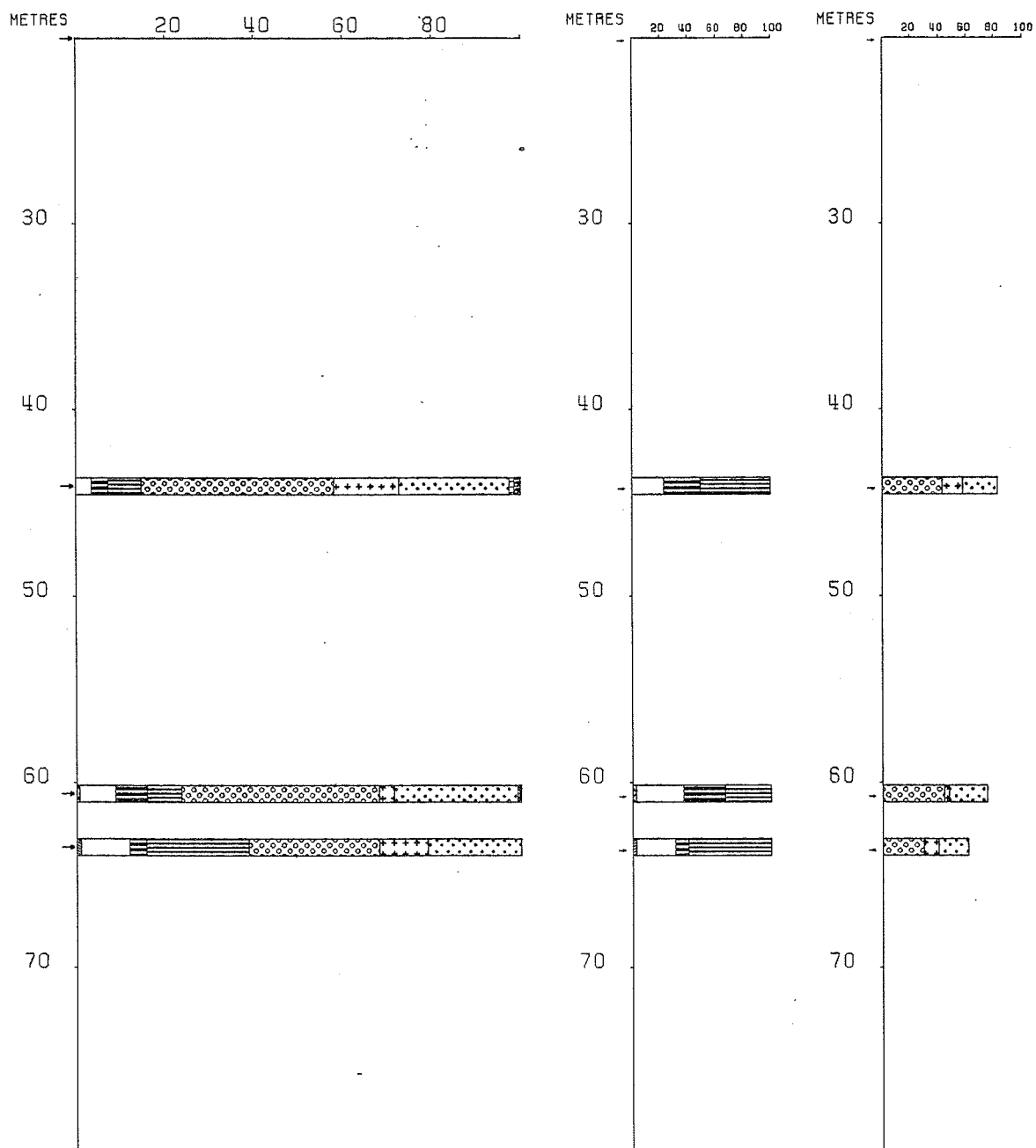


Figure 3.3.9 Whole rock mineralogy from core 7230/05-U-09 based on XRD analysis. Legend in Appendix A.3.

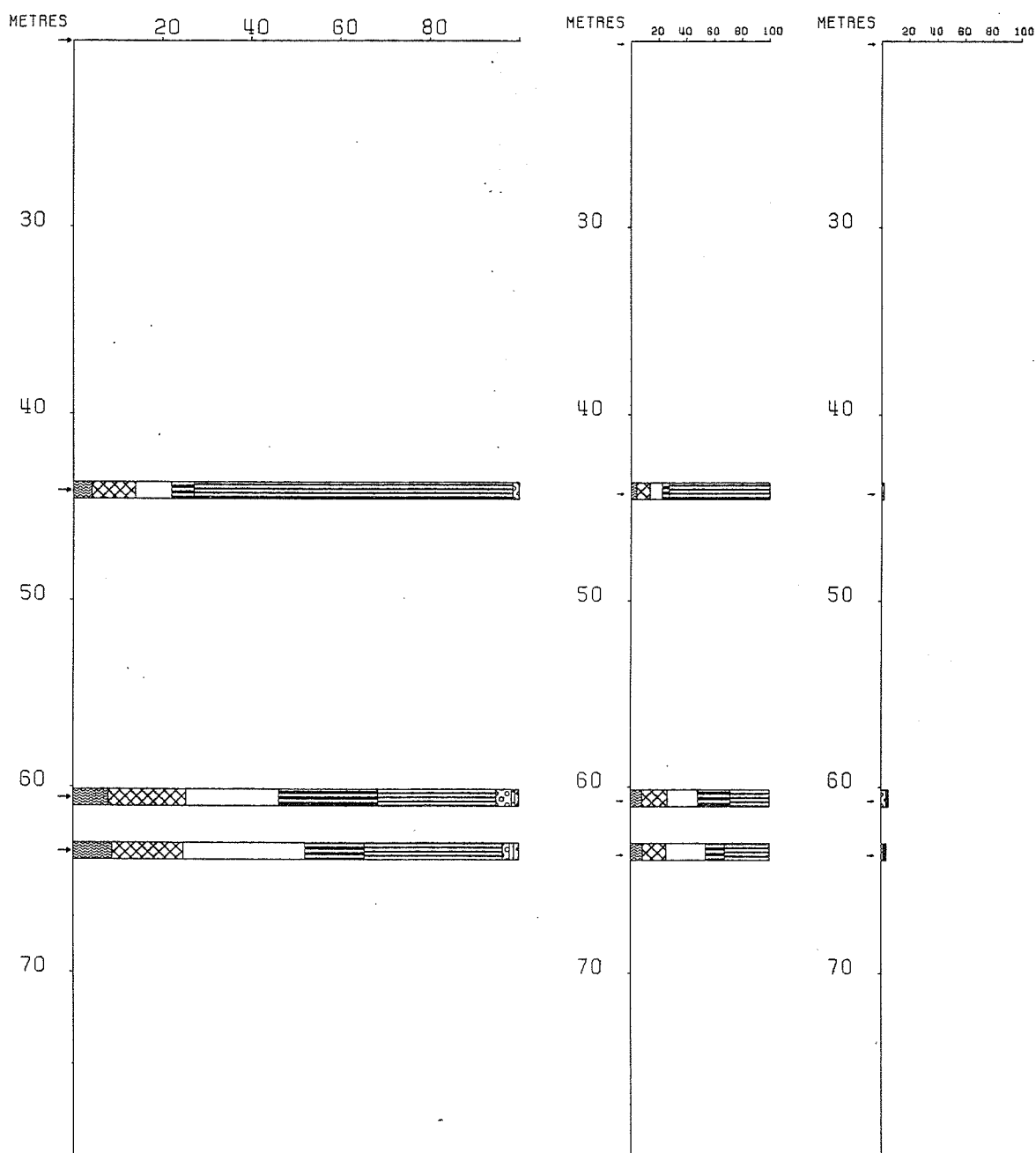


Figure 3.3.10 Clay mineralogy (<4 micron) from core 7230/05-U-09 based on XRD analysis. Legend in Appendix A.3.

Table 3.3.6 Tabulated values from XRD analysis of whole rock samples of core 7230/05-U-09. The values represent semiquantitative wt%. See Appendix A.3 for details.

XRD-values core 7230/05-U-9

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %
44.10	D-1043	0.0	3.4	3.9	7.5	43.4	14.6	24.8	0.0	1.1	0.0	0.0	1.4
60.57	D-1079	0.0	8.1	7.1	7.8	44.4	3.2	27.8	0.0	0.5	0.0	0.0	0.3
63.50	D-1087	1.0	10.9	3.8	23.0	29.5	10.9	21.0	0.0	0.0	0.0	0.0	0.0

Table 3.3.7 Tabulated values from XRD analysis of clay fraction (<4 micron) samples of core 7230/05-U-09. The values represent semiquantitative wt%. See Appendix A.3 for details.

XRD-values core 7230/05-U-09

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %	Expand 14-17A
44.10	D-1043	4.1	8.1	5.1	71.3	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Partly
60.57	D-1079	7.9	20.7	22.2	26.5	3.4	0.8	0.8	0.0	0.0	0.0	0.0	0.0	Partly
63.50	D-1087	8.7	27.2	13.4	30.9	1.7	0.9	1.1	0.0	0.0	0.0	0.0	0.0	Partly

Petrophysics

Natural γ -radiation

The natural γ -radiation from Th and U shows no variation over the cored interval, while small variations observed in the potassium activity probably reflects the grain size variation (Figure 3.3.11).

Sound velocity

Only a few measurements of the horizontal sound velocity have been undertaken from the upper half of the core, due to the low degree of consolidation. The lower half, however, has been measured more densely (Figure 3.3.11, Table 3.3.8). The sound velocity is rather uniform and low throughout the core, i.e. about 2000 m/s. This reflects the poorly consolidated nature of the sand. One measurement of about 4200 m/s at the top of the core is due to carbonate cementation. From the correlation of the core and the seismic data, interval sound velocities were calculated for each seismic unit (see Table 3.3.1). The values vary from 1850 to 2150 m/s, but are all very low. The general consistency between these values and the core measurements, seems to approve the reliability of both.

Porosity and permeability values

From this core 22 samples were sent to GECO for porosity and permeability measurements (Table 3.3.9). Two of the samples consisted of so poorly consolidated sandstones that no measurements were possible.

These results show that the rocks have porosity values in general between 35.4 and 40.3 %, which are very high values. The horizontal permeability ranges in values between 503 and 1800 mD, while the vertical permeability of 6 samples ranges between 277 and 954 mD. The horizontal and vertical permeability values both show good reservoir values. The sample at 48.80 m from a calcite cemented bed was the only sample with very low porosity and permeability.

Reservoir potential evaluation

Porosity and permeability values of the sandstone are high, suggesting that the rocks have a good potential as reservoir rock. The diagenetic study shows no troublesome diagenetic minerals as illite and kaolinite growing into the pores. The poor lithification may cause trouble as sand can be produced.

Three fairly homogeneous sandstone bodies are separated by impermeable clayey siltstones. Porosity and permeability measurements from a calcite-cemented sandstone bed show low porosity and permeability values. In addition a few cms thick clayey siltstone separates some of the sandstone beds and may cause a further stratification of the potential reservoir sandstone. The exact thickness of the sandstone dominated part of the core is uncertain, but is about 10 m in Unit B. The thickness may therefore be a major restriction of the rocks as a reservoir, but on the other hand these sands may be laterally persistent because continuous sand bodies are often developed in a coastal environment (see Chapter 3.3.6).

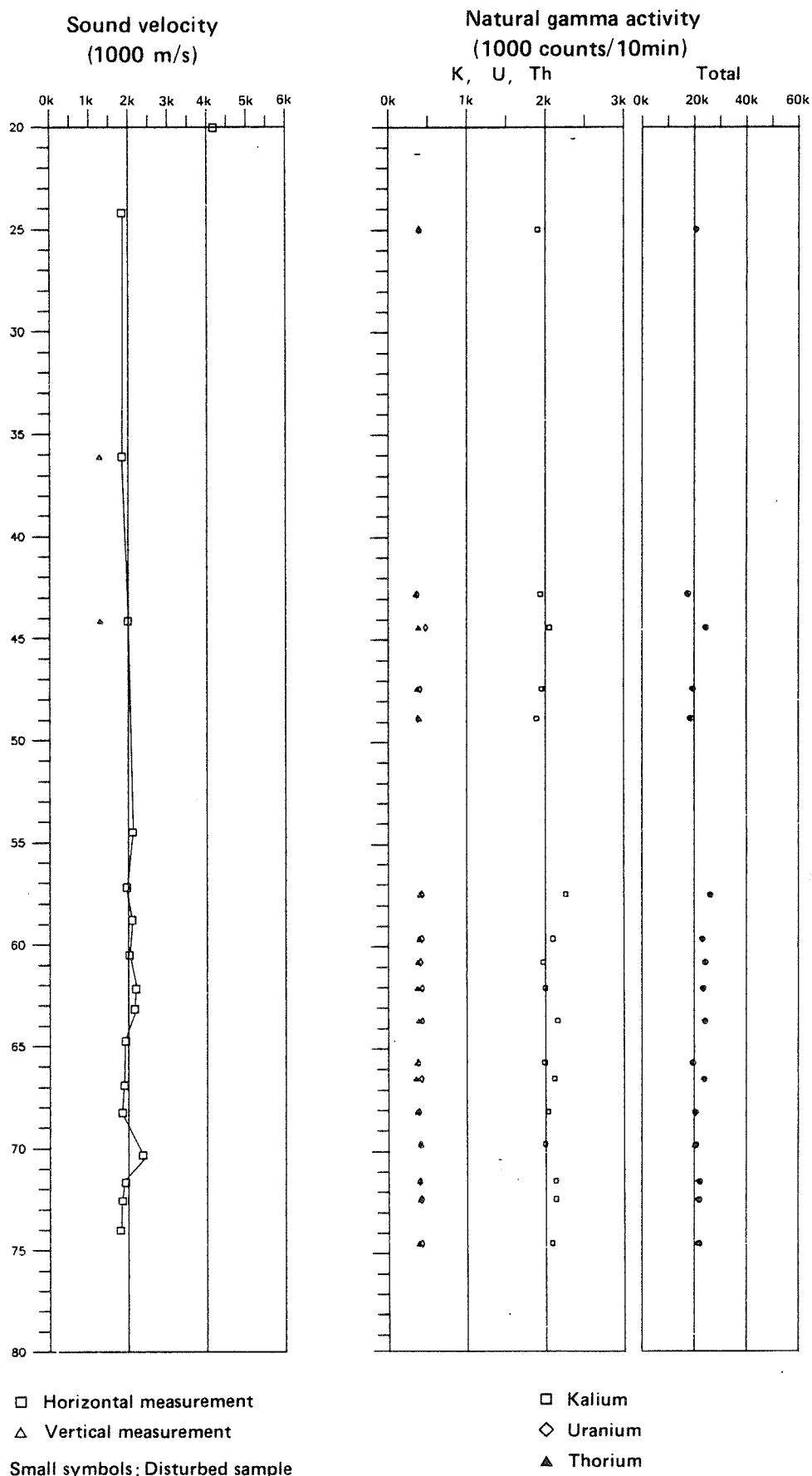


Figure 3.3.11 Natural γ -radiation (counts per 10 minutes) and sound velocity in core 7230/05-U-09.

Table 3.3.8 Sound velocity (m/s) in core 7230/05-U-09.

Sound velocities core 7230/05-U-09

Depth m	Horiz. velocity m/sec	Vert. velocity m/sec
20.05	4180	0
24.19	1848	0
36.10	1849	1266 *
44.15	2000	1294 *
54.50	2115	0
57.21	1964	0
58.79	2097	0
60.52	2031	0
62.19	2195	0
63.16	2163	0
64.77	1924	0
66.89	1900	0
68.26	1845	0
70.33	2362	0
71.67	1923	0
72.57	1848	0
74.02	1789	0

Table 3.3.9 Porosity and permeability measurements of the sandstones in core 7230/05-U-09.

DEPTH m	P E R M E A B I L I T Y (mD)				POROSITY	GRAIN
	HORIZONTAL		VERTICAL		He %	DENSITY
	KA	KEL	KA	KEL		
34.55	699	658	578	542	35.5	2.68
35.95	1440	1380	-	-	36.4	2.67
37.30	-	-	-	-	-	-
38.15	903	855	-	-	35.2	2.65
39.40	588	591	581	545	38.2	2.66
42.15	1430	1370	-	-	37.8	2.66
43.60	-	-	-	-	-	-
48.10	1480	1410	-	-	36.8	2.67
48.80	0.04	0.02	0.04	0.02	5.3	2.80
50.05	1800	1730	-	-	39.0	2.66
51.40	845	799	-	-	35.4	2.75
53.80	1220	1157	954	905	36.4	2.72
55.10	992	941	-	-	40.3	2.68
56.75	1350	1290	-	-	39.9	2.68
65.50	1080	1030	-	-	39.2	2.67
66.85	863	817	-	-	38.5	2.66
68.25	984	933	876	829	39.6	2.66
69.85	539	504	-	-	39.1	2.66
71.25	503	470	277	254	37.9	2.66
72.50	789	745	711	699	38.6	2.67
73.35	639	600	-	-	37.9	2.67
74.85	600	563	-	-	38.1	2.66

3.3.4 Paleontology

Macrofossils

Numerous specimens of the serpulid *Rotularia* sp. occur in the interval 50.60-49.35 m.

Palynology

The presence of dinoflagellate cysts *Epelidosphaeridia spinosa* and *Palaeohystrichophora infusoroides* throughout the core (Figures 3.3.12 and 3.3.13) restricts the dating to the latest Albian *S. dispar* Zone to early Middle Cenomanian *A. rhotomagense* Zone. The record of *Canningia torulosa* at 67.49 and 63.50 m supports a latest Albian *S. dispar* Zone to earliest Cenomanian *M. cantianum* Zone at these depths. Foucher (1979) found *Rhombodella paucispina* which occurs throughout the core exclusively in the Albian.

Scarce representatives of *Muderongia asymmetrica* in all examined samples up to 60.57 m is also an Albian evidence, although confusing, because Brideaux & McIntyre (1975) used the extinction of this species for defining the Early/Middle Albian boundary. Our own experience from Tromsøflaket and core 7231/04-U-01 supports the view of Brideaux & McIntyre (1975), but evidence from 7230/05-U-09 and future data may show that *M. asymmetrica* evolves into *M. pentaradiata*. We do not exclude the possibility that *M. asymmetrica* is reworked.

Samples at 51.60, 47.90 and 42.60 m contain low diversity, probably not fully marine palynological assemblages dominated by *Paralecaniella indentata*. *Fromea* cf. *amphora* with pronounced necks is also an important element in these samples. Some authors would have referred this species to the genus *Palaeostomotis*.

Both core 7324/07-U-01 and 7230/05-U-09 may straddle the Albian/Cenomanian boundary, but species of lower Cenomanian affinity in the upper part of 7324/07-U-01 (*Spongodinium canadense*, *Spiniferites porosus*) have not been recorded in 7230/05-U-09.

Microfauna

The core was nearly barren with respect to microfossils, except for some few specimens in the uppermost parts (Figure 3.3.14). Sample 25.73 m contained common *Gavelinella* ? sp., and rare *Lenticulina* spp., *Saracenaria* cf. *frankei* and *Marginulina jonesi*. Some few *Inoceramus* prisms, echinoderm debris and partly broken ostracods were also recorded. The latter may tentatively be referred to *Cythereis hirsuta*. Downhole only single occurrences of *Gavelinella* ? sp. (30.02 m and 63.50 m) and *Glomospirella* sp. were recorded. Minor amounts of *Inoceramus* prisms were recorded in intervals throughout, but might well be reworked.

Non of these sparse records are in conflict with the age conclusions based on palynomorphs.

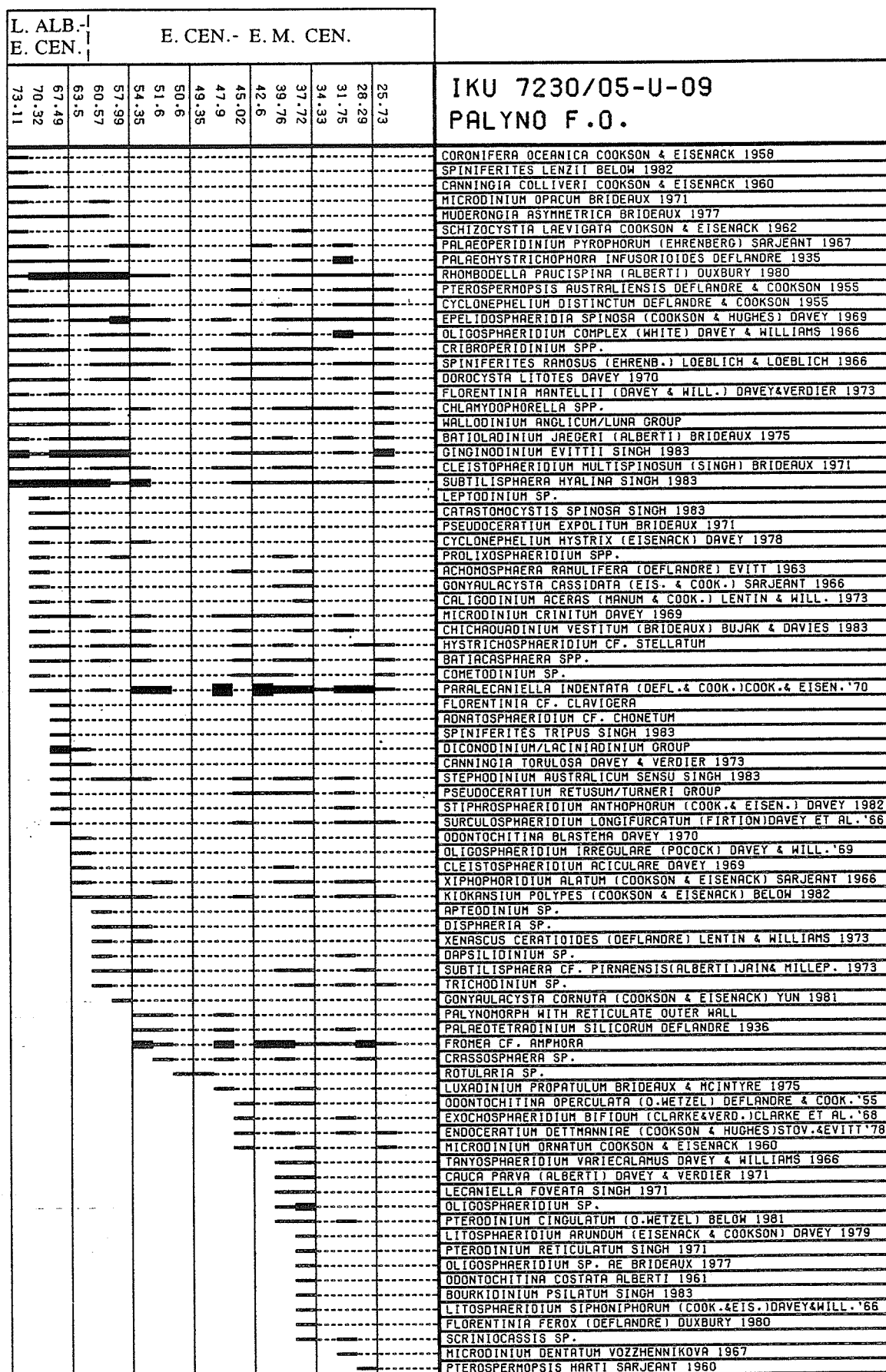


Figure 3.3.12 Palynological and serpulid range chart of core 7230/05-U-09.
(Sorted according to first occurrence).

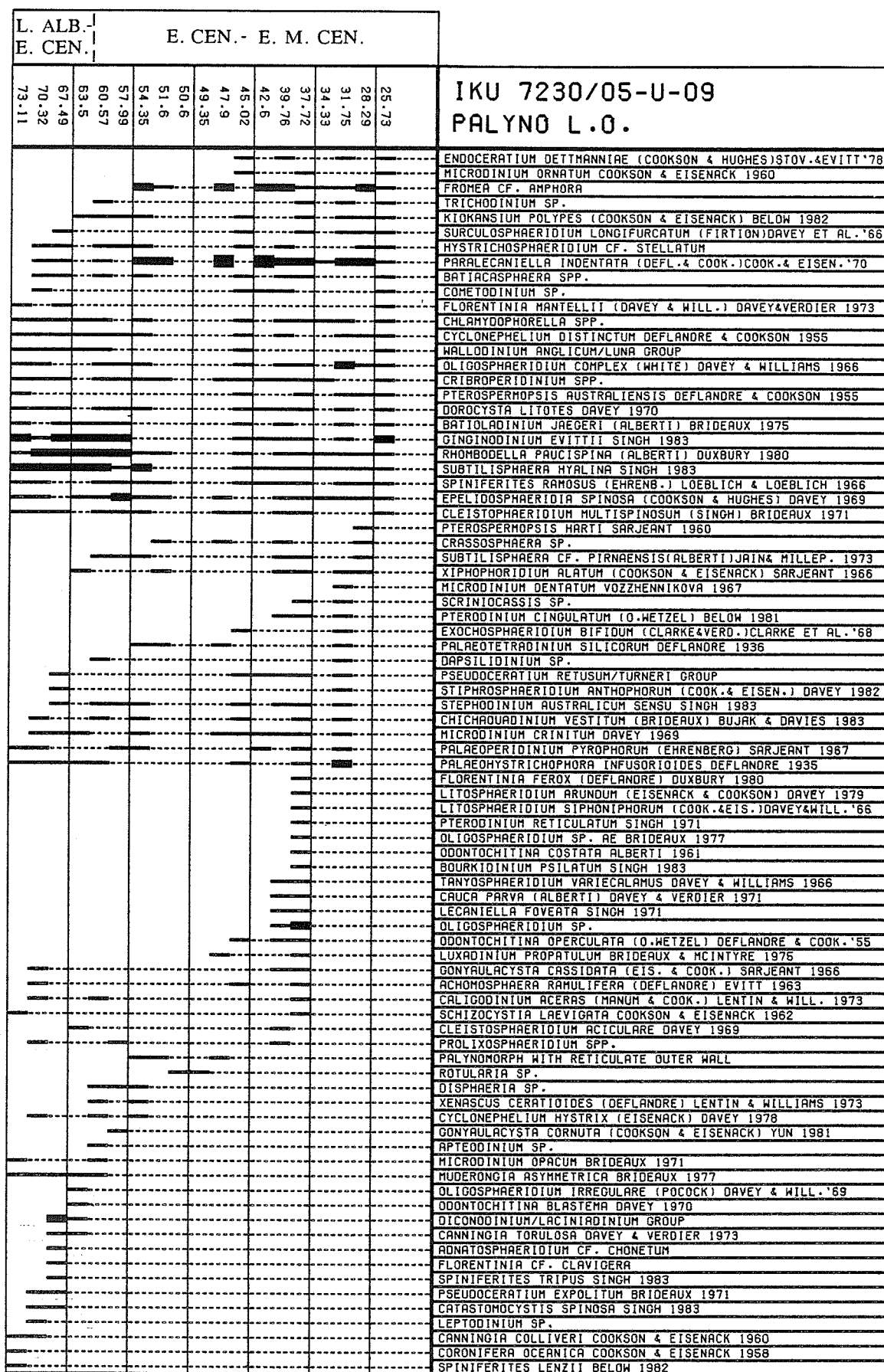


Figure 3.3.13 Palynological and serpulid range chart of core 7230/05-U-09.
(Sorted according to last occurrence).

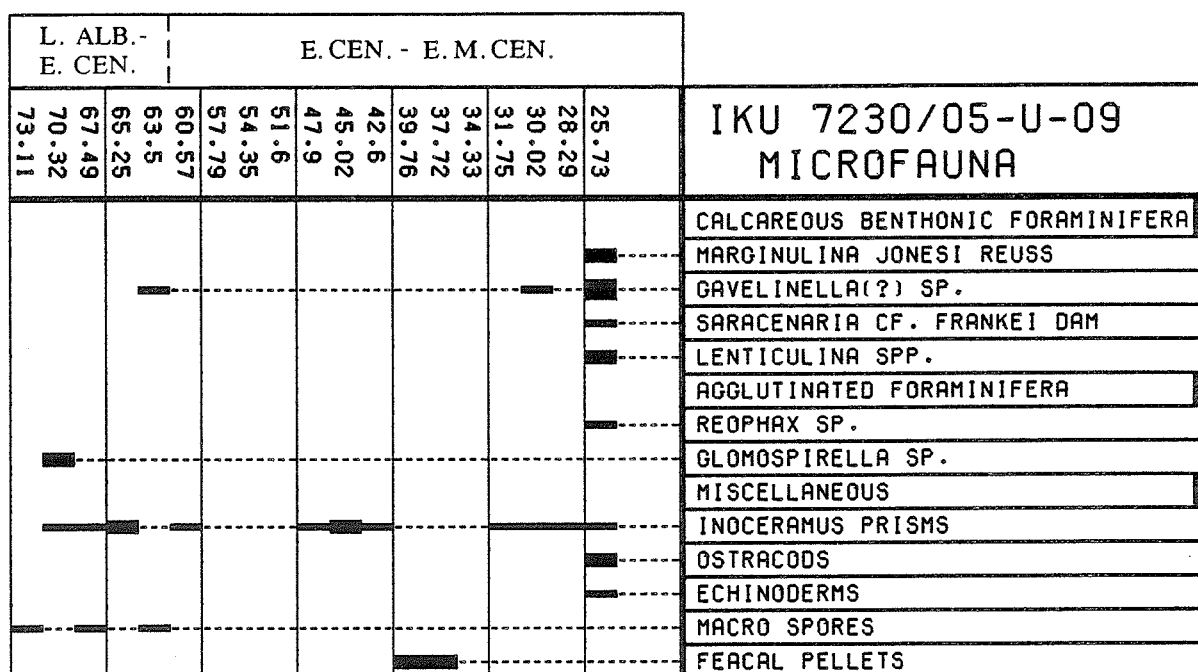


Figure 3.3.14 Foraminiferal range chart of core 7230/05-U-09.
 (Sorted according to first occurrence).

3.3.5 Organic geochemistry

The organic geochemical data figures and tables are presented in a separate volume of the report. Only summary figures will be presented in this section.

Seventeen canned core samples taken at ca. 3 m intervals were analysed for headspace and occluded gas. The total concentrations of both gas fractions are quite low (163 and 1318 μl gas/kg dry rock, respectively). Methane is the only compound recorded in the headspace gas and is also predominant hydrocarbon of the occluded gas, while the C_{2+} -compounds occur only in trace concentrations (max. 177 μl /kg dry rock, Figure 3.3.15). The resulting wetness is less than 13 %, but the values may be unreliable because of the low concentrations. The presence of significant amounts of migrated C_1 to C_6 -hydrocarbons can however be safely ruled out. Unsaturated compounds such as ethene, propene, and occasionally butene occur in the occluded gas together with, and in similar concentrations as, the alkanes. This may indicate that at least a part of the gas is of biogenic origin.

The 34 samples which were examined for organic richness contain variable but generally very low concentrations of organic matter due to the mainly coarse clastic lithology of this core. The total organic carbon (TOC) contents in the interval between ca. 24 to ca. 54 m depth are usually around 0.2-0.3 % of the rock weight. In the underlying section which contains interlayered sandstones and clayey siltstones, the TOC contents vary more strongly and locally reach values of up to 1.7 % (Figure 3.3.16).

Rock-Eval pyrolysis was performed on those samples which contain at least 0.5 wt% TOC. Extremely low hydrogen index values (max. 2-34 mg HC/g TOC) and medium to high oxygen index values (12-103 mg CO_2 /g TOC) persist throughout the core and suggest that the organic matter consists mainly of reworked or early oxidized material which is poor in hydrogen and devoid of any petroleum generation potential (Kerogen type IV). This is in accordance with the arenaceous lithology of the core. Low S_1 values suggest that migrated hydrocarbons are absent.

Because of the poor Rock-Eval S_2 peaks, the T_{max} values scatter considerably. The few reliable values range from 425 to 433°C and indicate that the organic material is thermally immature. Reliable vitrinite reflectance data were obtained from samples at 56.46, 57.22 and 70.79 m

depth, giving values of 0.37, 0.36 and 0.39 %R_o, respectively. These values agree with the T_{max} data and also with the thermal alteration index (TAI) values which range from 3.0 to 3.5.

Three samples with elevated organic content from the lower part of the core (57.22, 65.78, 70.79 m) were extracted in order to characterise the bitumen. Extract (EOM) yields of less than 400 ppm of rock weight and less than 40 mg/g TOC are consistent with the Rock-Eval data (Figure 3.3.17). The gravimetric determination of the bulk composition is little reliable at the low level fraction weights encountered, but the data at 65.80 and 70.79 m indicate that the bitumens contain less than 30 wt% hydrocarbons, the largest part of which are aromatics. Such a composition is often found in immature extracts.

The gas chromatograms of the saturated hydrocarbon fractions are fairly similar. The distributions of n-alkanes are characterised by a high proportion of compounds in the C₂₅ to C₃₁ range and a strong predominance of compounds with odd carbon number, which is characteristic of immature bitumens containing a contribution of higher plant material. Somewhat elevated concentrations of the C₁₇ to C₁₉ n-alkanes in the chromatogram at 65.78 m coincide with a relatively high Rock-Eval S1 value and may therefore possibly indicate a slight local enrichment of hydrocarbons in that sandstone. The isoprenoids pristane and phytane occur in low concentrations relative to the respective n-alkanes (n-C₁₇ and n-C₁₈; Figure 3.3.18) which is somewhat unusual for immature bitumens. However, the gas chromatographic ratios should be treated with caution because of the low concentrations.

The steranes (m/z 217) and terpanes (m/z 191) show typical immature compositions. The sterane mass fragmentograms are dominated by the peaks of the regular steranes, among which the C₂₇- and C₂₉-14α(H),17α(H) 20R steranes (j,t) are most prominent. The triterpanes show strong peaks of an unidentified compound eluting close to the trishomohopanes (*), of 17β(H)-homomoretane (I) and 17α(H)-norhopane. A relatively prominent peak tentatively identified as C₂₈-bisanthracene (Z) occurs in both samples. The very pronounced predominance of the biologically preferred over the thermally stable isomers of hopane and of the extended C₃₂₊-hopanes (E/F, G/H, J₁/J₂) indicates that the bitumens are quite immature.

In conclusion, core 7230/05-U-09 can be characterised as containing very

low concentrations of thermally immature and hydrogen-poor organic matter, which has no potential for generation of hydrocarbons. The low concentrations of bitumen found in this core are thermally immature and probably derived from continental organic material. The core does not contain any significant amounts of non-indigenous hydrocarbons, although redistribution of trace amounts of immature hydrocarbons may have occurred at a very local scale.

7230/05-U-09.

C1-C4 HYDROCARBONS C5+ HYDROCARBONS WETNESS (%)

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

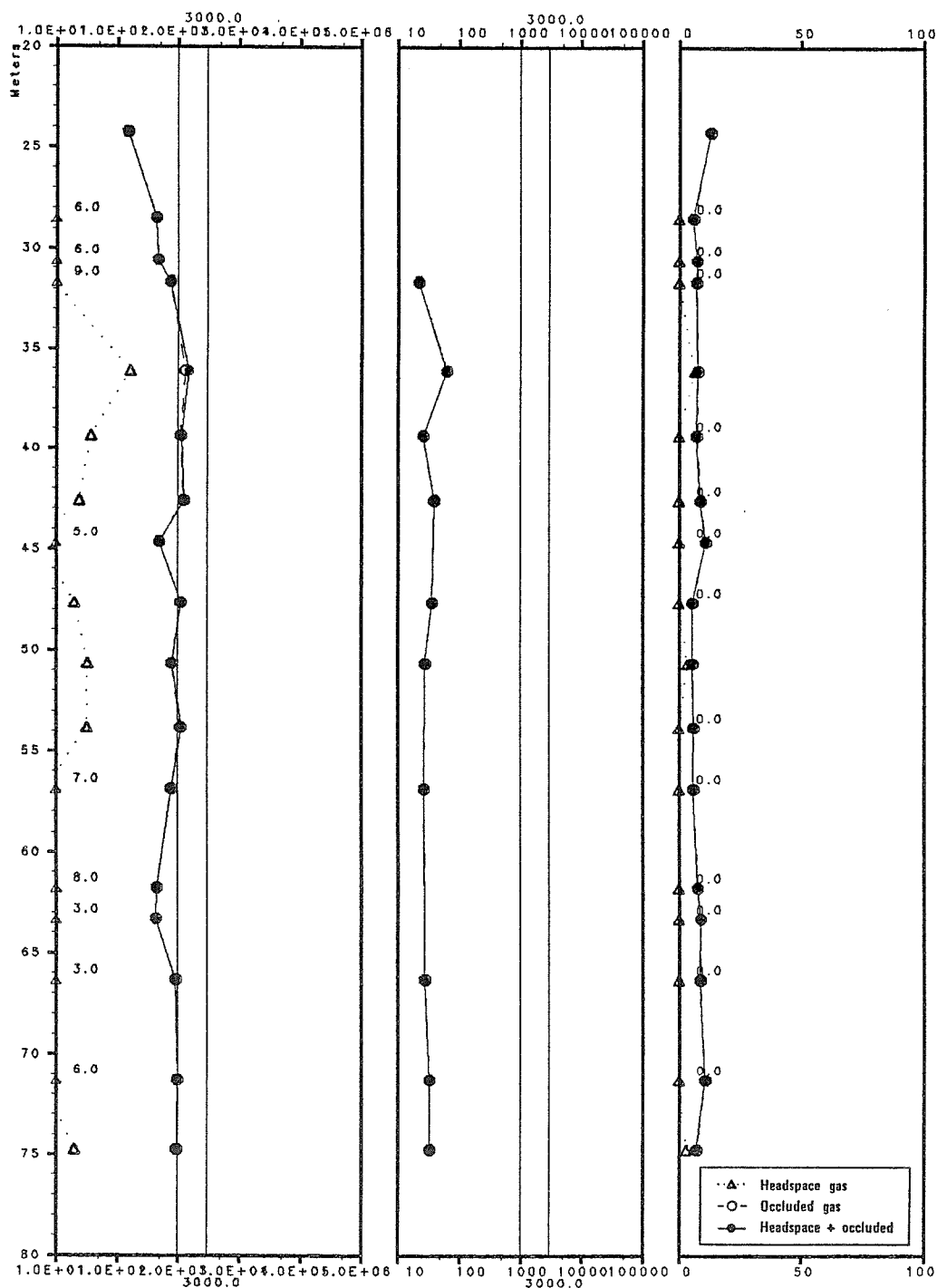


Figure 3.3.15 Yield and composition of headspace/occluded gas of core 7230/05-U-09.

7230/05-U-09

ROCK-EVAL PYROLYSIS DATA

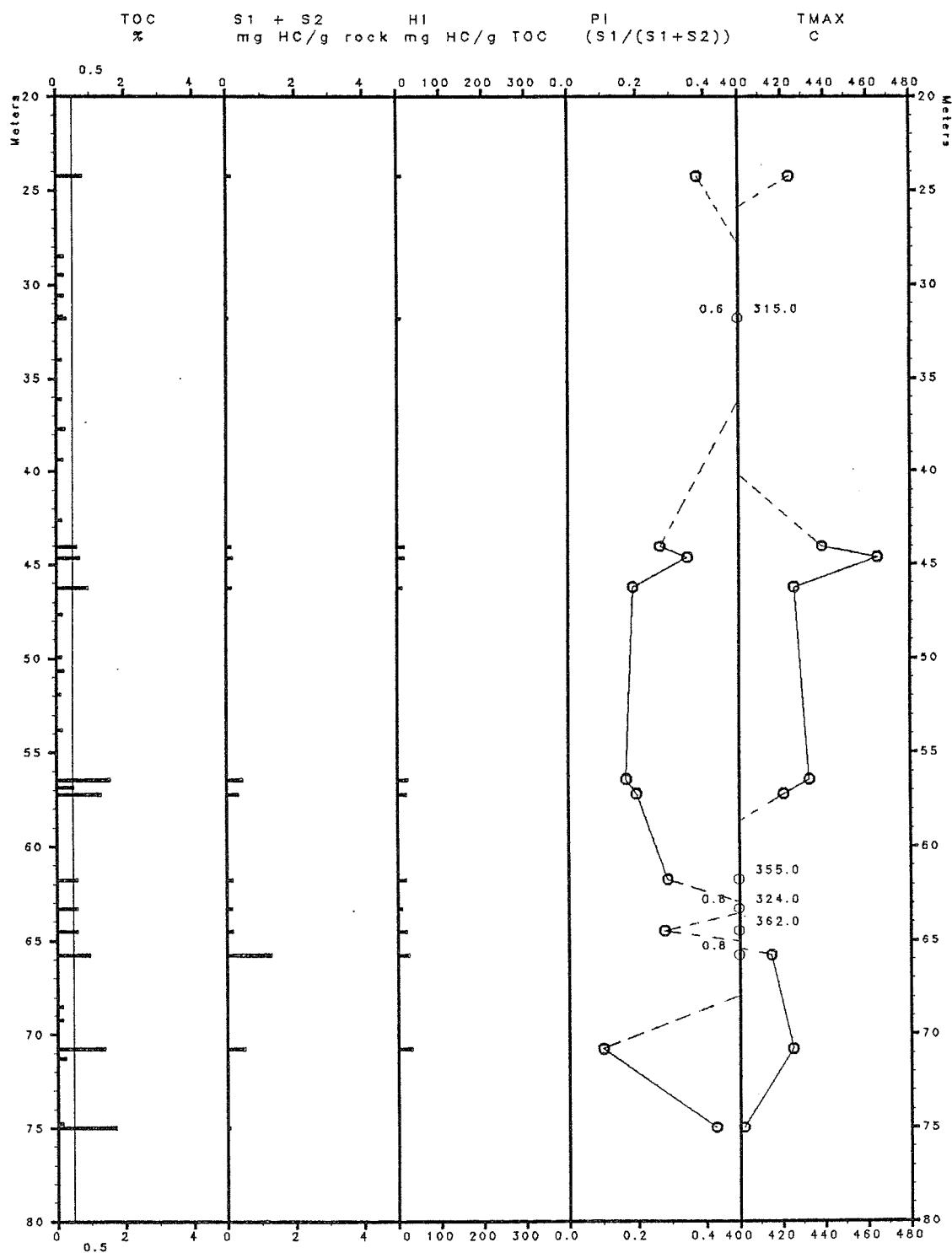


Figure 3.3.16 Total organic carbon content and Rock-Eval data of core 7230/05-U-09.

7230/05-U-09

EXTRACTABLE ORGANIC MATTER

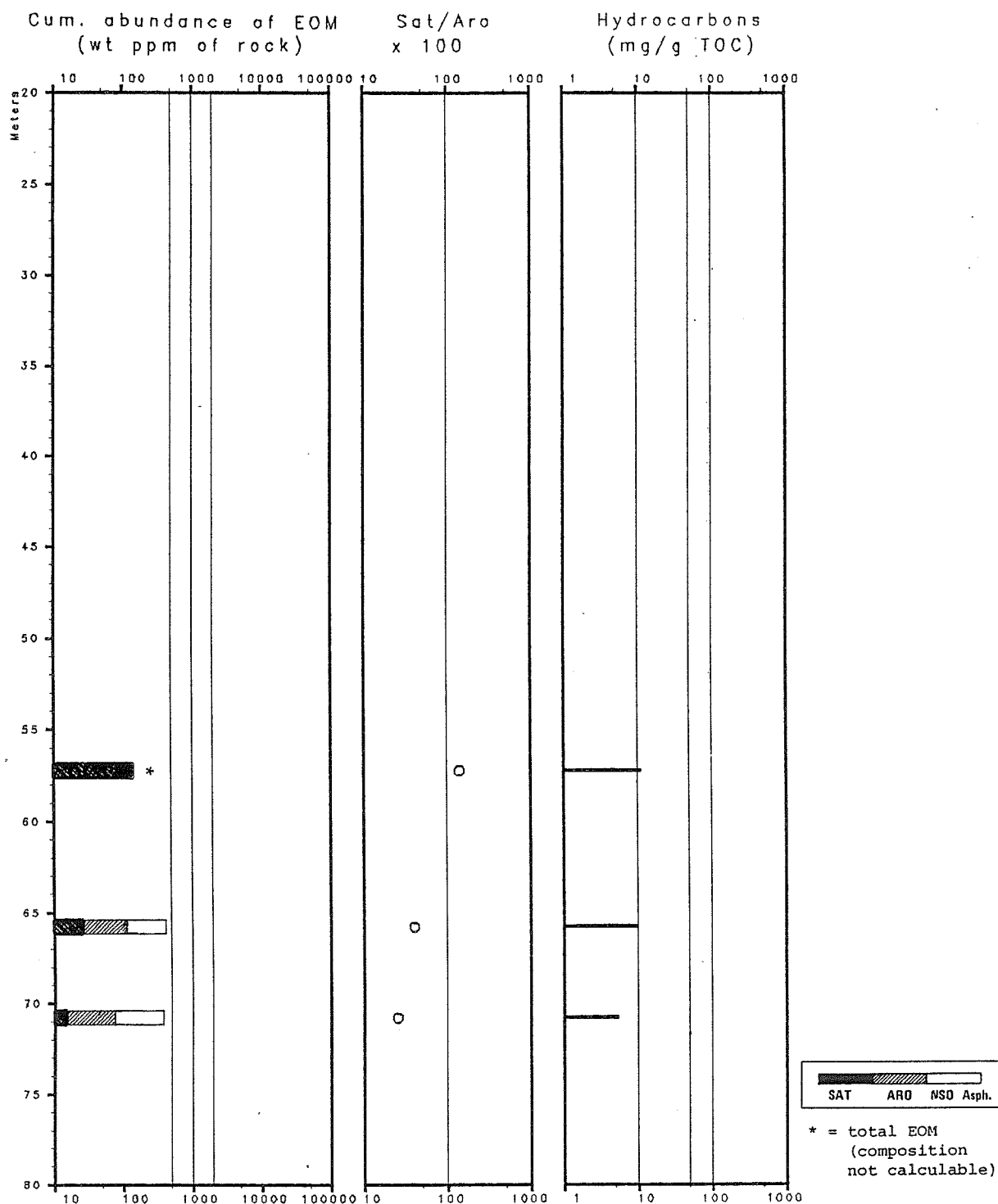


Figure 3.3.17 Extract data for core 7230/05-U-09.

7230/05-U-09

GAS CHROMATOGRAPHIC RATIOS

CPI 2

Pristane/Phytane

Pristane/n-C17

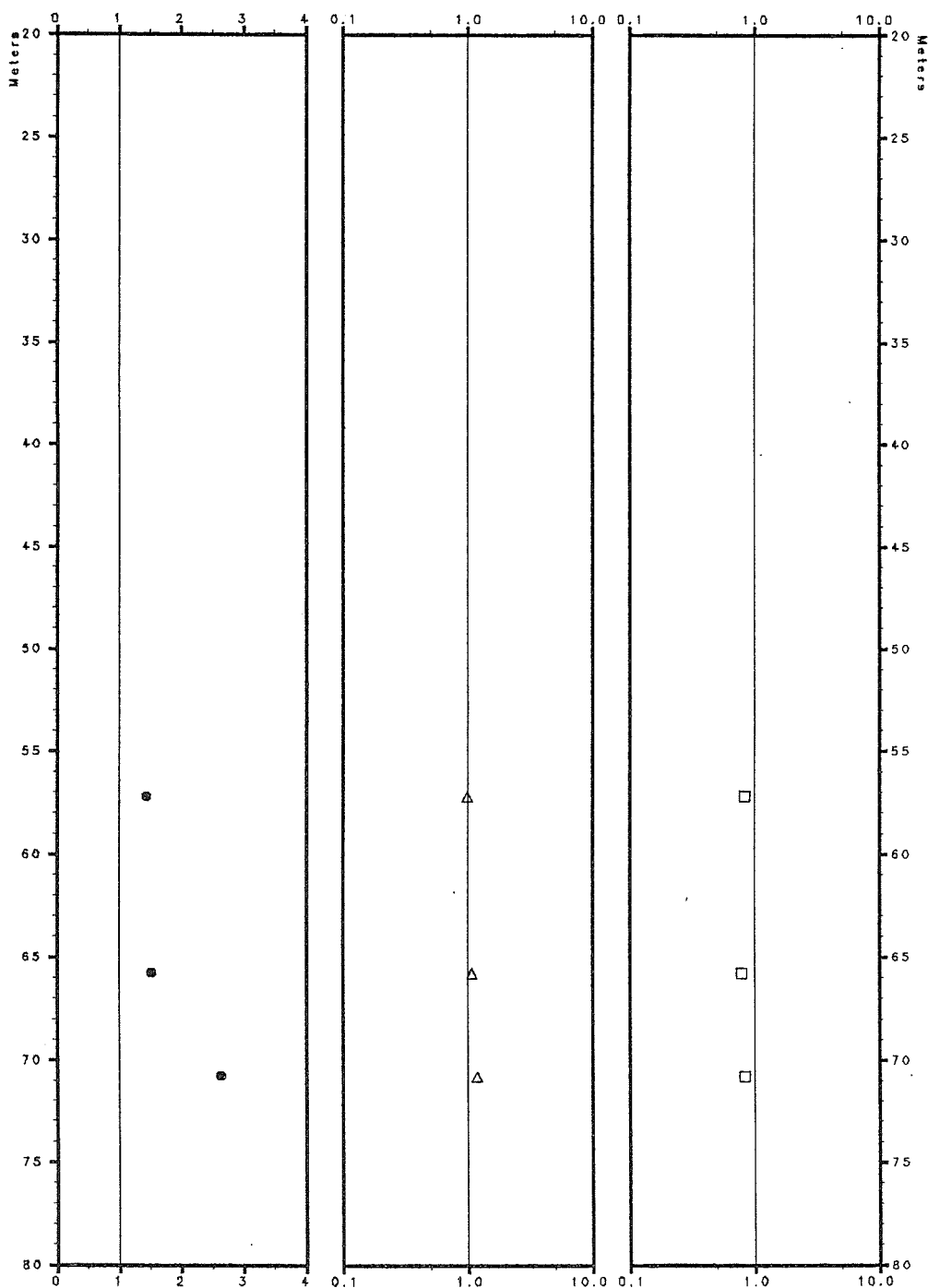


Figure 3.3.18 Compound ratios from gas chromatograms of saturated hydrocarbon fractions from core 7230/05-U-09.

3.3.6 Depositional environment

Marine palynomorphs occur throughout the core, although in varying abundance and diversity. Variation in energy level during deposition is reflected in both grain size distribution and sedimentary structures, as often found in marginal marine deposits. In conclusion the two lower units may represent progradational units, while minor fluctuations in a more restricted environment seem represented in the uppermost unit. These transitions were probably controlled by minor transgressions and regressions.

Unit A forms a coarsening upwards succession. Hummocky crossbeds and wave ripples occur in the lower part of the unit. This combination of structures points towards a lower shoreface depositional environment. These beds are overlain by trough cross bedded sands which turn to parallel laminated beds towards the top of the unit. The succession of structures indicates a regressive development from lower to upper shoreface. At top of the unit there is a thin conglomerate bed of mudclasts and siderite.

Unit B also forms a coarsening upwards sequence. The basal part of strongly bioturbated shaly development is interpreted to be the response of a transgression. Shallowing depositional environment is also suggested for this unit, demonstrated by a succession of laminated mudstones and siltstones at the base overlain by hummocky crossbeds, and followed by trough crossbeds and plane parallel laminated beds at the top of the unit. The hummocky beds also show wave ripples. While the lower part of the unit contains diversified open marine palynomorph assemblages, the upper part shows low diversity of this flora, indicating some restrictions. This upper part is interpreted to represent a regressive succession from shallow offshore through lower shoreface to upper shoreface depositional environment.

Unit C uppermost in the core is more complex and also more difficult to interpret due to poorly preserved core, where most sedimentary structures are disturbed. Missing and disturbed intervals probably reflect the coarser grainsizes and beds with sparse cementation. The diversity of palynomorphs is low in the lower part, and increases somewhat upwards, however individual beds show high abundance. This variation may reflect variation in the marine influence on sedimentation, possibly by lagoonal

sedimentation with varying change in salinity due to fresh water influx. The lower and upper part of this Unit C may thus represent lagoonal deposits, while higher energy deposits, possibly upper shoreface may be found between.

The vertical stacking pattern of depositional units in this core may indicate presence of shallow marine, barrier island or shore systems with intermixed lagoons.

3.4 Core 7324/07-U-01

3.4.1 Summary

In core 7324/07-U-01 49.0 m of bedrock was drilled in the interval between 75.4 m and 124.4 m below the sea floor, with 98.8 % core recovery. The core contains two main subunits, but because a sequence boundary may be present in the upper part of the lower unit, the upper portion of this unit has been defined as a separate subunit. The core has therefore been subdivided into three litho-units, A, B and C, with the boundaries at 88.2 and 86.2 m, respectively (Figure 3.4.1). The seismic sequence boundary is tentatively related to the lower of these boundaries.

The lowermost Unit A (36.2 m thick) consists of a silty claystone with laminae of graded siltstone beds and lenses. Siderite concretions occur sporadically in the unit.

Unit B (2.0 m thick) consists of silstones with thin beds and lenses of calcareous siltstone and sandstone, which show current ripple laminations as well as horizontal laminations.

The uppermost Unit C (10.8 m thick) consists of a silty claystone, with a siderite bed containing small phosphorite nodules at 82 m. The sediments are all moderately bioturbated with abundant *Chondrites*, and were deposited in an open marine shelf environment.

Poorly preserved ammonites indicate an age close to the Early-Middle Albian boundary, based on observations on the generic level and correlated to European faunas. This conclusion is in conflict with datings based on palynomorphs, nannofossils and foraminifera, which all point to an age close to the Albian - Cenomanian boundary. Our present interpretation is that the entire core is deposited during the latest Albian to earliest Cenomanian, i.e. *S. dispar* to *M. cantianum* ammonite zones. Nannofossils from 87.71 - 84.40 m favour an Albian dating.

Samples from this core show fair to good organic richness, but the organic material is a hydrogen-poor type IV kerogen which has no significant

potential for the formation of hydrocarbons. The organic matter has a thermal maturity which is well before the onset of oil generation (ca. 0.4 %Ro). Significant concentrations of redistributed hydrocarbons were not found in this core.

7324/07-U-01
Age: Latest Albian

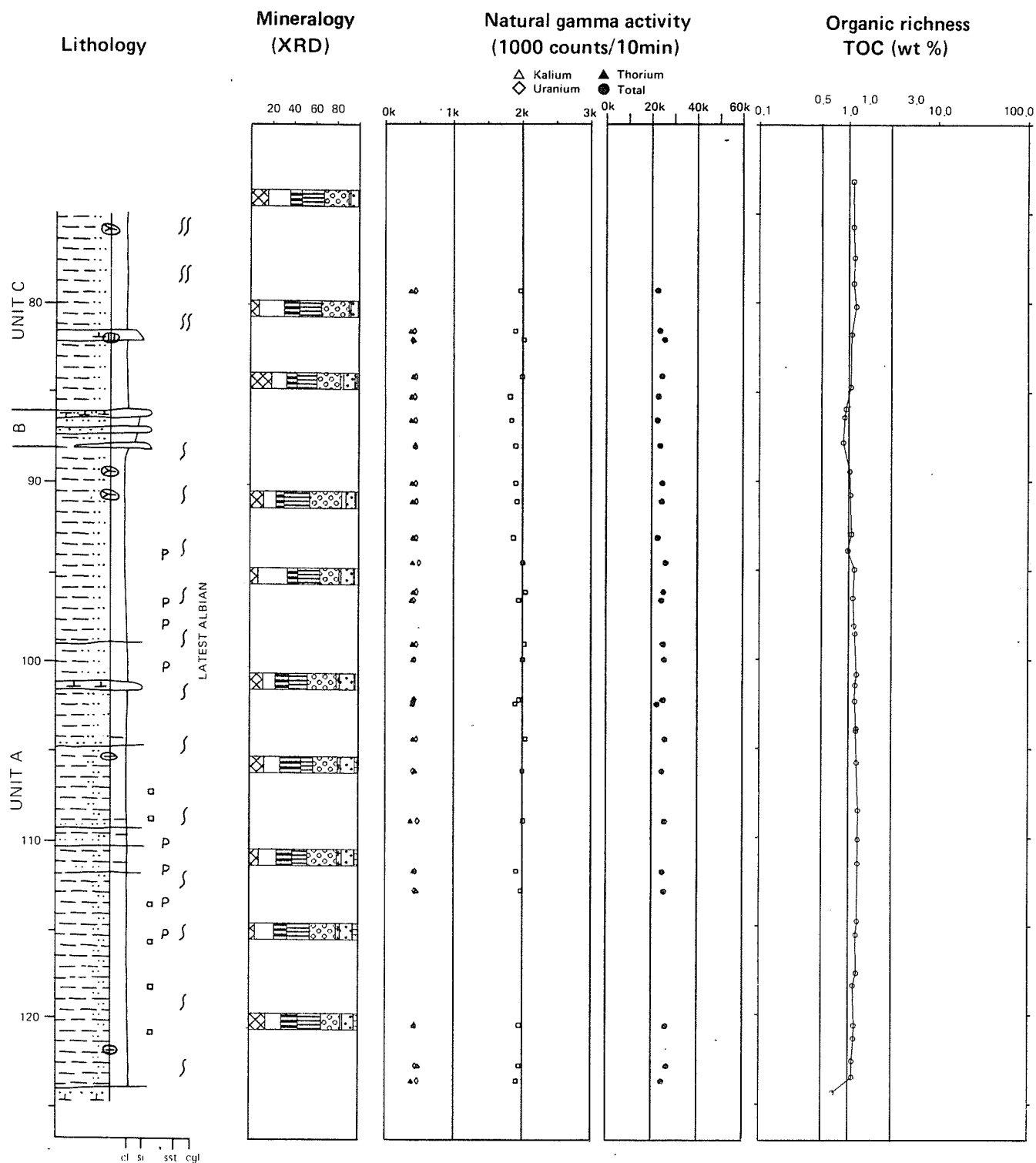


Figure 3.4.1 Summary figure of core 7324/07-U-01. Legend in Appendix A.3.

3.4.2 Seismic interpretation

This site and site 7323/12-U-01 are both located along a seismic line heading NE-SW on the northeastern side of the Dia-Structure. In order to provide high resolution data, line IKU-21-87 was shot overlapping the conventional seismic line GLRI-86-101. The lines run from the northeast into the rim syncline of the Dia-Structure. The location of the two drill sites were selected in order to penetrate the two youngest seismic sequence boundaries in the area. Site 7324/07-U-01 is the stratigraphically older of the two.

Because the seismic data show only faint indications of erosion, it is hard to define the sequence boundary exactly from the seismic data, but from the core we believe that it occurs at 88.2 m. The seismic reflection is probably coming from the top of the sandy Unit B, i.e. at 86.2 m. Below this, two seismic reflectors are correlated with possible unit boundaries in the core, at 101.5 m and close to the base of the core, at 124.3 m (Figure 3.4.2 and Table 3.4.1).

Table 3.4.1 Key data of the correlation between core 7324/07-U-01 and seismic line IKU-21-87.

Depth below seabed		Core unit	Thickness of seismic unit		Interval sound velocity
75.4 m	79 msec	Overburden	75.4 m	79 msec	1900 m/s
86.2 m	90 msec	C	10.8 m	11 msec	1960 m/s
101.5 m	103 msec	B/A	15.3 m	13 msec	2350 m/s
124.3 m	123 msec	A	22.8 m	20 msec	2280 m/s
TD124.4 m	123.1 msec	A	0.1 m	0.1 msec	2280 m/s (estimated)
Total TD below sea surface: 526.1 m / 672 msec					

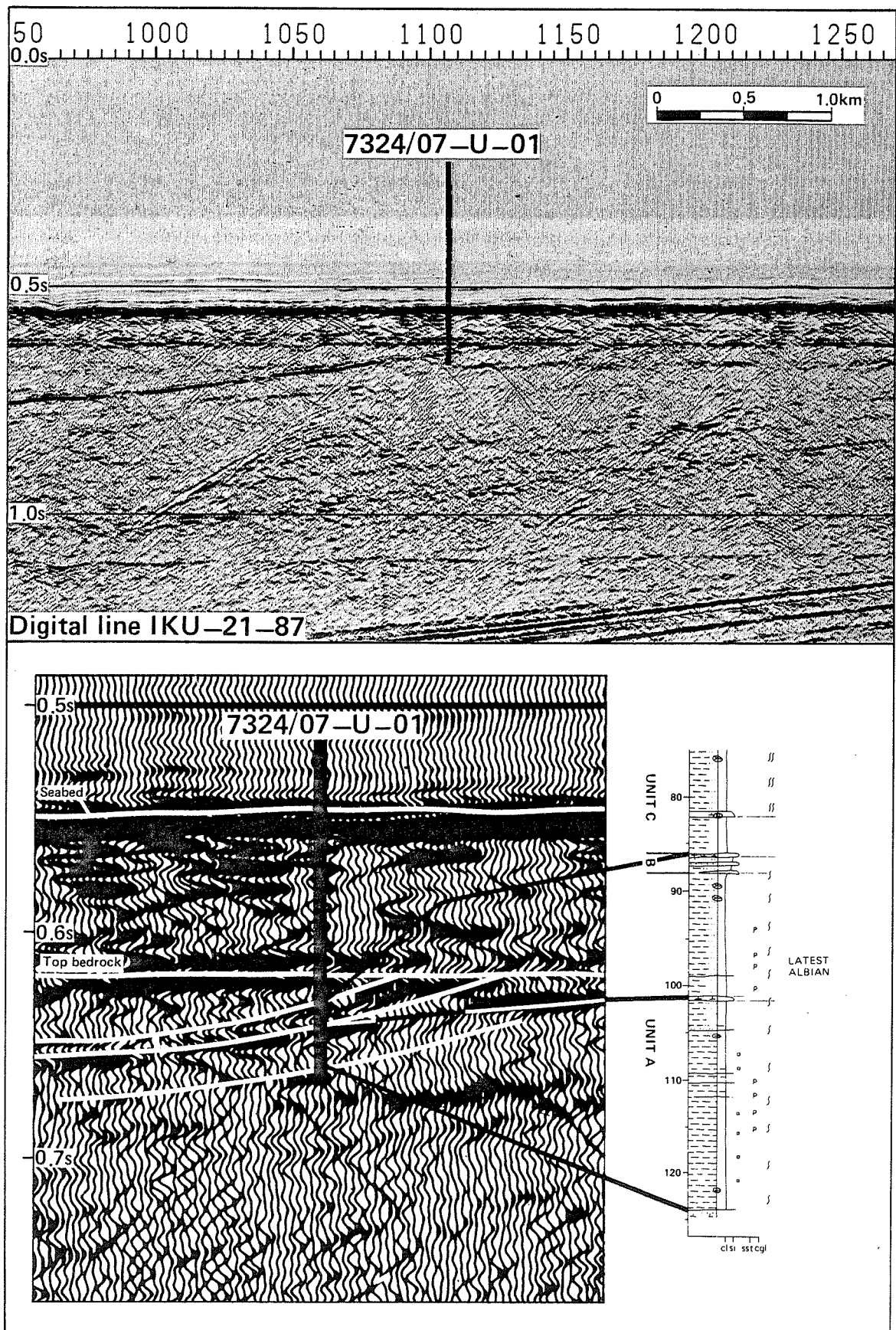


Figure 3.4.2 Correlation between core 7324/07-U-01 and seismic data.

3.4.3 Sedimentology

Core description

Totally 48.4 m of core have been drilled between 75.4 m and 124.4 m below sea floor. The recovery was 98.8 %.

The core is subdivided in Units A, B and C as shown in the stratigraphical column (Figure 3.4.3). The boundary between the lowermost Unit A and Unit B is gradual and defined at 88.2 m and the two units may be regarded as one single coarsening upwards sequence. The sharp boundary between Unit B and C is defined on top of a calcite cemented sandstone bed at 86.2 m.

Unit A is dominated by a medium dark grey silty claystone. Between about 112 and 99 m some 1-2 mm thick graded siltstone beds and lenses occur. These beds and lenses have a sharp base and a gradual transition toward the overlying silty claystone.

Siderite concretions occur sporadically in the unit. In thin sections the siderite is either microcrystalline or has a sucrosic texture with abundant inclusions of microcrystalline siderite, indicating formation by recrystallization of microcrystalline siderite. A siderite cemented bed occurs at 82 m.

The silty claystones are moderately bioturbated. Most common is *Chondrites*, but up to 10 mm wide horizontal burrows also occur. Below 107 m the burrows are often filled with pyrite, while above siderite is more common as filling.

Fossil fragments occur throughout the unit. Most common are bivalve fragments of *Inoceramus*, but also other types of bivalves are present. In addition, fish remains and poorly preserved ammonite fragments have been found.

Unit B is only 2 m thick and consists of siltstones and up to 2 cm thick calcareous siltstone and sandstone beds and lenses. The beds and lenses show current ripple lamination and/or horizontal lamination. Optical microscopy reveals that the sandstones consist of *Inoceramus* (and other bivalve fragments (prisms), calcite pellets and glauconitic pellets. The unit is moderately bioturbated. *Chondrites* type burrows are fairly frequently observed.

7324/07-U-01

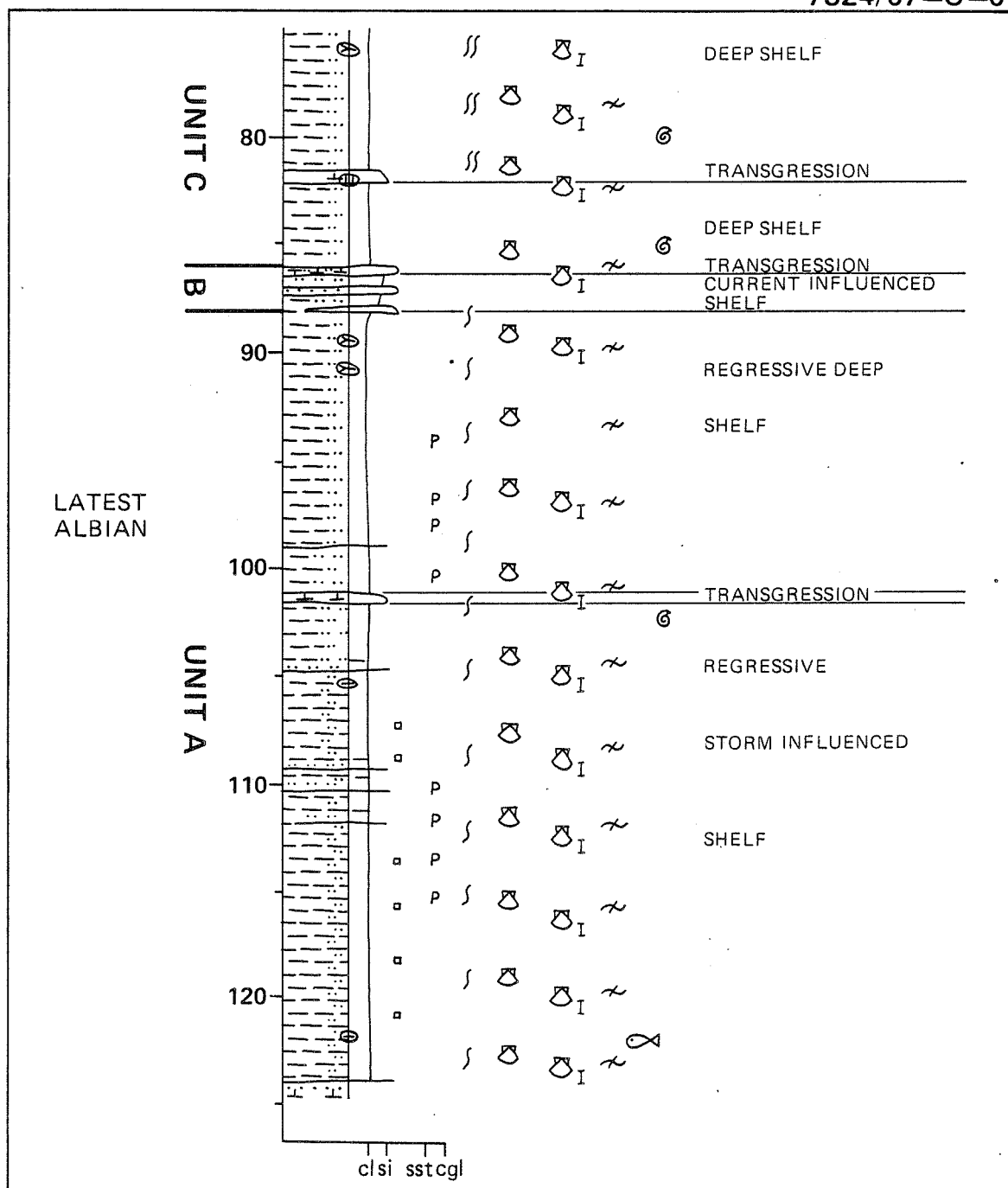


Figure 3.4.3 Simplified log of core 7324/07-U-01. Detailed log in scale 1:50 is found in Appendix A.5.

Unit C consists of medium dark grey silty claystone. At 82 m a 10 cm thick siderite bed with inclusions of phosphorite nodules with diameter up to 3 mm and microcrystalline to microsparry calcite occur (Figure 3.4.4). SEM analysis and thin section studies indicate that calcite is the oldest cement generation followed by phosphorite and siderite. The siderite shows both microcrystalline and sucrosic texture. The boundary between the different types of siderite is gradual, indicating that sucrosic siderite has formed by recrystallization of microcrystalline siderite. This is supported by frequent observations of microcrystalline siderite inclusions in the sucrosic siderite.

The unit is moderately bioturbated. Most common are 1 to 3 mm wide burrows of *Chondrites*, but up to 7 mm wide horizontal burrows also occur.

Fossil fragments are numerous in the unit. *Inoceramus* and other types of bivalve fragments are the most common, but also fragments of poorly preserved ammonites have been found.

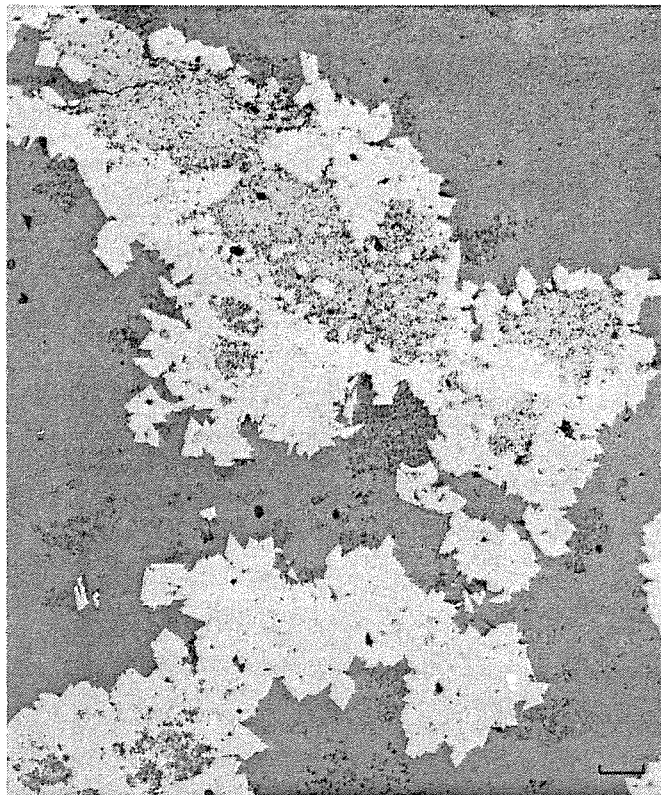


Figure 3.4.4 Backscatter electron microscope image from the nodular bed at 82 m. Darker grey areas are microcrystalline to microsparry calcite cement. Lightest grey is sucrosic siderite, and grey coloured zones are microcrystalline (probably collophane) phosphorite.

X-ray diffraction

Eleven samples from core 7324/07-U-01 have been analysed for whole rock and clay mineral composition (<4 μm fraction) (Figures 3.4.5 and 3.4.6, Tables 3.4.2 and 3.4.3). The whole rock diffraction profiles show a dominance of quartz, feldspars and chlorite/kaolinite, the latter based on the ~ 7 Å reflection. Reflections at 10 Å, 14 Å and mixed layer 10-14 Å are also prominent in the profiles, while carbonates are present in some of the samples only.

The diffraction profiles of the clay fraction show prominent clay mineral reflections equivalent to d-values 7 Å, 10 Å and ~ 14 Å, both with irrational series of reflections at their low angle sides. In addition to the clay minerals, minor amounts of quartz and feldspars are present. Heating the samples for 2 hours at 600 °C leads to an increase of the intensity of the 10 Å reflection while the intensity of the 14 Å reflection is drastically lowered. There is still an irrational series of reflections between 10 Å and 14 Å after heating indicating mixed layered illite-chlorite. The decrease of the 14 Å reflection and the decrease of mixed layered clays combined with an increase of the 10 Å reflection indicates the presence of smectite and randomly interstratified smectite-illite.

Upon glycol-saturation some of the clay material expand and show a broad reflection around 17.2 Å (smectite), occasionally with minor reflections superimposed on the high angle side indicating the presence of interstratified chlorite-smectite.

The diffraction profiles of the clay fraction show a complex content of clay minerals. Illite, kaolinite, chlorite and smectite occur as discrete minerals. In addition there are randomly interstratified illite-smectite, illite-chlorite and chlorite-smectite. The clay mineralogy indicates immature diagenesis and a maximum burial temperature less than 70°C.

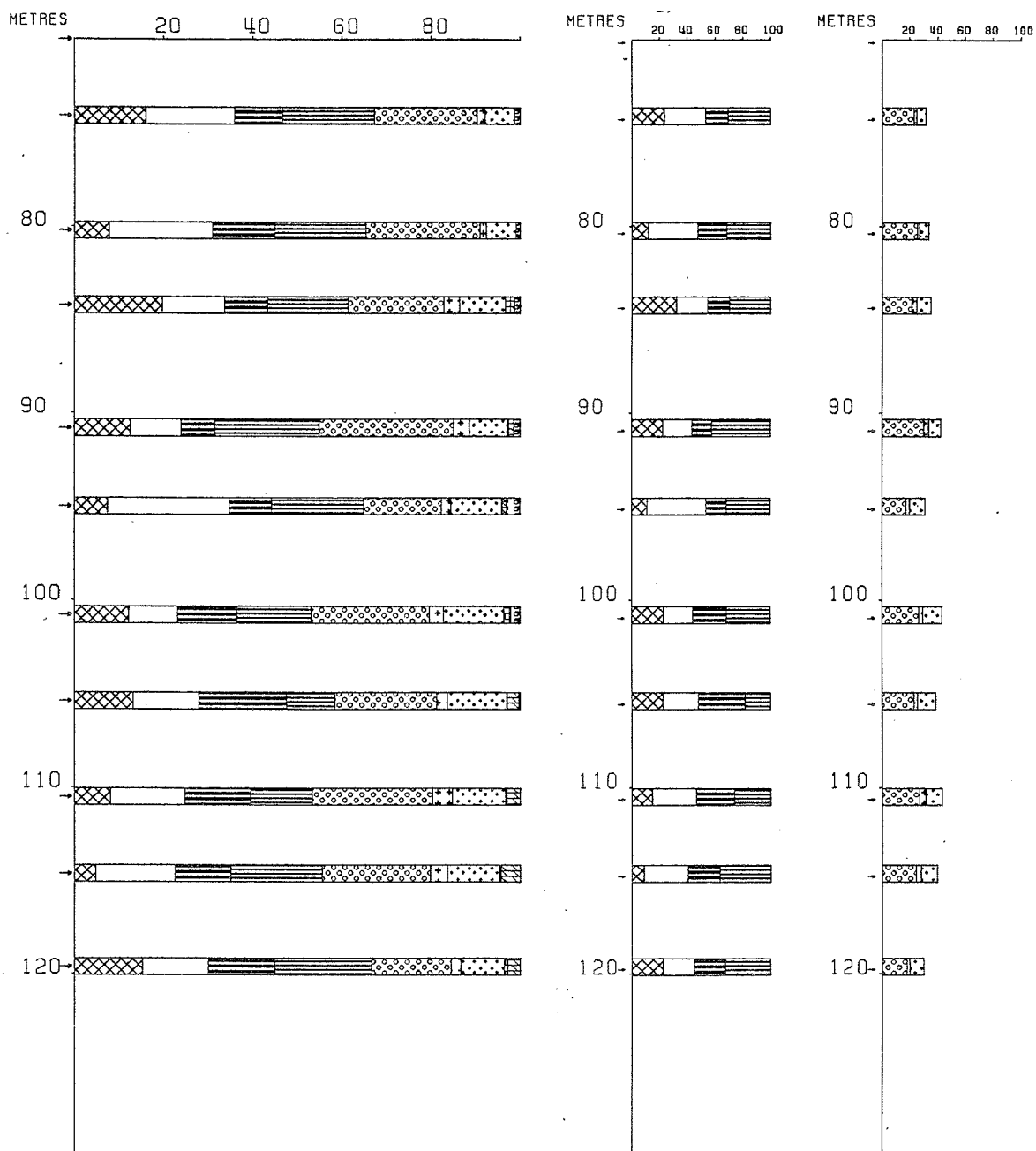


Figure 3.4.5 Whole rock mineralogy from core 7324/07-U-01 based on XRD analysis. Legend in Appendix A.3.

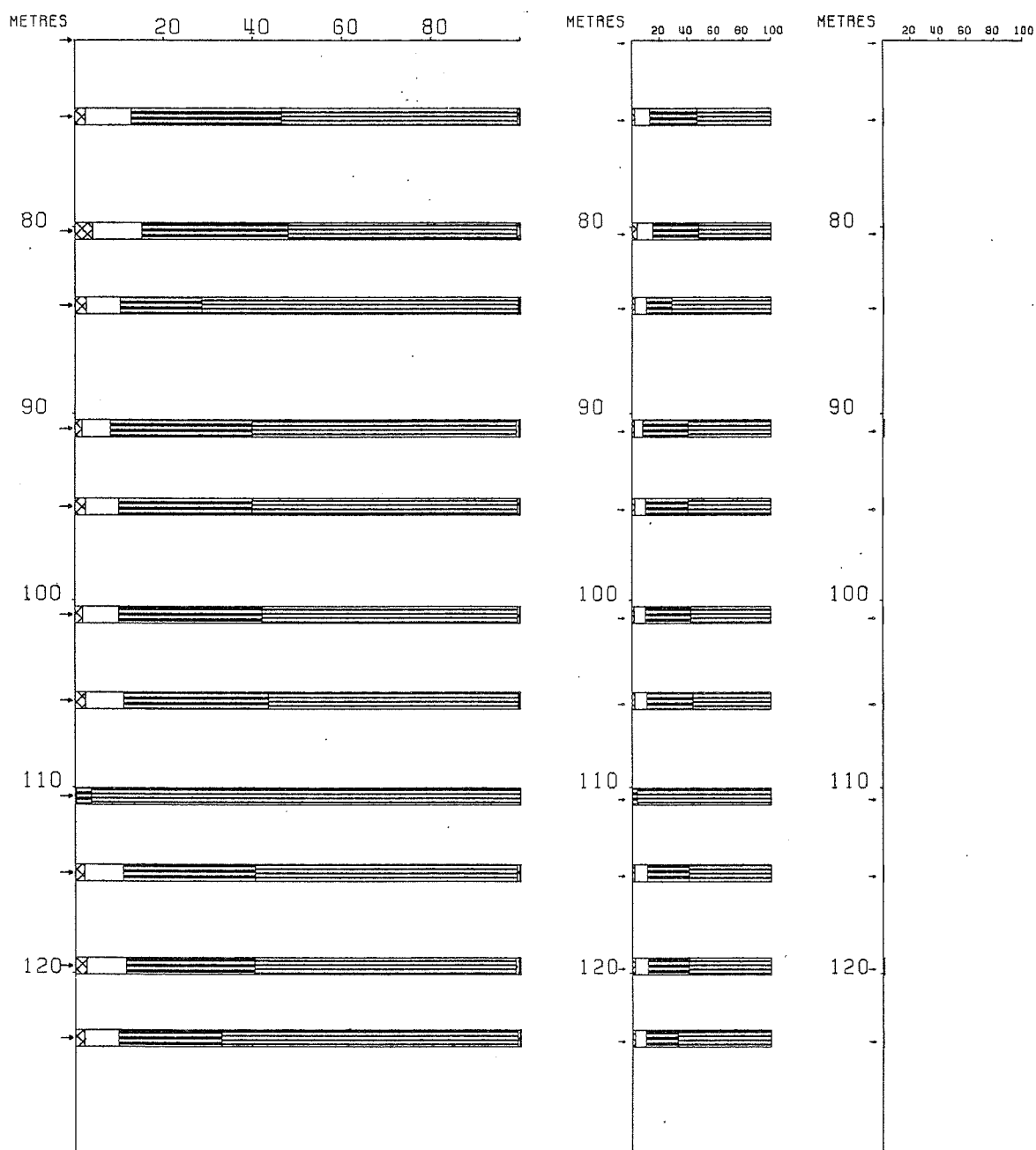


Figure 3.4.6 Clay mineralogy (<4 micron) from core 7324/07-U-01 based on XRD analysis. Legend in Appendix A.3.

Table 3.4.2 Tabulated values from XRD analysis of whole rock samples of core 7324/07-U-01. The values represent semiquantitative wt%. See Appendix A.3 for details.

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %
110.47	D-1416	0.0	16.8	14.7	13.8	27.0	4.5	11.9	0.0	0.3	3.0	0.0	0.0
74.07	D-1357	0.0	19.8	10.8	20.6	23.0	1.8	6.7	0.0	0.0	0.0	0.0	1.2
80.22	D-1366	0.0	23.2	13.9	20.6	25.4	1.5	6.6	0.0	0.0	0.0	0.0	1.0
84.23	D-1374	0.0	13.9	9.7	18.1	21.5	3.5	10.3	1.1	0.0	1.0	0.0	1.2
90.78	D-1380	0.0	11.5	7.7	23.3	30.2	3.6	8.5	0.4	0.0	1.0	0.0	1.5
94.96	D-1391	0.0	27.3	9.5	20.6	17.5	2.2	11.4	0.1	0.1	0.8	0.0	3.1
100.85	D-1400	0.0	11.0	13.2	16.7	26.5	3.2	13.4	1.3	0.0	0.4	0.0	2.0
105.39	D-1407	0.0	14.8	19.7	10.8	22.9	2.4	13.3	0.0	0.3	2.4	0.0	0.4
114.56	D-1424	0.0	17.7	12.5	20.5	24.3	3.8	11.7	0.1	0.3	4.3	0.0	0.0
119.62	D-1432	0.0	14.8	14.9	21.7	17.8	2.2	9.8	0.8	0.0	2.8	0.0	0.0

Table 3.4.3 Tabulated values from XRD analysis of clay fraction (<4 micron) samples of core 7324/07-U-01. The values represent semiquantitative wt%. See Appendix A.3 for details.

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %	Expand 14-17A
74.07	D-1357	0.0	10.3	33.8	52.9	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	Partly
80.22	D-1366	0.0	11.1	32.9	51.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Partly
84.23	D-1374	0.0	7.7	18.4	70.8	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	Partly
90.78	D-1380	0.0	6.3	32.0	59.2	0.5	0.2	0.2	0.0	0.0	0.0	0.0	0.0	Partly
94.96	D-1391	0.0	7.4	30.1	59.4	0.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	Partly
100.85	D-1400	0.0	8.2	32.2	57.4	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	Partly
105.39	D-1407	0.0	8.7	32.5	55.9	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	Partly
110.47	D-1416	0.0	0.2	3.3	96.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Partly
114.56	D-1424	0.0	8.7	29.7	58.7	0.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	Partly
119.62	D-1432	0.0	9.0	28.9	58.7	0.7	0.2	0.2	0.0	0.0	0.0	0.0	0.0	Partly
123.50	D-1436	0.0	7.6	23.1	66.7	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	Partly

Petrophysics

Natural γ -radiation

The natural γ -activity (Figure 3.4.7) of thorium and uranium along core 7324/07-U-01 shows practically no significant variation. The potassium activity shows some variation, i.e. the upper, more silty part of the core has a lower average potassium activity than the claystone below. The same situation is reflected by the total γ -activity as well.

Sound velocity

Forty-one measurements of the horizontal sound velocity has been undertaken along this core. The average sound velocity is about 2100 m/s. This is in relatively good agreement with the interval velocities found from correlation between the core and the seismic data. The interval velocities increase from 1960 m/s at the top of the core to 2280 m/s in the lower part (see Table 3.4.1). The same trend is found in the core measurements. Some few high values are due to carbonate cementation of siltstone laminae (Figure 3.4.7, Table 3.4.4).

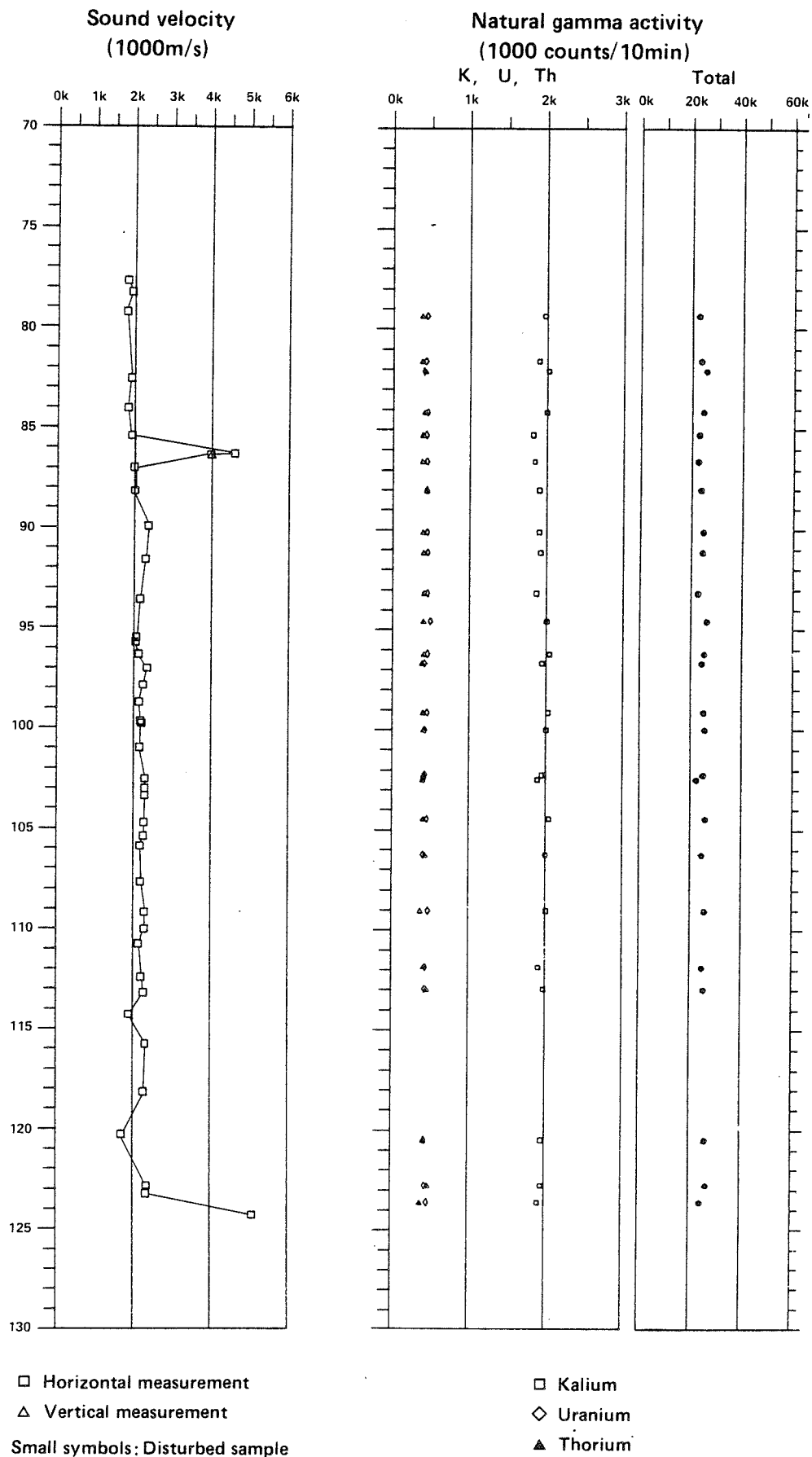


Figure 3.4.7 Natural γ -radiation (counts per 10 minutes) and sound velocity (m/s) in core 7324/07-U-01.

Table 3.4.4 Sound velocity (m/s) in core 7324/07-U-01.

Depth m	Horiz. velocity m/sec	Vert. velocity m/sec
77.70	1818	0
78.25	1928	0
79.25	1800	0
82.57	1907	0
84.05	1838	0
85.42	1935	0
86.32	4593	0
86.37	3985	0
86.37	0	4005
87.00	1993	0
88.20	2015	0
89.95	2358	0
91.62	2288	0
93.57	2169	0
95.49	2057	0
95.74	2053	0
96.34	2126	0
97.02	2348	0
97.87	2241	0
98.72	2143	0
99.69	2186	0
99.79	2204	0
100.99	2160	0
102.53	2298	0
103.03	2289	0
103.38	2291	0
104.74	2284	0
105.39	2264	0
105.89	2174	0
107.69	2195	0
109.17	2298	0
110.02	2291	0
110.77	2140	0
112.42	2204	0
113.21	2284	0
114.31	1888 *	0
115.79	2319	0
118.19	2277	0
120.29	1703 *	0
122.85	2360	0
123.25	2342	0
124.30	5104	0

*) Velocities from samples marked by * represent disturbed samples.

3.4.4 Paleontology

Ammonites

Cleonicer sp. has been recorded at 103.50, 91.43 and 85.70 m. The genus *Cleonicer* Parona & Bonarelli 1896 appears in the Lower Albian, but is most frequent in the upper part of this substage (*Douvilleicer* *mammillatum* Zone) and disappears in the lowermost Middle Albian (*Hoplites dentatus* Zone).

Representatives of *Cleonicer* are commonly noted from England, France, North Germany, Bornholm and Mangyshlak in the Soviet Union (Spath 1925, Imlay 1961, Savelev 1973, Kennedy & Hancock 1978, Kennedy & al. 1981, Owen 1979).

A representative of the genus *Otohoplites* close to *O. guersanti* (d'Orbigny) occurs at 98.98 m. The genus *Otohoplites* Steinmann 1925 occurs near the Lower/Middle Albian boundary (*Otohoplites roulinianus* through *Isohoplites eodentatus* Subzones) and it is noted from England (Casey 1965, Owen 1971, Kennedy & Hancock 1978), Northern France (Destombes et al. 1973), Northern Germany (Owen 1979), Bornholm (Kennedy et al. 1981), Poland (Marcinowski & Wiedmann 1985), Mangyshlak in the Soviet Union (Savelev 1973) and also described by Nagy (1970) from Spitsbergen.

The ammonites, although poorly preserved, are characteristic for the upper part of *Douvilleicer* *mammillatum* Zone (highest Lower Albian), but the presence of the lowermost Middle Albian cannot be excluded.

The conflict between the ammonite dating and the microfossil based datings is not easy to explain. To our knowledge latest Albian ammonite faunas from the present Arctic have not been studied. This may imply that the answer could be of paleobiogeographical nature, although the discrepancy seems large.

Palynology

Diverse dinoflagellate cyst assemblages are found with *Oligosphaeridium albertense*, *Odontochitina operculata*, *Epelidosphaeridia spinosa*, *Rhombodella paucispina*, *Cribroperidinium edwardsii/muderongense* group, *Gingiodinium evittii* and *Dorocysta litoles* as the most consistently and commonly occurring taxa (Figures 3.4.8 and 3.4.9). The co-occurrence of *Cauca parva* and *Litosphaeridium siphoniphorum* throughout the core

according to Foucher (1981) restrict the dating to the latest Albian *S. dispar* (ammonite) Zone to earliest Cenomanian *M. cantianum* Zone. The presence of *Achomosphaera sagena* at 83.19 and *Palaeohystrichophora infusoroides* at 75.95 m is supporting evidence for a *S. dispar* Zone or younger age. *P. infusoroides* is a cosmopolitic species with a stratigraphical significant first occurrence. *Polysphaeridium laminaspinosum* sensu Brideaux & McIntyre 1975, *Muderongia pentaradiata* and *Discorsia nanna* are recorded up to 105.39 m and *Oligosphaeridium* sp. AE (Brideaux 1977) to 89.46 m.

Florentinia mantelli and *Xiphophoridium alatum* occur from 83.19 m to the top of the core and *Florentinia ferox* from 78.72 m to the top. All these species seem to be useful for a local biozonation.

Spongodinium canadense and *Spiniferites porosus* have been recorded upwards from 92.97 and 83.19 m, respectively. Singh (1983) found *S. canadense* and the above mentioned *Muderongia pentaradiata* exclusively in the Upper Shaftesbury Formation, Alberta. Based on indirect evidence he concluded that this formation is of early Cenomanian age.

Microfauna

The core displayed very poor to fairly poor microfaunas, mainly of agglutinating foraminifera (Figure 3.4.10 and 3.4.11). Significant calcareous elements were recorded in the 83-86 m interval in addition to the lowermost few metres. *Inoceramus* prisms were present throughout, and sparse records of echinoderms, radiolarians and fragmented ostracods were noted in the upper half of the core.

The most characteristic faunal feature is scattered but partly common occurrences of *Hedbergella planispira* throughout the core. The more age significant records are *Tritaxia pyramidata* and *Praeglobotruncana delrioensis* (both at 124.95 m), *Dorothia filiformis* (122.59 and 75.95 m), *Lingulogavelinella jarzevae* (85.97 m) and *Gavelinella intermedia* (85.97 and 83.19 m). Based on occurrences in sections in Great Britain, Germany and France (Hart et al. 1981, Bartenstein and Bettenstaedt 1962, Caron 1985), these elements point toward a stratigraphical position close to the Albian - Cenomanian boundary, and thus supporting the age conclusion based on palynomorphs and nannofossils.

Nannofossils

In this core, nannofossils occur from 87.71 m to 84.40 m (Figure 3.4.12). Several samples in the overlying and underlying shales are all barren. According to the zonation by Sissingh, emended by Perch-Nielsen (1985), the interval with a nannoflora can be attributed to zone CC 9a of latest Albian age, because of the presence of the earliest forms of *Eiffellithus* together with *Braarudosphaera africana*. A regional zonation of the Early Cretaceous of Great Britain by Taylor (1982) allows a very detailed correlation to the Late Albian *P. inflatum* ammonite zone, because of the co-occurrence of *Eiffellithus turriseiffelli* and *Octocylus magnus*. In a regional nannofossil zonation of the North Sea by Jakubowski (1986), the association of this borehole fits into zone 1 that straddles the Cenomanian - Albian boundary. Evidently the various zonations give results that are very similar, although the applied zonal boundaries are not the same. The sum of the evidence is strongest for a Late Albian age, and an attribution to zone CC 9a of the zonation by Sissingh.

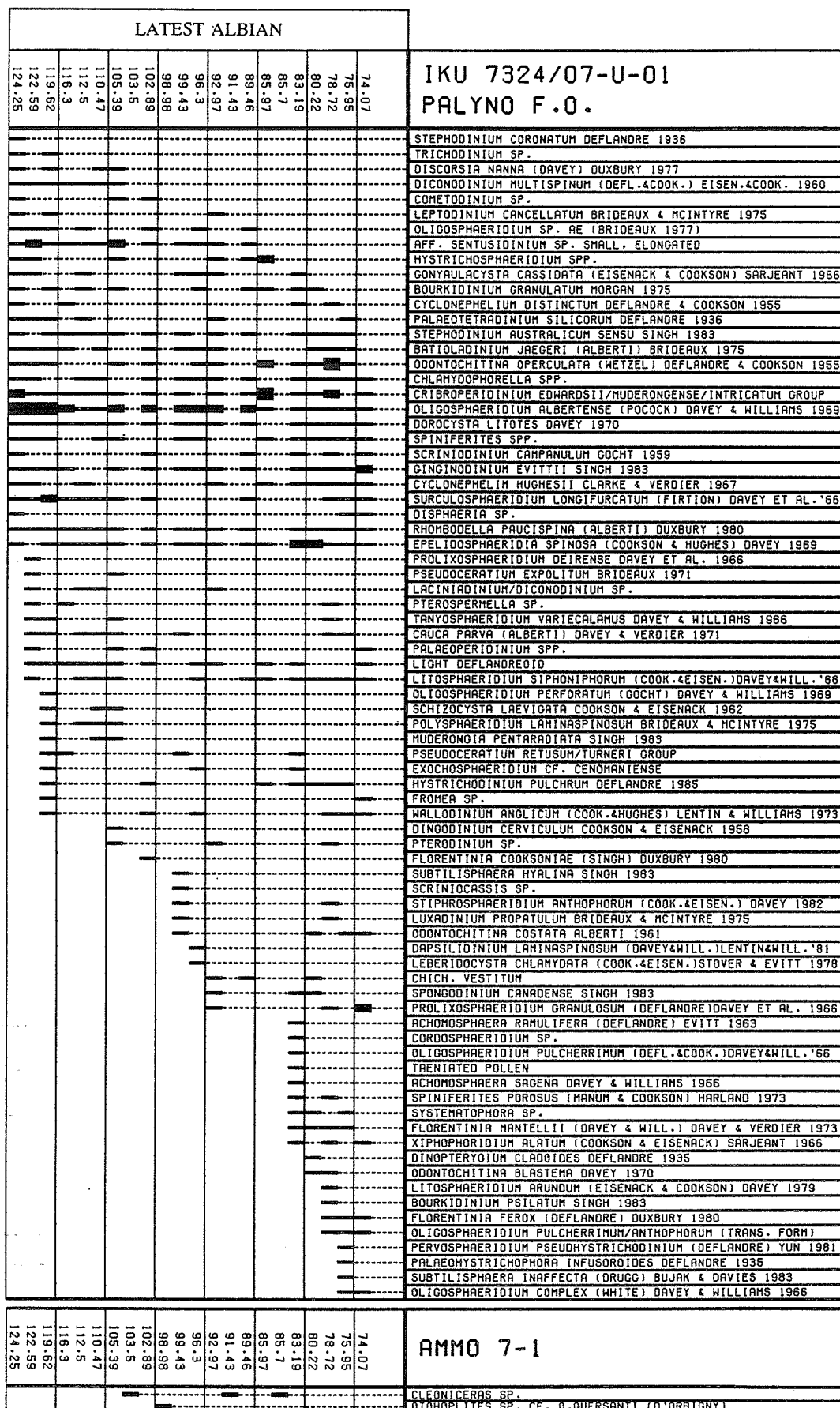


Figure 3.4.8 Palynological and ammonite range chart of core 7324/07-U-01.
(Sorted according to first occurrence).

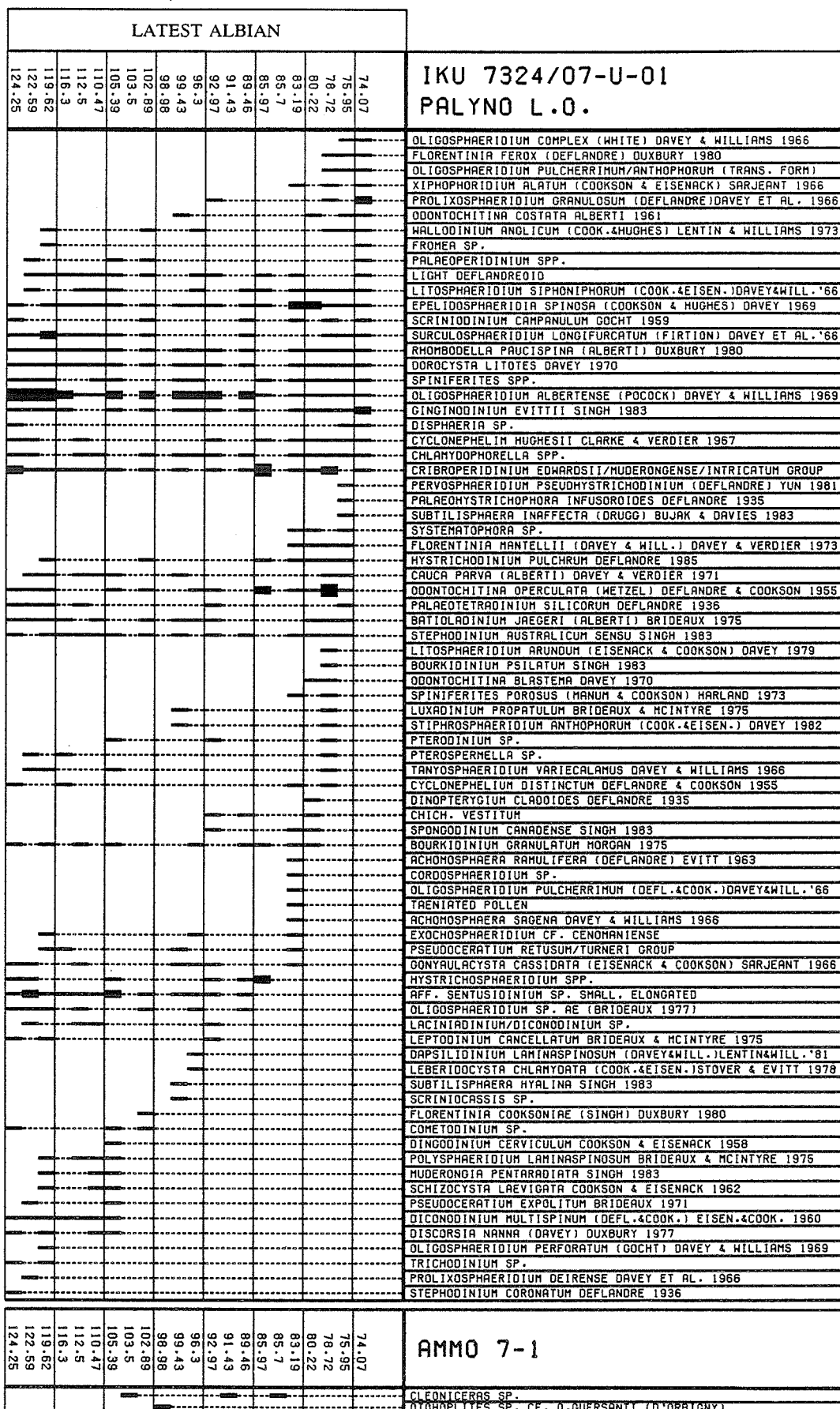


Figure 3.4.9 Palynological and ammonite range chart of core 7324/07-U-01. (Sorted according to last occurrence).

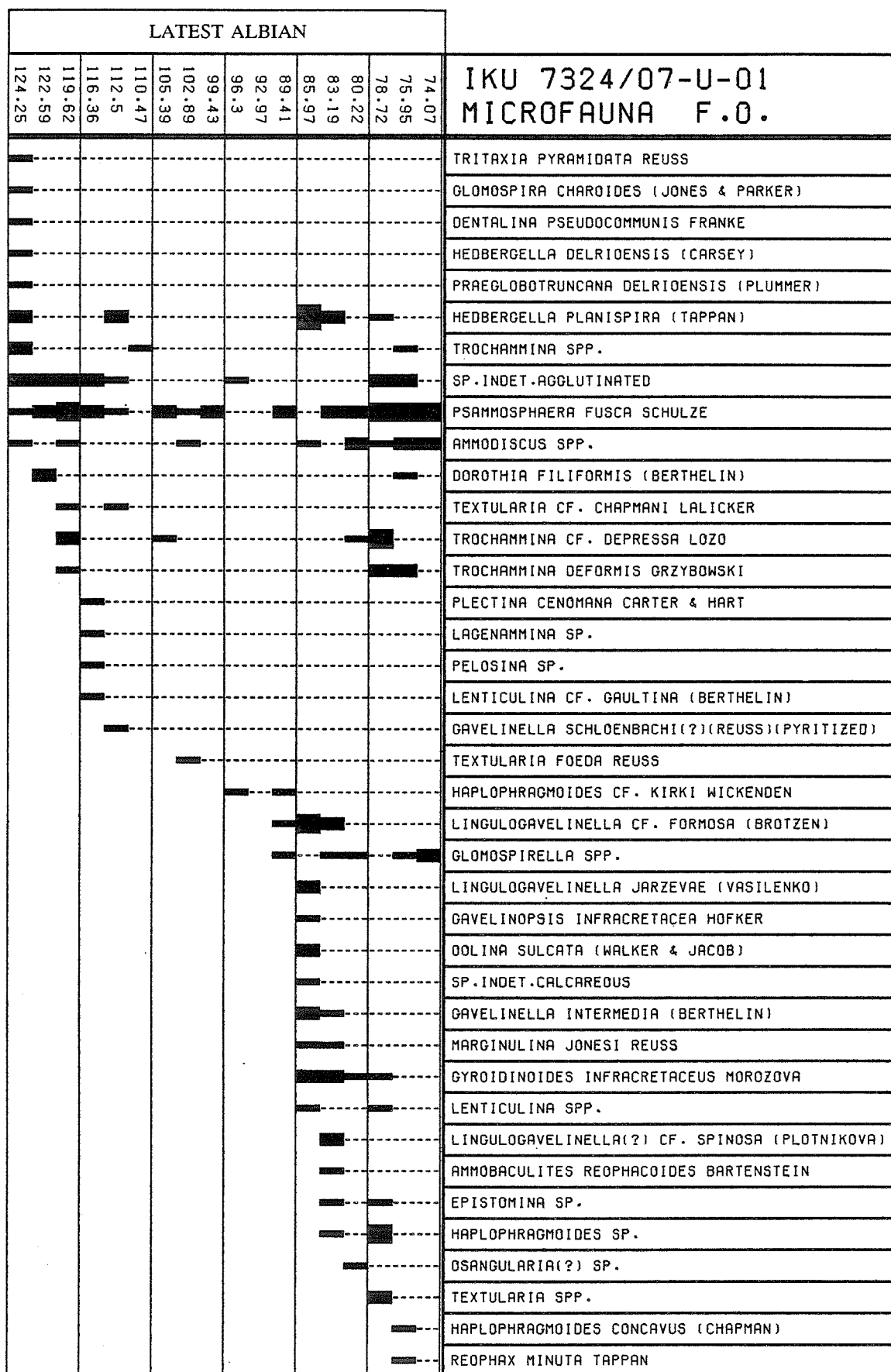


Figure 3.4.10 Foraminiferal range chart of core 7324/07-U-01. (Sorted according to first occurrence).

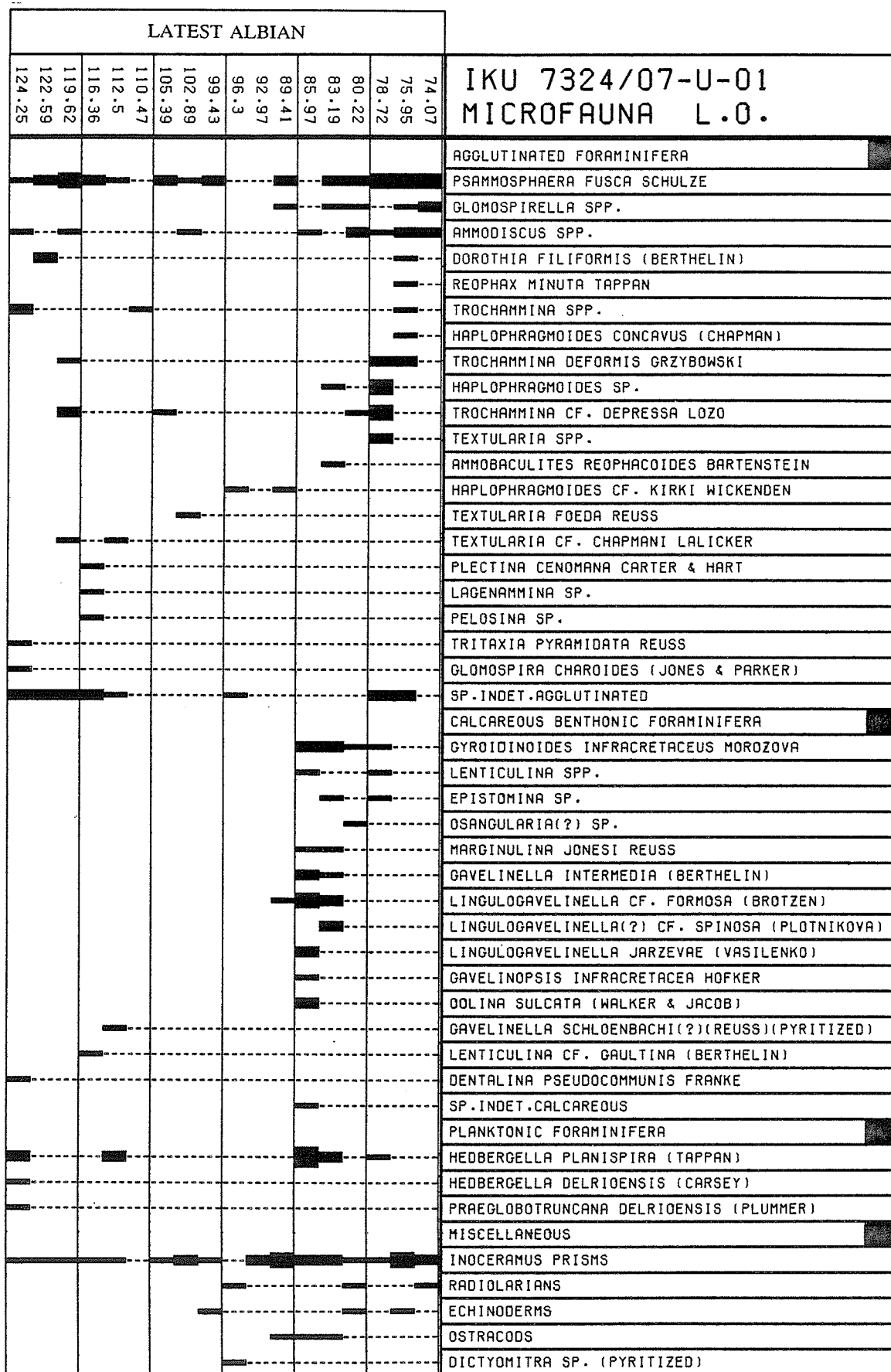


Figure 3.4.11 Foraminiferal range chart of core 7324/07-U-01). (Sorted according to last occurrence).

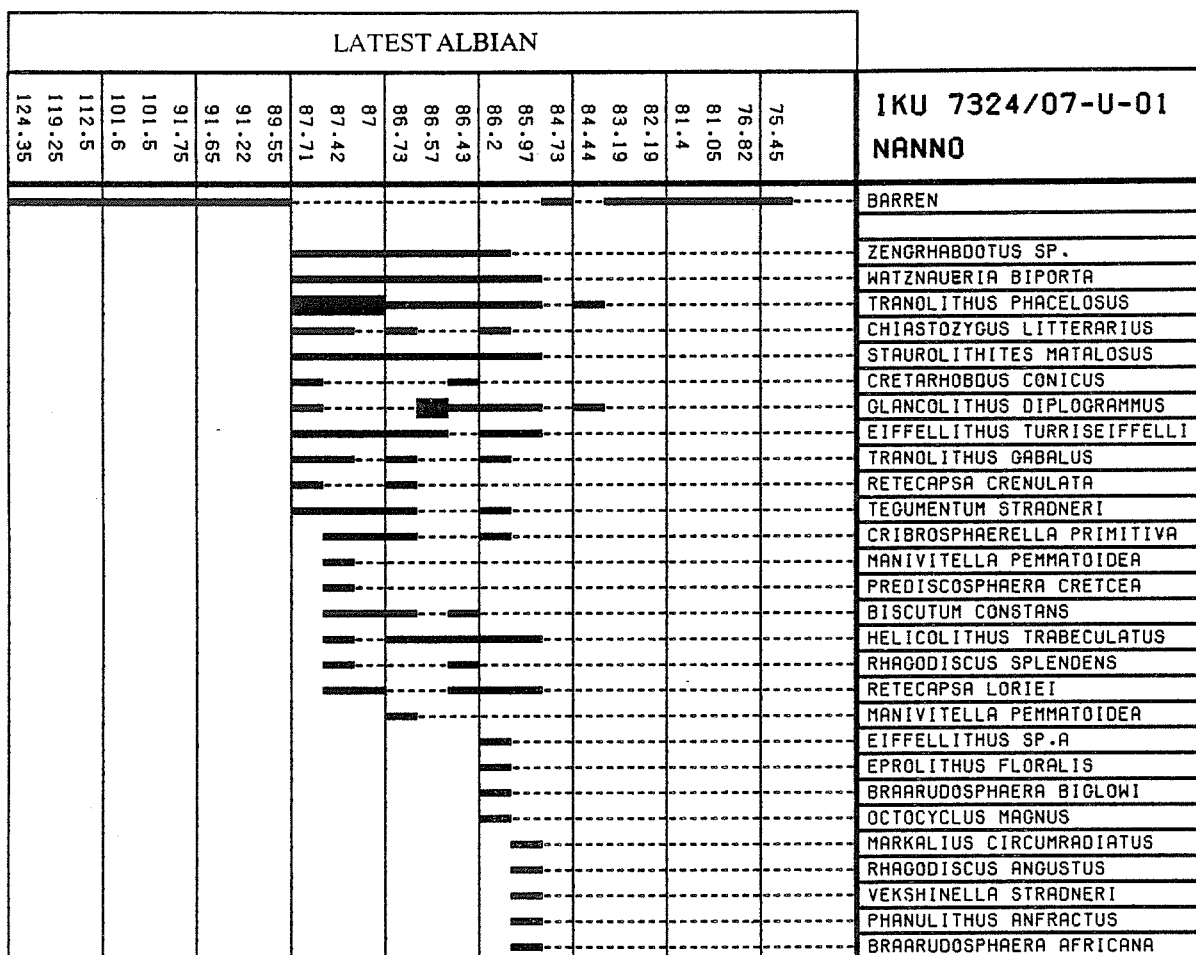


Figure 3.4.12 Calcareous nannoplankton range chart of core 7324/07-U-01.
(Sorted according to first occurrence).

3.4.5 Organic geochemistry

The organic geochemical data figures and tables are presented in a separate volume of the report. Only summary figures will be presented in this section.

A total of thirteen canned core samples have been analysed for headspace and occluded gas. The combined gas concentrations are in the order of 16,000 to 76,000 $\mu\text{l/kg}$ dry rock, the largest part of which the methane in the headspace gas accounts for (Figure 3.4.13). C_1 - to C_4 -hydrocarbons occur in the headspace gas of most of the samples, and the concentrations of these compounds reach a maximum at ca. 115 to 121 m depth (2258-3121 $\mu\text{l/kg}$). Trace amounts of C_{5+} -hydrocarbons were registered at 115.51 m depth (15 $\mu\text{l/kg}$). The occluded gas at 78.92 and 81.78 m depth contains only methane and ethane while the full range of C_1 - to C_{5+} -hydrocarbons is represented in all the other samples. A maximum concentration of 1414 $\mu\text{l C}_{5+}$ -hydrocarbons/kg rock is found at 93.90 m. The wetness of the occluded gas increases from zero at the top of the core to values between 42 and 50% in the interval between 111.47 to 121.32 m. An $i\text{-C}_4/n\text{-C}_4$ ratio between 0.8 and 2.5 suggests that the gas in this core probably originates from a source which has not yet reached oil-window maturity (Connan & Cassou 1980).

The analysis of thirty-six rock samples for total organic carbon shows that the rocks contain constantly fair to rich concentrations of organic matter (0.87 - 1.26 wt% TOC; Figure 3.4.14). Rock-Eval pyrolysis of selected samples yielded invariably low hydrogen index values of less than 38 mg HC/g TOC and oxygen index values of 19 to 679 mg CO_2 /g TOC. This data indicates that the organic matter belongs to a hydrogen-poor type of organic matter which does not have any significant hydrocarbon generation potential (kerogen type IV). Consequently, a low petroleum potential was observed (<0.6 mg HC/g rock).

The production index reaches a maximum value of 0.37 at 87.85 m, but does usually not exceed 0.25, which suggests that no major redistribution of hydrocarbons should have occurred. The data are however not very reliable because of the poor S1 and S2 peaks.

Reliable Tmax data were obtained from 21 samples. The values show a fairly narrow distribution with a mean value of 426°C (std. dev. 3.5°C), which

indicates that the organic matter is well below oil window maturity.

Samples at 77.49, 100.85 and 117.65 m were selected for determination of vitrinite reflectance. The wide range of values obtained (0.38–0.81 %R_o) is considered to reflect a significant contribution from reworked organic material. This may also explain the observed large variation in liptinite fluorescence colours. Mean reflectance values of 0.38 to 0.41 %R_o are thought to represent the maturity of the indigeneous vitrinite population. Although the reliability of these values as such is limited by the poor quality and low number of suitable vitrinite particles in the samples, they agree with the T_{max} data. A low level of maturity is also indicated by the thermal alteration index (TAI) which has been determined on 17 samples and shows values between 3 and 3.7.

Five samples (80.22, 87.85, 100.85, 110.12, 117.65 m) have been extracted for characterisation of the bitumen. The EOM concentrations range from 288 ppm of rock weight at 110.12 m to 928 ppm at 80.22 m, which are fair to good concentrations considering the poor quality of the kerogen (Figure 3.4.15). Although the hydrocarbon concentrations and the bulk composition data are not very reliable because of the low fraction weights, they indicate a relatively HC-poor composition for most of the extracts, which would be expected at this low thermal maturity of the organic matter.

The gas chromatograms of the saturated hydrocarbon fractions at 80.22 and 87.85 m show relatively broad and uniform n-alkane distributions, while the chromatograms at 100.85, 110.12 and 117.65 m exhibit maximum n-alkane concentrations at C₂₅–C₂₇. Considering the low fraction amounts, care should be taken in the interpretation of these distributions, as they may be affected by evaporation losses. A pronounced predominance of odd-numbered n-alkanes in the range of C₂₁–C₃₁ can be observed in all samples and indicates low maturity and the probable presence of terrestrial organic material (Figure 3.4.16).

Four of the saturated hydrocarbon fractions were analysed by gas chromatography-mass spectrometry (GC-MS) for the composition of biomarkers. Three of the samples show quite similar sterane and terpane distributions suggesting immaturity while the biomarker composition of the shallowest sample is somewhat different. The sterane distribution patterns of these three samples are characterized by prominent peaks of C₂₇- and C₂₉-14α(H),17α(H) 20R regular steranes, absence or low concentrations of the 20S-isomers at C₂₉ (q,s), and low concentrations of diasteranes (a-g).

The composition of the terpanes is dominated by strong peaks of $17\alpha(\text{H})$ 22R homohopane (H), $17\alpha(\text{H})$ -hopane (E) and, at 100.85 m, $17\alpha(\text{H})$ -norhopane (C). The unidentified compound eluting at the end of the chromatogram ("*") which was mentioned earlier is also present in these samples. The thermally stable 20S-diastereomers of the C_{31} - and C_{32} -extended hopanes are present at low concentrations.

Compared with these samples, the mass fragmentograms of the bitumen at 80.22 m show an increased concentration of diasteranes relative to regular steranes, a relatively increased concentration of $5\alpha(\text{H})$ -steranes (u,v) and tricyclic terpanes (P-S), an increased concentration of $18\alpha(\text{H})$ -trisnorhopane (T_s), and slightly increased concentrations of 22S-extended hopanes relative to the respective 22R-diastereomers. This suggests that the maturity of this extract is slightly higher than in the three other samples. The extract is, however, far from being mature as indicated by the ratio $22\text{S}/(22\text{R} + 22\text{S})$ which is still at 22 % but would reach values of ca. 50-60 % at the beginning of the oil window.

To summarize, the organic richness of core 7324/07-U-01 is fair to good, but the organic material is a hydrogen-poor type IV kerogen which has no significant potential for the formation of hydrocarbons. The organic matter has a thermal maturity which is well before the onset of oil generation (probably around 0.4 %Ro). Significant concentrations of redistributed hydrocarbons were not found in this core.

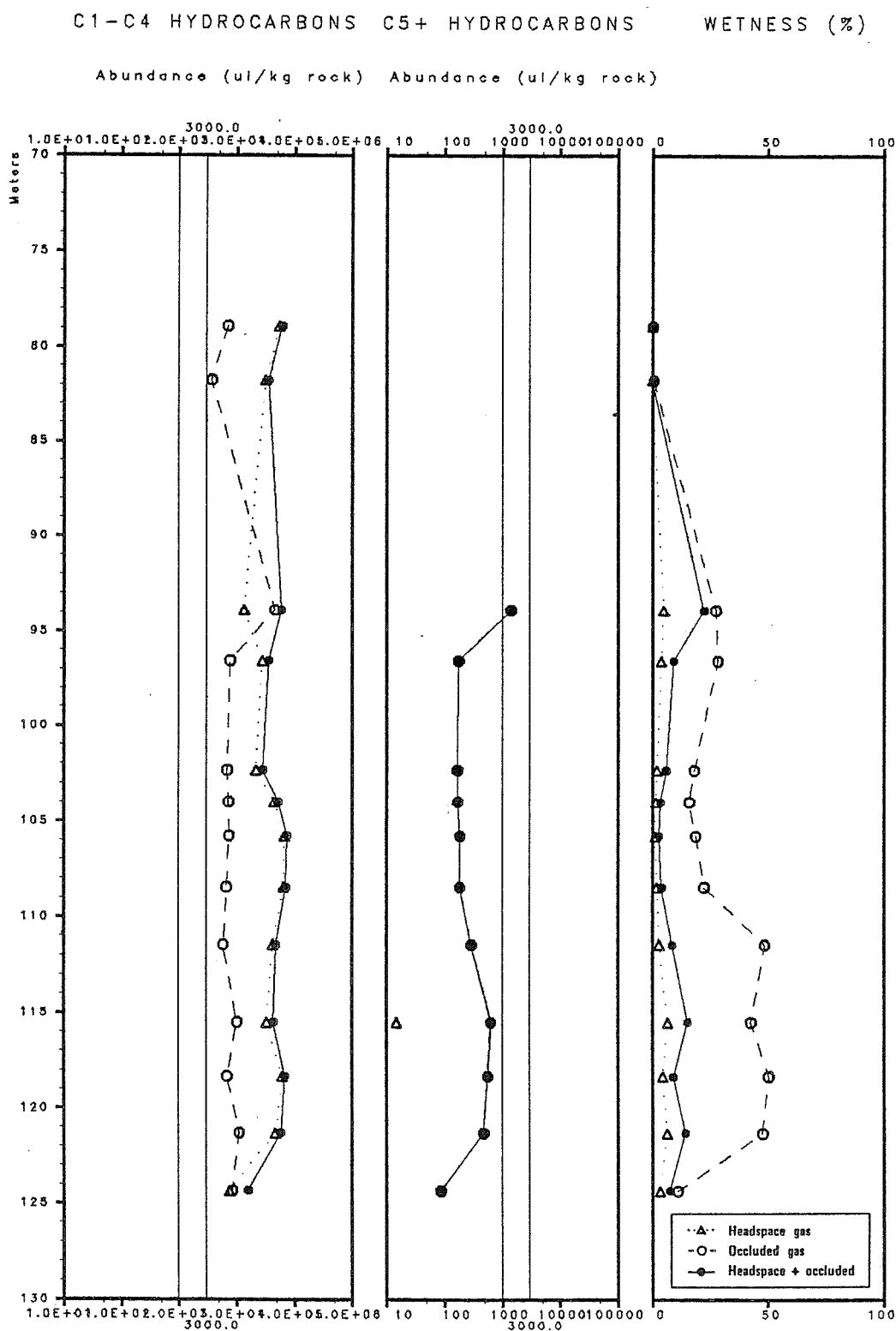


Figure 3.4.13 Yield and composition of headspace/occluded gas of core 7324/07-U-01.

ROCK-EVAL PYROLYSIS DATA

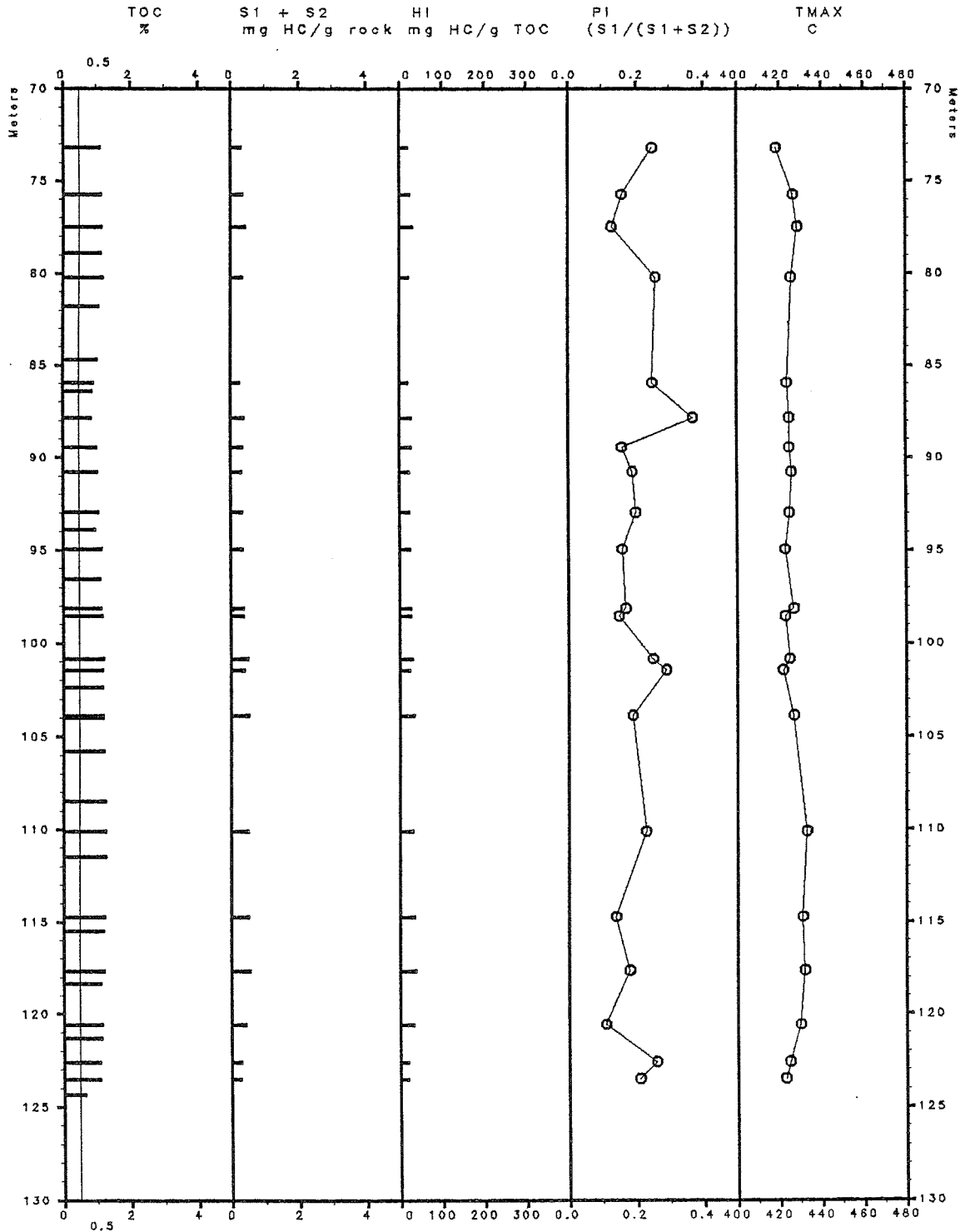


Figure 3.4.14 Total organic carbon content and Rock-Eval data of core 7324/07-U-01.

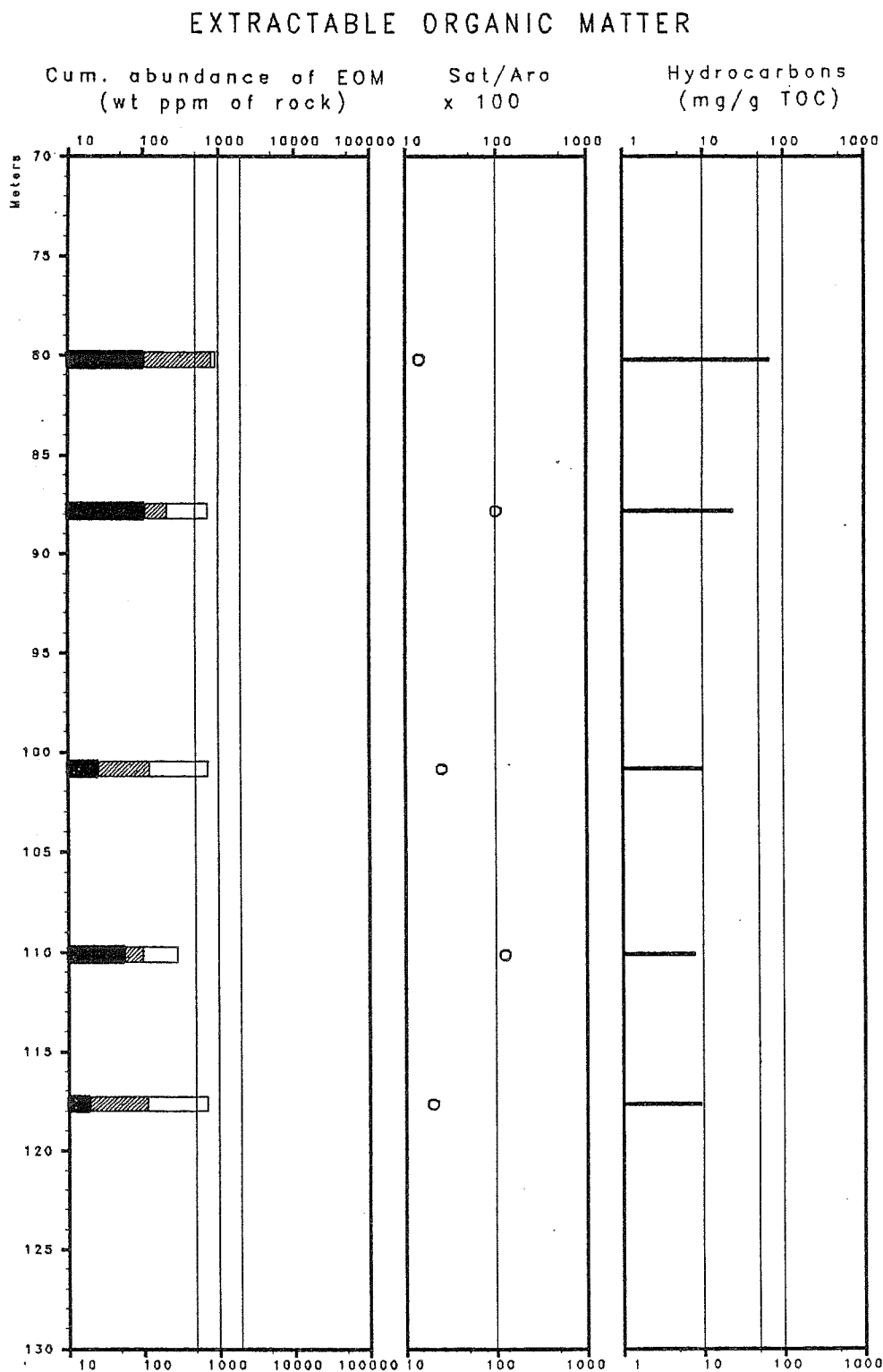


Figure 3.4.15 Extract data for core 7324/07-U-01.

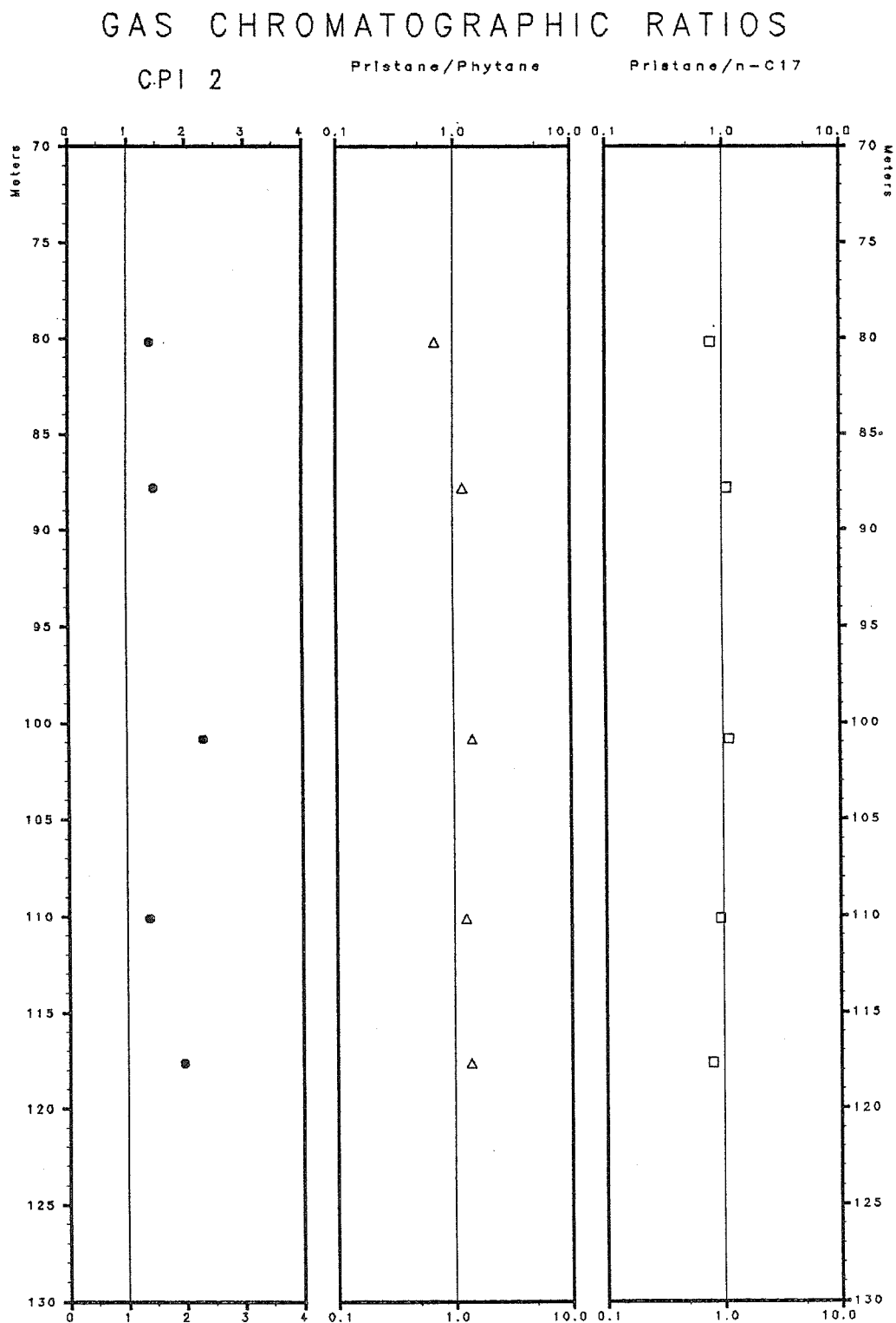


Figure 3.4.16 Compound ratios from gas chromatograms of saturated hydrocarbon fractions from core 7324/07-U-01.

3.4.6 Depositional environment

Marine fossils throughout the core demonstrate the marine nature of the depositional environment.

Units A and B together form a coarsening upward succession, and probably reflect increasing energy level during deposition.

The lower part of Unit A contains pyrite filled burrows, while siderite is more common above 107 m. Both minerals indicate reducing environment during deposition, in the upper part of the sequence. The pyrite indicates more reducing environment in the lower part of Unit A than in the upper part.

The calcite cemented bed with a siderite concretion at 101.5 m indicates a very slow accumulation rate. This bed probably correlates with a faint continuous seismic reflector. The bed may therefore represent an event of slow deposition caused by a transgression.

Unit B contains current ripple laminated sandstone lenses and beds, with intraformational grains. The sandstone indicates increasing energy during deposition with possible reworking of underlying deposits. The shallow seismic profile also indicates some erosion of the underlying deposits. The 15 cm thick calcite cemented sandstone bed at 86.3 m comprises the abrupt transition to the silty claystones of Unit C. The boundary indicates a drop of the energy in the depositional environment, and may represent a transgression.

Unit C does not display sedimentary structures which indicate deposition above storm wave base, and is consequently interpreted to be a deep shelf deposit. The siderite and phosphate containing bed at 82 m may indicate a period of low sedimentation. More oxygenated bottom conditions in Unit C than in unit A is indicated by more abundant bioturbation and a higher proportion of calcareous benthic foraminifera.

3.5 Core 7323/12-U-01

3.5.1 Summary

In core 7323/12-U-01 60.6 m of bedrock was drilled in the interval between 69.2 and 129.8 m below the sea floor, with 100% core recovery. The core has been divided in litho-units A and B at the 102.3 m level (Figure 3.5.1), coinciding with a seismic sequence boundary.

The lower Unit A (27.5 m thick) consists of a generally coarsening upward section of calcareous claystones, glauconitic limestones and greensands.

Unit B (33.1 m thick) consists of a fining upward sequence of limestones (80-90 % *Inoceramus* prisms) and calcareous claystones.

The sediments are all strongly bioturbated with common *Zoophycos*, *Teichicnus* and *Chondrites* type of burrows, probably deposited below the photic zone in an open, well oxygenated deep shelf environment.

Palynomorphs, nannofossils and foraminifera indicate a more or less continuous sequence of Middle Turonian to Santonian age. The seismic sequence boundary is located within an interval dated as Coniacian to Santonian.

The core is extremely poor in organic matter, which belongs to the hydrogen-poor kerogen type IV and lacks any significant hydrocarbon generation potential. Vitrinite reflectance and Rock-Eval Tmax values could not be obtained from this core due to the strong reworking and oxidation of the organic material, however, thermal alteration indices of 3-3.5 suggest that this material is thermally immature.

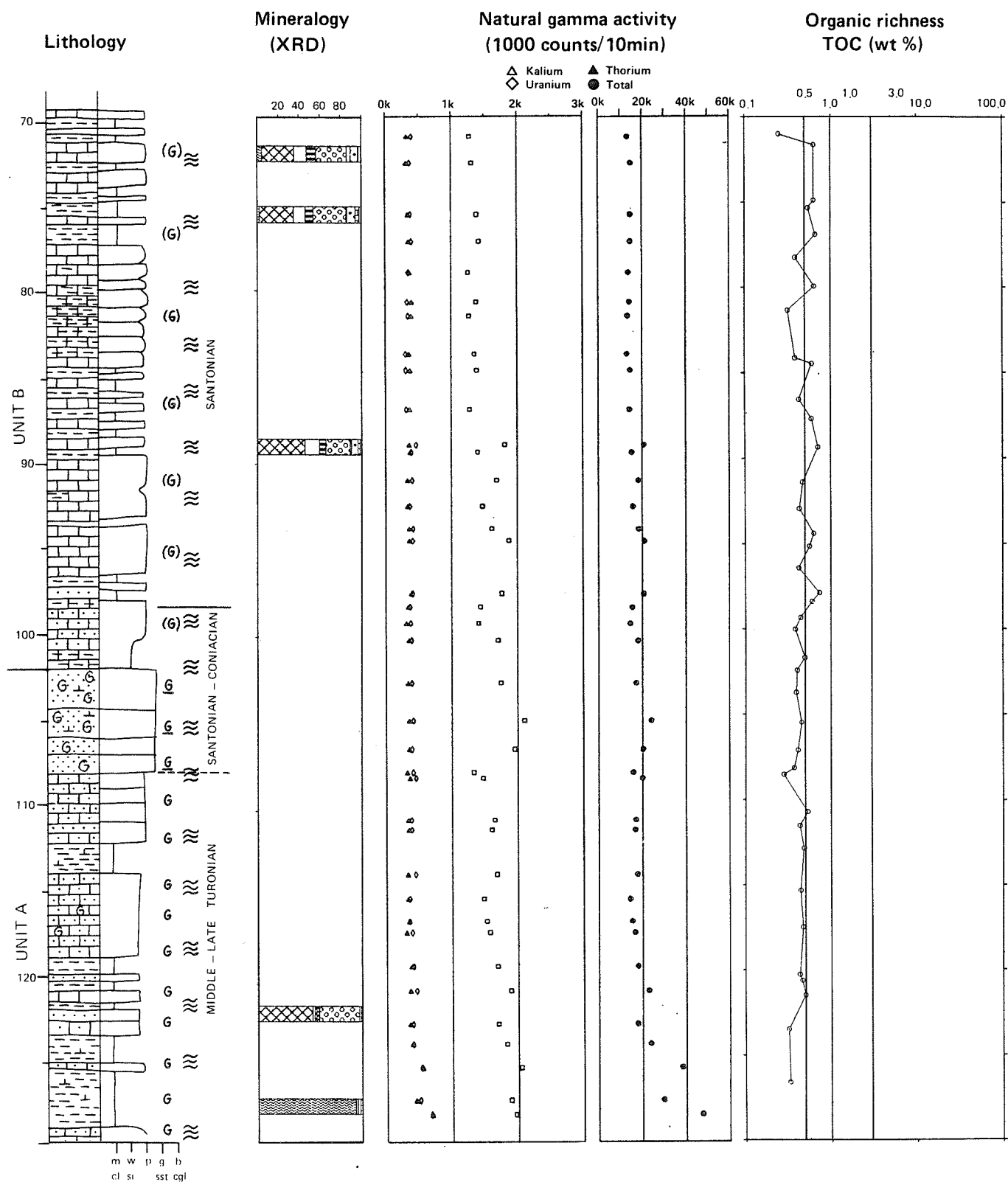


Figure 3.5.1 Summary figure of core 7323/12-U-01. Legend in Appendix A.3.

3.5.2 Seismic interpretation

The objective at this site was to penetrate the youngest sequence boundary in the area (see Chapter 3.4.2). The underlying sequence, of which the base was cored at site 7324/07-U-01, has apparently been slightly eroded and is truncated by the sequence boundary at the present site. The sequence is thinning along the line, but from the sparse seismic data available it is not possible to decide whether part of the thinning could be a primary depositional feature.

The seismic sequence boundary is probably found at 112.3 m in the core. One unit boundary below this (at 123.5 m) and two above (at 102.3 m and 89.4 m) are correlated with seismic reflectors (see Figure 3.5.2 and Table 3.5.1). The reflector at 102.3 m is much stronger than the one which is interpreted as the sequence boundary, and it is probably composed of reflections from more than one interface.

Table 3.5.1 Key data of the correlation between core 7323/12-U-01 and seismic line IKU-21-87.

Depth below seabed		Core unit	Thickness of seismic unit		Interval sound velocity
69.0 m	72.6 msec	Overburden	69.0 m	72.6 msec	1900 m/s
		B	20.4 m	17.0 msec	2400 m/s
89.4 m	89.6 msec	B	12.9 m	10.5 msec	2460 m/s
102.3 m	100.1 msec	A	10.0 m	8.0 msec	2500 m/s
112.3 m	108.1 msec	A	11.2 m	9.0 msec	2500 m/s
123.5 m	117.1 msec	A	5.8 m	4.6 msec	2500 m/s (estimated)
TD129.3 m	121.7 msec				
Total TD below sea surface: 531.3 m / 671 msec					

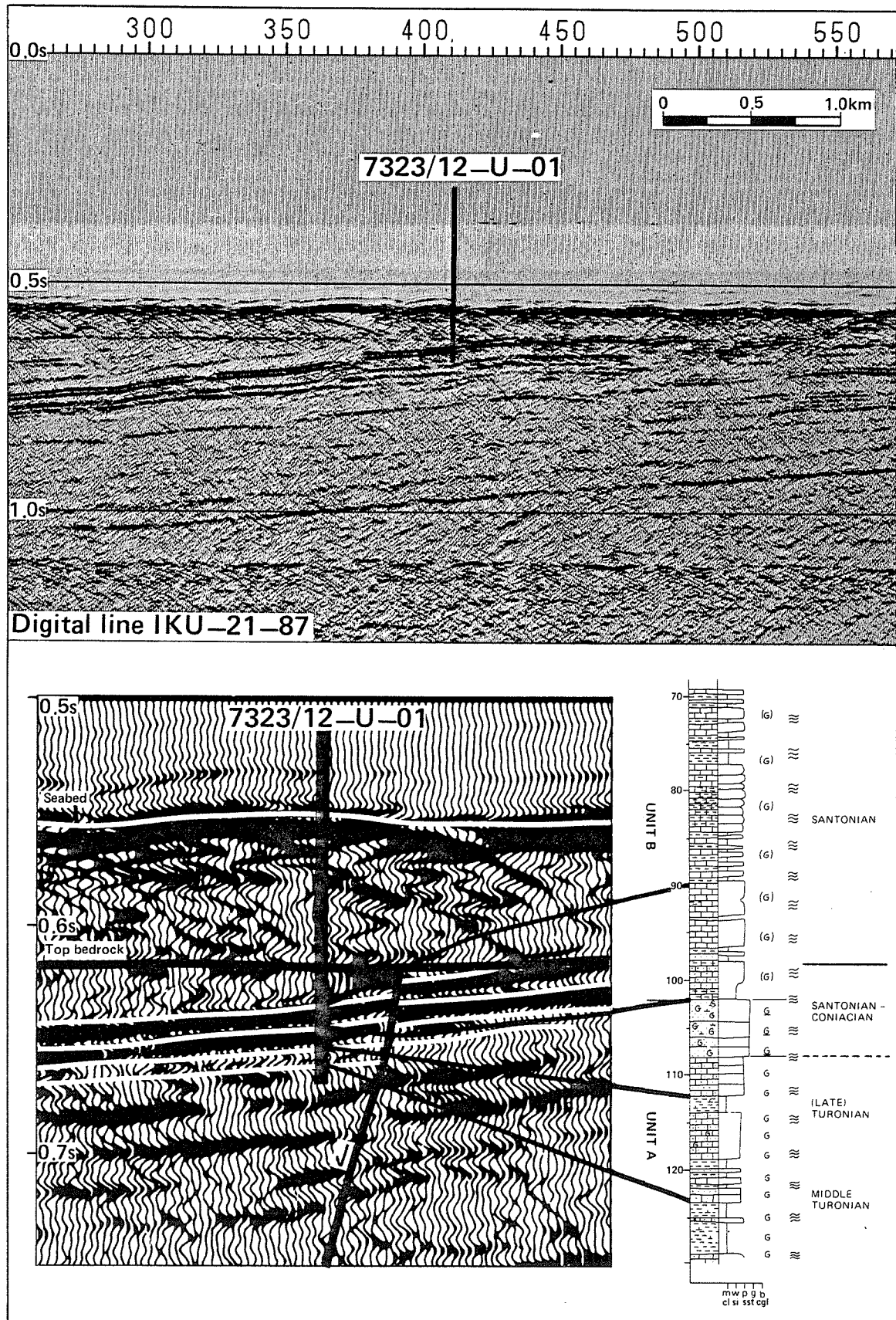


Figure 3.5.2 Correlation between core 7323/12-U-01 and seismic data.

3.5.3 Sedimentology

Core description

Totally 60.6 m of rocks were cored between 69.2 and 129.8 m below sea floor. The core recovery was 100 %.

A sedimentological column of the core is shown in Figure 3.5.3. Below 102 m the rocks contain abundant glauconite, while glauconite is less common above. The core is consequently subdivided in two units with the boundary at 102.3 m. Phosphorite and glauconite pebbles up to 5 mm in diameter occur at the boundary bed.

The lowermost Unit A shows a coarsening upward trend caused by an increase in glauconitic packstones/greensands relative to the claystone rich lowest part. The medium dark grey calcareous claystones are strongly bioturbated, mainly by *Zoophycos*. The burrows are often filled with glauconitic grains.

The uppermost glauconitic packstones/calcareous greensands are light grey to greenish in colour. Thin section studies (see below) show that the rocks consist of 30 to 60 % *Inoceramus* fragments, 20 to 60 % glauconitic pellets, 5 to 20 % calcareous pellets, up to 5 % clastic grains (predominantly quartz, but also feldspars, micas, tourmalines and zircons) with trace amounts of foraminiferal fragments, often embedded in a clayey matrix.

Both the greensands and the glauconitic limestone/greensands are very strongly bioturbated, mainly by *Zoophycos*, *Teichicnus* and *Chondrites*.

Unit B displays a fining upward trend in grain size as the claystone content slowly increases.

Light grey packstones and grainstones contain subordinate amounts of wackestone with calcareous claystone matrix. The limestone beds are strongly bioturbated. *Zoophycos*, *Teichicnus* and *Chondrites* types of burrows are common.

7323/12-U-01

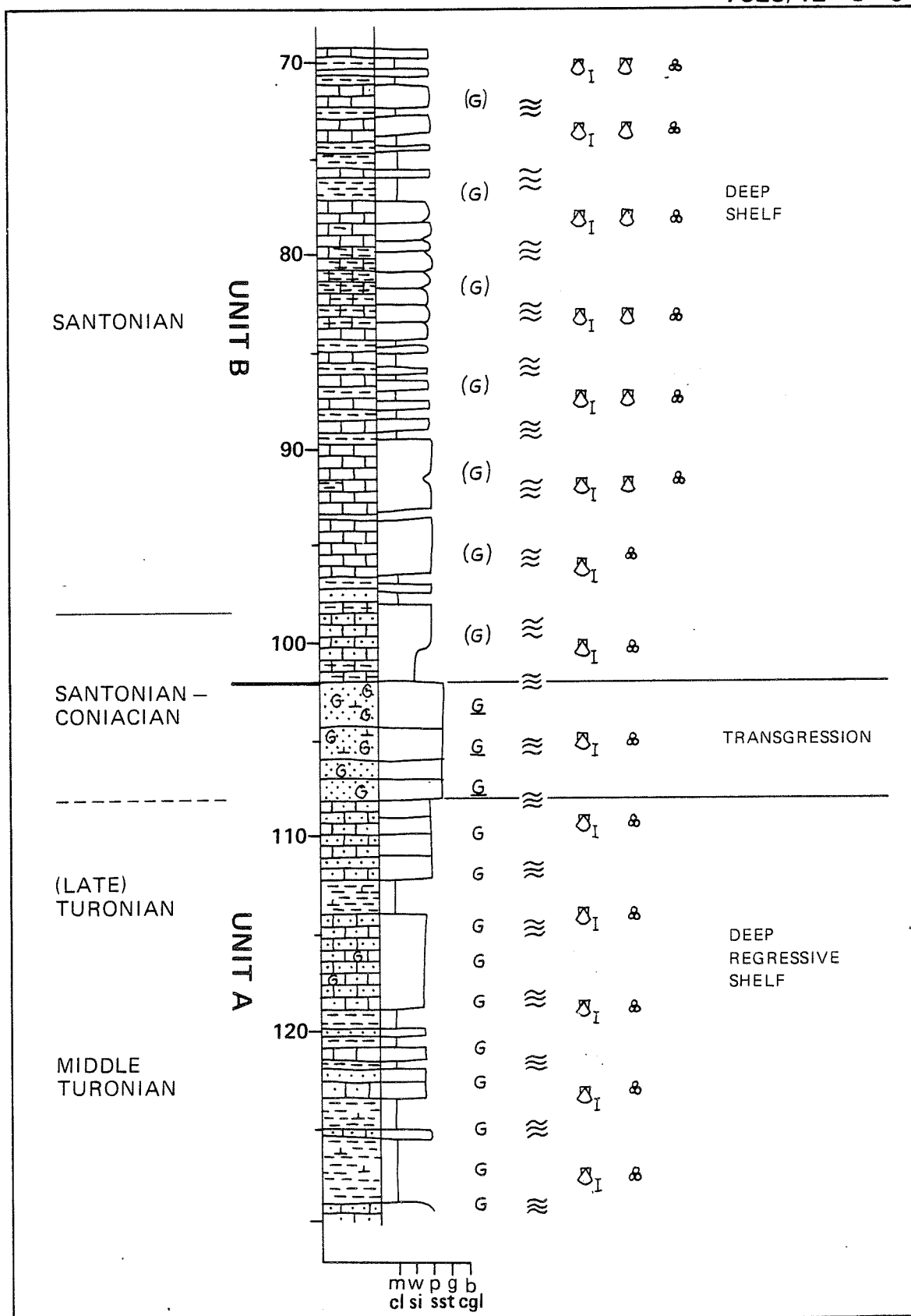


Figure 3.5.3 Simplified log of core 7323/12-U-01. Detailed log in scale 1:50 is found in Appendix A.5.

Thin section observations show (see below) that the limestones consist of 80 to 90 % *Inoceramus* prisms and fragments, 5 to 15 % pellets, scattered glauconite grains, foraminiferal fragments and very few clastic silt grains. Above 93 m also other type of bivalve fragments occur. The fossil fragments show 100-300 µm wide borings (?sponges), but no clear algal borings have been observed.

The medium dark grey claystone is strongly bioturbated. *Zoophycos* type of burrows is the most common, but also *Chondrites* occur. The burrows are commonly filled with packstones.

Petrography

The present investigation is based on 26 thin sections, five are also studied under the scanning electron microscope.

The thin sections are dominated by packstones. *Inoceramus* fragments are the major constituent and contribute to 30 to 60 % of Unit A, and 80 to 95 % of Unit B. Normally the fragments are single prisms, but also large (2 cm thick) shell fragments occur. Above 92 m also other bivalve fragments are present. The shell fragments and clastic grains show little evidence of mechanical abrasion and most grains are angular. Other constituents are foraminifera, pyritized radiolarians and calcareous nannoplankton. Fecal pellets are fairly common (5-20 %) in both units, while clastic grains as quartz, alkalifeldspars, albite, micas, zircons, tourmalines, and opaques also occur. In Unit A the clastic content is about 5 %, while it is very small in Unit B. In Unit A the clastic grains are of fine grained sand, while they seldom are larger than siltgrains in Unit B. The matrix in Units A and B consists of clay minerals without any significant amount of fine grained carbonite minerals.

Glauconite is a very important constituent in the limestone of Unit A where it contributes with 20 to 60 %. In Unit B it is less common, and contributes with less than 5 % of the rocks. Most grains are about 0.25 mm in diameter, but may be up to 5 mm. They are elliptical to spherical with a smooth surface (Figure 3.5.4). Radial fractures, a few microns wide, that widen outward in the grains are very common. These fractures are often filled with the surrounding matrix, but in a few occasions they may be

filled with glauconite. The fractures are probably developed during the expansional growth of glauconite. A few irregular glauconite masses also occur as well as partial glauconitization of some *Inoceramus* fragments. Glauconite is also present as filling of foraminifera chambers, of borings of shell fragments and as inclusions in phosphorite grains.

The colour of glauconites is bright green in thin sections from Unit A, while it usually is lighter green with yellowish interference colours in samples from Unit B. Some grains show zonation with a brownish central part and a bright green rim. The brown colour is probably caused by limonitic inclusions in the glauconites. Chemical analyses of glauconites have been carried out from two intervals (Table 3.5.2). The analysis shows that the mineral is highly evolved glauconites in accordance to Odin & Matter (1981).

Phosphorite is present in the upper part of Unit A. It occurs as 0.25 to 2 mm large black grains. In thin sections the phosphorite is microcrystalline and brownish with inclusions of clay matrix, pyrite and glauconite grains.

Pyrite is present in small amounts in all thin sections (Figure 3.5.5). It occurs as less than 50 μm large spherically to irregularly shaped grains in burrows, as minor cement in grain supported rocks, as filling of borings in some shell fragments, and as filling of a few foraminifera chambers. It has also been discovered as replacement of silica in radiolarian tests.

Borings in shell fragments are very commonly recognized in thin sections. There are several types of borings, related to the diameter of the tubes. Most shell fragments show 50 to 150 μm wide borings. They are spherical and/or pear-shaped in cross sections, and most commonly have a smooth surface. The borings usually are empty, but they may also be filled with glauconite, pyrite and clay matrix. In some large *Inoceramus* fragments, borings up to 350 μm occur.

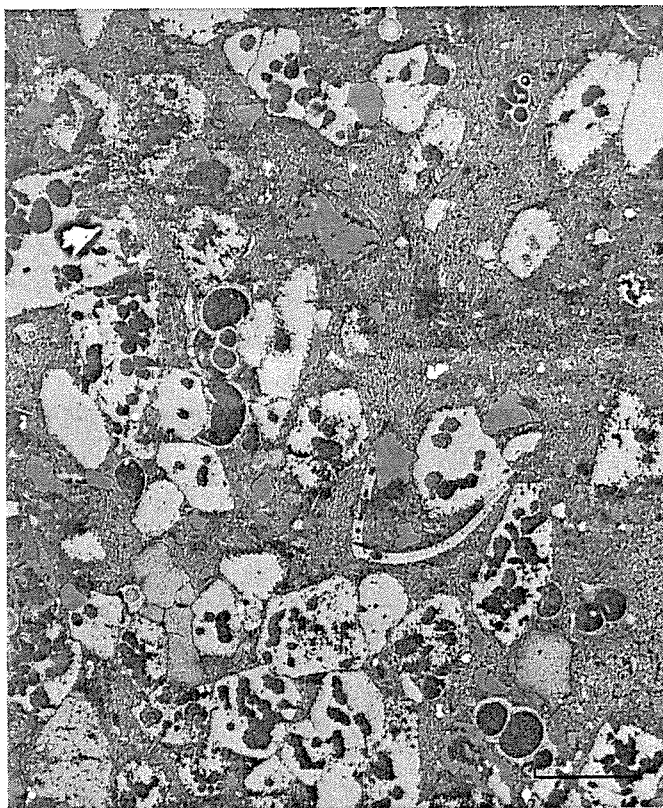


Figure 3.5.4 Backscattered electron microscope image of a claystone (dark grey) rich lamina with scattered glauconite grains (lighter grey, smooth surface), *Inoceramus* prisms (slightly darker gray than glauconite), and abundant sideritized foraminifera fragments (white). Notice also the borings in the *Inoceramus* prisms. Sample 117.90 m. Bar is 0.1 mm.

Table 3.5.2 Calculated chemical formulas of glauconites with 11 oxygen atoms in the general formula.

100.81 m	: K _{.70} Na _{.01}	(Fe _{1.24} Mg _{.41} Al _{.30})	(Si _{3.83} Al _{.17})	O ₁₀	(OH) ₂
100.83 m	: K _{.69} Na _{.03}	(Fe _{1.22} Mg _{.40} Al _{.32})	(Si _{3.84} Al _{.16})	O ₁₀	(OH) ₂
100.85 m	: K _{.69} Na _{.01}	(Fe _{1.22} Mg _{.40} Al _{.32})	(Si _{3.88} Al _{.12})	O ₁₀	(OH) ₂
100.87 m	: K _{.67} Na _{.01}	(Fe _{1.16} Mg _{.41} Al _{.38})	(Si _{3.86} Al _{.14})	O ₁₀	(OH) ₂
100.89 m	: K _{.67}	(Fe _{1.16} Mg _{.38} Al _{.20})	(Si _{3.74} Al _{.26})	O ₁₀	(OH) ₂
112.30 m	: K _{.71} Na _{.03}	(Fe _{1.11} Mg _{.41} Al _{.43})	(Si _{3.81} Al _{.19})	O ₁₀	(OH) ₂
112.31 m	: K _{.68}	(Fe _{1.08} Mg _{.41} Al _{.47})	(Si _{3.83} Al _{.17})	O ₁₀	(OH) ₂
112.32 m	: K _{.67} Na _{.02}	(Fe _{1.06} Mg _{.42} Al _{.50})	(Si _{3.80} Al _{.20})	O ₁₀	(OH) ₂
112.33 m	: K _{.65} Na _{.05}	(Fe _{1.06} Mg _{.41} Al _{.48})	(Si _{3.83} Al _{.17})	O ₁₀	(OH) ₂
112.34 m	: K _{.71}	(Fe _{1.15} Mg _{.40} Al _{.40})	(Si _{3.80} Al _{.20})	O ₁₀	(OH) ₂

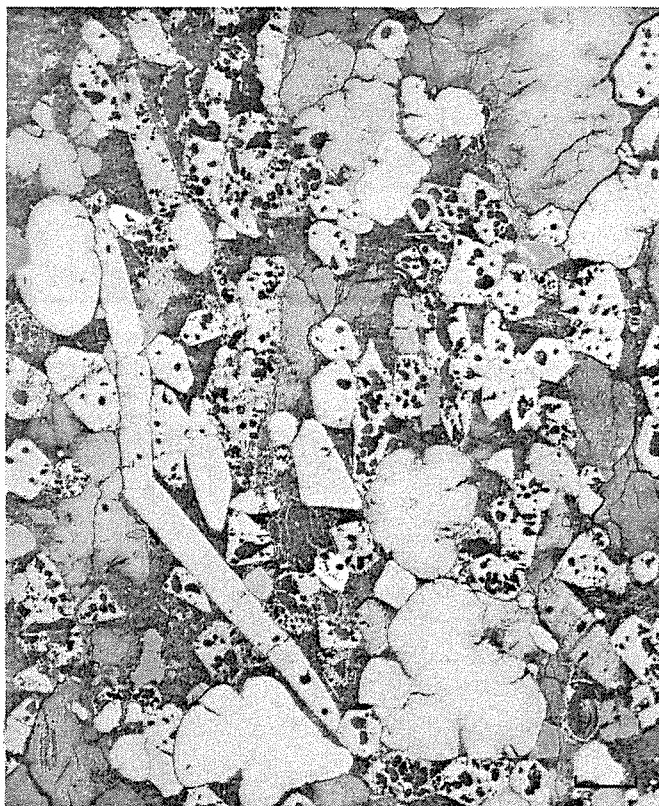


Figure 3.5.5 Backscattered electron microscope image of glauconite sandstone consisting of glauconite grains (grey), *Inoceramus* prisms (grey, elongated fragments), in a clayey (darkest grey) matrix with scattered pyrite (white). Sample 112.05 m. Bar is 0.1 mm.

X-ray diffraction

Five samples from core 7323/12-U-01 are analysed for whole rock and clay mineral composition (Figures 3.5.6 and 3.5.7, Tables 3.5.3 and 3.5.4). The whole rock diffraction profiles show the presence of abundant clay minerals in addition to quartz and feldspars (mainly albite) and some calcite. The clay mineral reflections show the presence of chlorite and illite. In addition there are broad reflections between the 10 Å and 14 Å reflections, usually with a maximum at about 12.2 Å, and a small 14 Å reflection with a "shoulder" at the low angle side.

The diffraction profiles of the clay mineral fractions (<4 µm) are all dominated by a reflection equivalent to value of ~14 Å. It is usually broad and high compared to the 10 Å reflection, thereby overprinting possible

reflections in the 10-14 Å area. Other reflections present are those of chlorite (7 Å, 4.74 Å and 3.54 Å) and quartz (4.26 Å and 3.34 Å).

By heating at 600 °C for 2 hours the intensity of the 14 Å reflection decreases and the intensity of the 10 Å reflection increases. The remaining reflection at 14 Å shows the presence of chlorite.

Glycol saturation produces two kinds of patterns. The samples from 72.11 m, 121.68 m and 127.05 m show well defined reflections of expanded material (d ~ 17 Å). The samples from 75.56 m and 89.01 m show a broad reflection about 14-15 Å. The analyses show that the clay mineral fraction is composed of smectite as the major component, and illite and chlorite as less abundant components. The broad reflections of the glycolated samples from 75.56 m and 89.01 m also indicate the presence of interlayered chlorite-smectite. Due to the broad and intense reflections of smectite in the untreated samples, possible interstratification of illite-smectite is not evaluated except for the sample from 127.05 m. The untreated sample shows a narrow peak which splits into two peaks (10 Å and 16.4 Å) upon glycol saturation, indicating randomly interlayered illite-smectite with an illite/smectite ratio of 1/9.

The low 10 Å reflection in Unit A compared with Unit B shows that glauconite (Figure 3.5.3) in Unit A must be concentrated in the limestones. The presence of smectite in these samples demonstrates immature diagenetic grade and that the temperature never exceeded 70 °C.

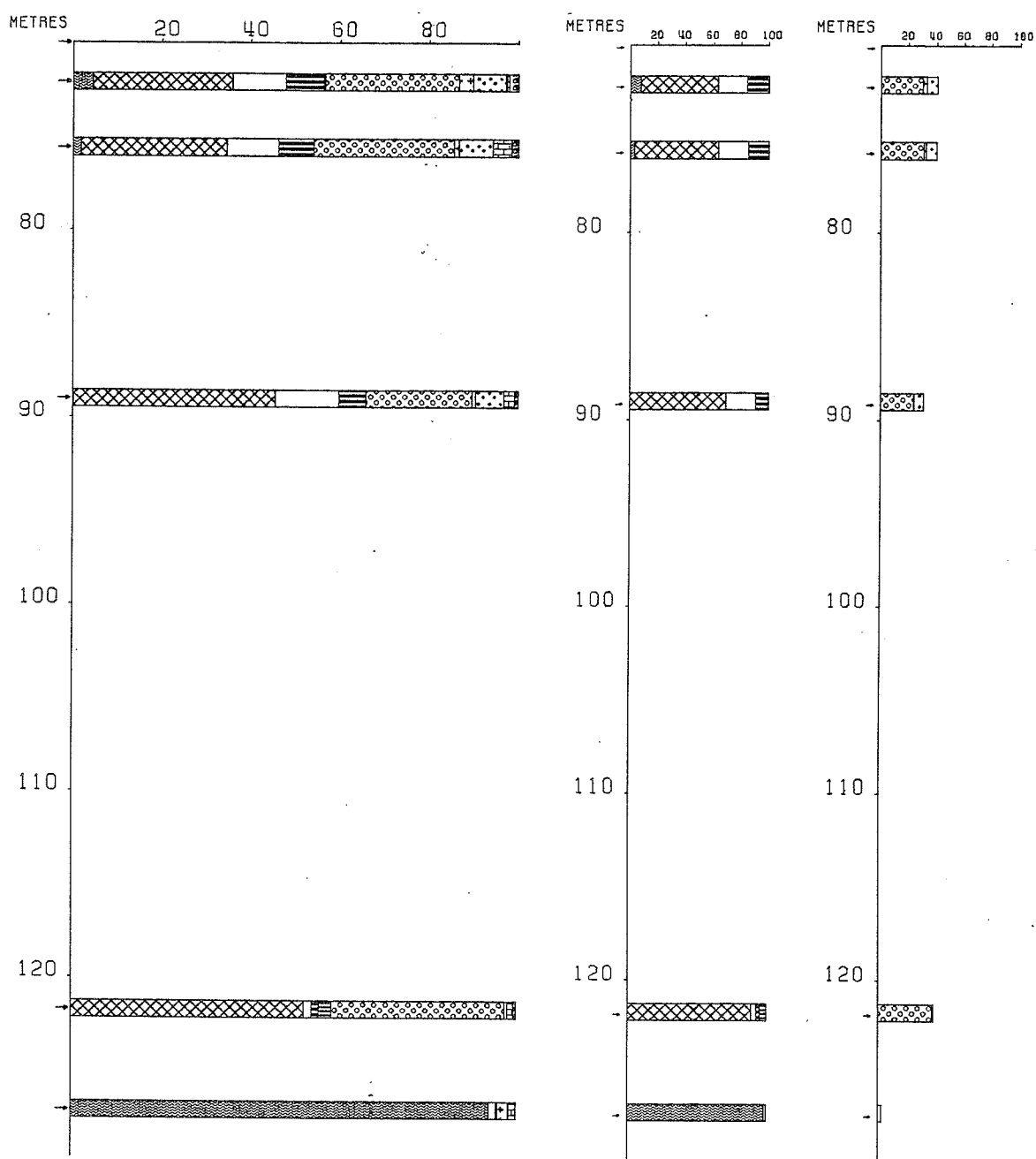


Figure 3.5.6 Whole rock mineralogy from core 7323/12-U-01 based on XRD analysis. Legend in Appendix A.3.

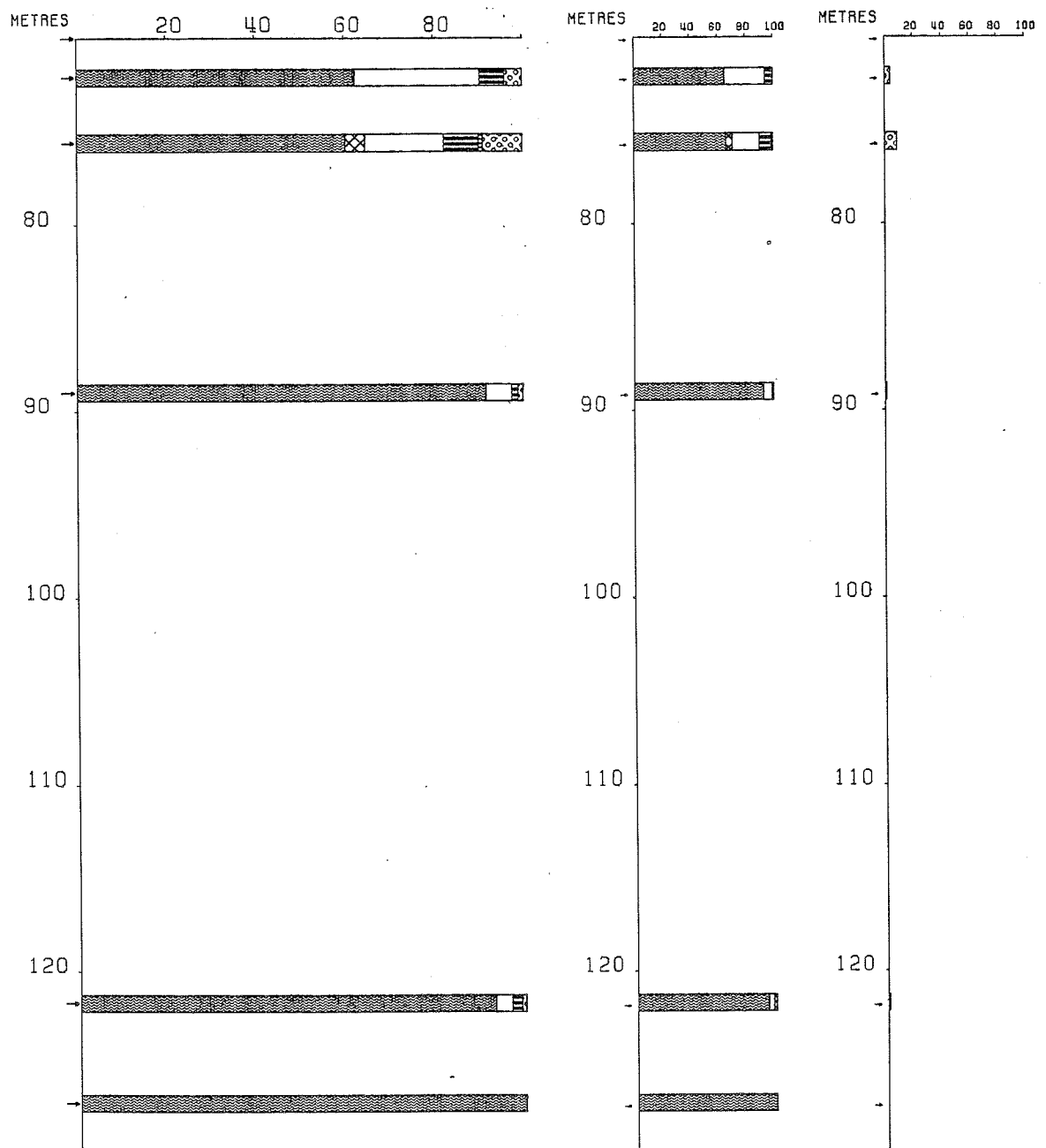


Figure 3.5.7 Clay mineralogy (< 4 micron) from core 7323/12-U-01 based on XRD analysis. Legend in Appendix A.3.

Table 3.5.3 Tabulated values from XRD analysis of whole rock sample, of core 7323/12-U-01. The values represent semiquantitative wt%. See Appendix A.3 for details.

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %
72.11	D-1445	4.5	11.9	8.6	0.4	29.9	3.3	7.3	0.2	0.0	0.5	0.0	2.1
89.01	D-1476	0.1	14.2	6.1	0.0	23.8	0.8	6.3	2.4	0.0	0.0	0.0	0.8
121.68	D-1529	0.0	1.8	1.6	2.8	38.9	0.0	0.7	1.3	0.0	0.0	0.0	0.6
127.05	D-1539	94.0	1.6	0.0	0.0	0.2	2.5	0.1	1.6	0.0	0.0	0.0	0.0
75.56	D-1454	1.8	11.5	7.9	0.1	31.3	1.1	7.7	4.1	0.0	0.2	0.0	1.4

Table 3.5.4 Tabulated values from XRD analysis of clay fraction (< 4 micron) sample, of core 7323/12-U-01. The values represent semiquantitative wt%. See Appendix A.3 for details.

Depth m	IKU no	Smect %	Mica %	Chl %	Kaol %	Qtz %	KFsp %	Plag %	Calc %	Dolo %	Sidr %	Apat %	Pyr %	Expand 14-17A
72.11	D-1445	62.6	27.9	5.6	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Expands
75.56	D-1454	60.3	17.6	7.9	0.9	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Partly
89.01	D-1476	91.6	5.8	1.4	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Partly
121.68	D-1529	93.3	3.6	2.2	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Expands
127.05	D-1539	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Expands

Diagenesis

Mechanical and chemical compaction are the most important porosity reducing processes in the investigated rocks, and cementation is less pronounced. Mechanical compaction is indicated by:

- the dense packing of the solid grains of the rocks,
- the commonly observed squeezed glauconite grains,
- the fairly frequently broken shell fragments.

The dense packing of grains indicates that grains in contact were allowed to move during fairly shallow burial. This stage must have caused important reduction of porosity as the original porosity in the rocks probably was fairly high.

Pressure solution at grain contacts is indicated by some long or convex-concave contacts. The amount of grains dissolved during this stage of diagenesis is low.

An up to 50 µm thick coating of syntaxial calcite cement is seen on some *Inoceramus* fragments. The cement was probably derived from pressure solution of the shell fragments.

Petrophysics

Natural γ -radiation

The natural γ -radiation from thorium and uranium shows only minor variations above 124 m. Below 124 m, the activity increases due to the change in lithology from very fine grained sandstone to claystone. The potassium variation reflects the content of potassium bearing minerals, in this case the glauconite content. The highest activity is measured at about 105 m where glauconite is most abundant.

The log of the total γ -activity shows increasing values up to 124 m, due to high uranium and thorium activities in the smectite rich claystone. Between 124 m and 89 m the glauconite varies, but is very uniform above 89 m (Figure 3.5.8).

Sound velocity

The sound velocity measurements (Figure 3.5.8, Table 3.5.5) vary extensively both vertically and horizontally. Some of them are obviously too low because of expansion and fracturing due to stress release of the core. Most of the variations are, however, probably due to the many lithological variations in the core. When the values from low velocity silt-/claystone layers are excluded, the average velocities are in fair agreement with the interval sound velocities calculated from correlation between the core and the seismic data (Table 3.5.1). The interval velocities are slightly lower, and as they represent mainly vertical velocities and the core measurements mainly horizontal velocities, we find it a reasonable trend with the anisotropy observed in the core.

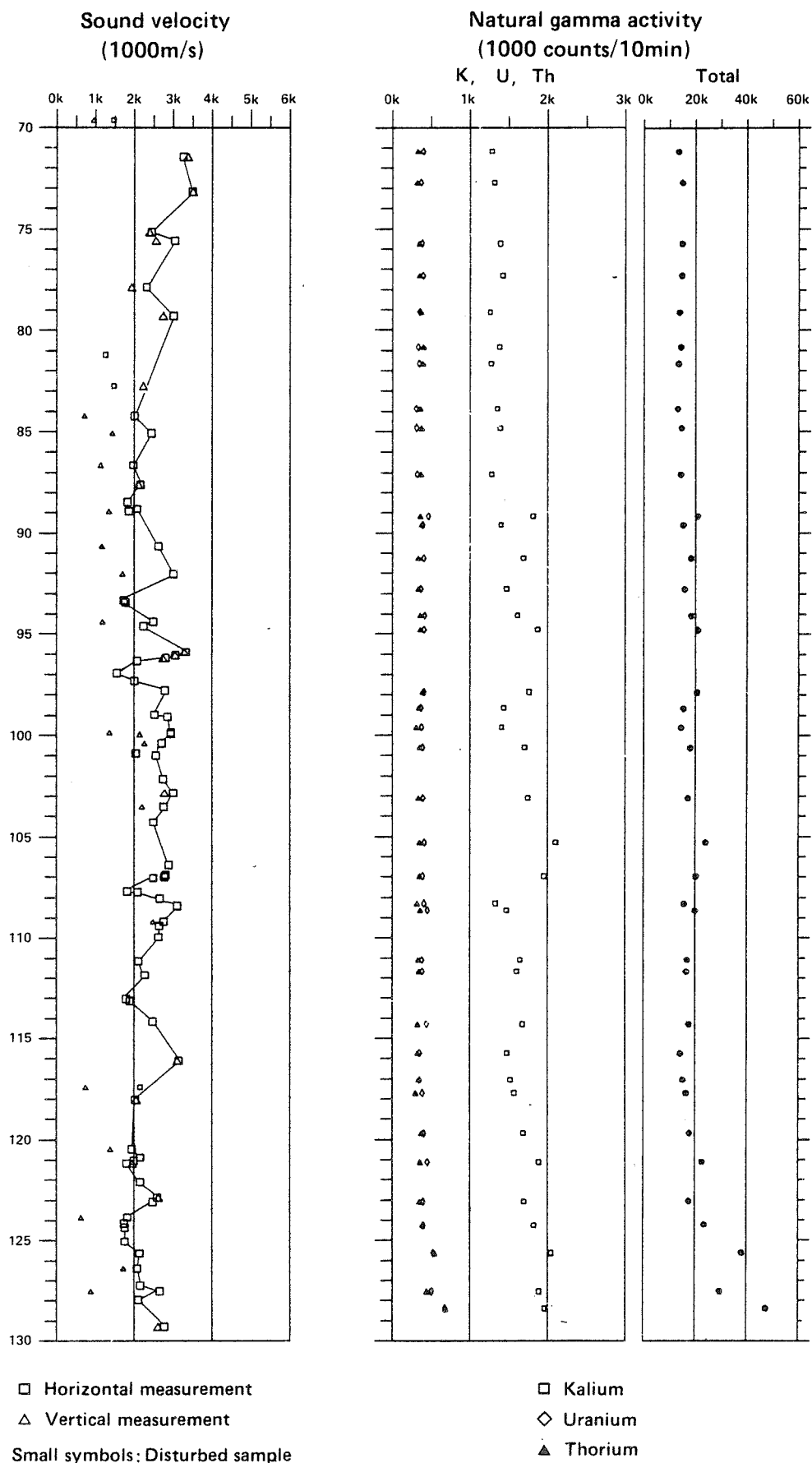


Figure 3.5.8 Natural γ -radiation (counts per 10 minutes) and sound velocity (m/s) in core 7323/12-U-01.

Table 3.5.5 Sound velocity (m/s) in core 7323/12-U-01.

Depth m	Horiz. velocity m/sec	Vert. velocity m/sec	Depth m	Horiz. velocity m/sec	Vert. velocity m/sec
69.66	1465 *	946 *	103.54	2760	2196 *
71.46	3267	3386	104.29	2493	0
73.19	3490	3511	106.39	2894	0
75.16	2439	2395	106.89	2809	0
75.59	3051	2560	106.99	2776	0
77.88	2322	1935	107.04	2491	0
79.27	3022	2750	107.69	1834	0
81.21	1266 *	0	107.74	2093	0
82.75	1483 *	2236	108.06	2658	0
84.22	2007	719 *	108.39	3122	0
85.08	2443	1427 *	109.19	2755	2482 *
86.64	1985	1131 *	109.39	2650	0
87.62	2160	2112	109.94	2637	0
88.45	1822	0	111.14	2105	0
88.80	2081	0	111.84	2274	0
88.93	1869	1348 *	113.04	1800	0
90.66	2634	1166 *	113.14	1898	0
92.04	3017	1701 *	114.14	2472	0
93.34	1736	0	116.10	3140	3114
93.44	1778	0	117.39	2160 *	757 *
94.39	2493	1188 *	118.04	2030	2061
94.59	2245	0	120.47	1939	1383 *
95.89	3327	3311	120.88	2155	0
96.06	3057	3060	121.03	1989	0
96.19	2807	2746	121.18	1815	1956
96.34	2077	0	122.08	2155	0
96.92	1565	0	122.88	2601	2628
97.32	2007	0	123.08	2486	0
97.77	2798	0	123.84	1831	644 *
98.97	2523	0	124.14	1751	0
99.07	2862	0	124.34	1768	0
99.85	2945	1373 *	125.04	1767	0
99.95	2940	2150 *	125.64	2147	0
100.40	2704	2271 *	126.39	2085	1714 *
100.90	2053	0	127.25	2156	0
101.00	2569	0	127.53	2663	890 *
102.15	2751	0	127.95	2114	0
102.84	3017	2779	129.28	2774	2618

*) Velocities from samples marked by * represent disturbed samples.

3.5.4 Paleontology

Palynology

The presence of *Hystriochphaeridium difficile* in all the five examined samples between 128.85 and 120.68 m (Figures 3.5.9 and 3.5.10) points to a Middle Turonian or younger age for the bottom of the core according to Foucher (1979, 1981). At 124.55 and particularly at 122.93 m the species occur in high numbers. The latest occurrence of this species at 120.68 m coincides with the highest observation of *Surculosphaeridium longifurcatum* and seems to be of some biostratigraphical significance. *Xiphophoridium alatum* has been recorded at 122.93 and 120.68 m and may restrict the dating up to 120.68 m to the Middle Turonian (Foucher 1979), but *H. difficile* and *S. longifurcatum* both range higher elsewhere.

Representatives of the *Cleistosphaeridium multifurcatum/distinctum* group are abundant at 104.34 and 98.40 m and this event may be used in a local zonation.

Dinoflagellate type E Ioannides 1986 and *Spinidinium lanternum* have well defined first occurrences at 95.62 m, but the interpretation of this in terms of stage assignation is uncertain.

Florentinia tenera at 92.95 m suggest that post Turonian strata have been reached. Davey & Verdier (1976) recorded *F. tenera* down to 10 m above what they interpreted as the Turonian/Senonian boundary in a French borehole.

The palynoassemblages above 100 m have many elements in common with the Arctic Canadian Santonian to early Campanian palynological Division H1 of McIntyre (1974) and the Santonian to Campanian palynological interval I of Ioannides (1986), but the changes within Division H1 commented on by McIntyre cannot be recognized. Manum & Cookson (1964) also studied a sample from Arctic Canada with a palynoassemblage of the same general character. This sample has later been referred to the Santonian-Campanian lower Kanguk Formation (Felix & Burbridge 1976). Coniacian microfloras have not been studied from Arctic Canada due to a disconformity in the area.

The upper part of the core cannot be very accurately dated on the basis of dinoflagellate cysts due to somewhat imprecisely dated sections in areas

with comparable floras, but our Santonian to early Campanian dating is in good agreement with the Santonian dating as indicated by the foraminifera.

Microfauna

Common to very abundant occurrences of *Inoceramus* prisms are recorded throughout (Figures 3.5.11 and 3.5.12). Scattered occurrences of radiolarians, fish debris, echinoderms and (fragmented) ostracods were also recorded. The foraminiferal faunas were in general poor in the lower half and fairly rich to very rich and diverse in the upper half of the core. Agglutinated and calcareous dominated faunas alternate throughout.

The lowermost part of the core contains but few age significant forms, and is dated by palynomorphs to be of Middle Turonian or younger age. However, the upper boundary of this interval is based on the occurrence of *Lingulogavelinella globosa* at the 117.50 m level. This widely distributed species is assigned a Late Cenomanian - Middle Turonian range by Hart et al. (1981). The Turonian (or older) age on this lower interval is supported by the presence of *Gavelinella* cf. *belorussica*, *Textularia foeda* and *Uvigerinammina* sp. Poorly preserved planktonic foraminifera (117.50 m) were tentatively referred to the genus *Whiteinella*, and no age conclusions were drawn on this occurrence.

The lower boundary of the Santonian interval (98.40-69.0 m) is dated by means of nannofossils. Initially there was some discussion whether the Campanian stage was represented in the core. A number of foraminifera represented in the uppermost sample (69.73 m) are known to straddle the Santonian - Campanian boundary, e.g. *Pullenia cretacea*, *Gavelinella pertusa*, *Cibicides ribbingi*, *Ramulina kittli*, *G. sandidgei*, *Gyroidinoides nitidus*, *G. girardanus*, *Osangularia cordieriana*, *Globorotalites michelinianus*, *Praebulimina reussi* and *Loxostomum eleyi*. The presence of *Ataxophragmium* (?) cf. *compactum* and *Lingulogavelinella* cf. *vombensis* (sensu Hart et al. 1981), however, shows that the entire interval is within the Santonian stage (Hanzlikova 1972 and Hart et al. 1981, respectively).

The record of *Planulina* aff. *lundegreni*, which tops in sample 98.40 m, the first appearance of *O. cordieriana* at the same level and *Stensioeina granulata granulata* (86.93 m) may infer a mid Coniacian age in the lowermost 10 - 12 m of this

interval (compared to the British succession as reported by Hart et al. 1981). However, *S. granulata granulata*, which by far possesses the best chronostratigraphical potential of the three forms mentioned, is also recorded in the basal Santonian.

Nannofossils

The deepest occurrence of *Eiffellithus eximius* (at 118.10 m, Figures 3.5.13 and 3.5.14) is characteristic for the base of zone CC 12 (Late Turonian, Perch-Nielsen 1985). However, Mortimer (1987) who studied North Sea material, situated the first appearance of this species at the base of the Middle Turonian. According to this author, the earliest appearance of *Eiffellithus eximius* and *Ahmuellerella octoradiata* (at 121.08 m and upwards) are virtually coeval and fits well to the observations in our core.

One specimen of *Marthasterites furcatus* at 108.15 m gives evidence of a Coniacian age. Most samples from the interval 107.12-102.20 m are barren or have an extremely poor nannofossil content.

Calcareous nannoplankton

A few representatives of typical *Micula concava* have been recorded from 98.40 m and above. It has its earliest appearance in zone CC 15, that is slightly younger than basal Santonian. Typical specimens are very rare in this borehole. *Reinhardtites anthophorus* at 91.40 m confirms the attribution to an age that is not earlier than the CC 15 zone. Positive evidence of a later age than zone CC 15 is not available. The sample quality in this interval is very variable. Above 81.91 m, all samples are barren.

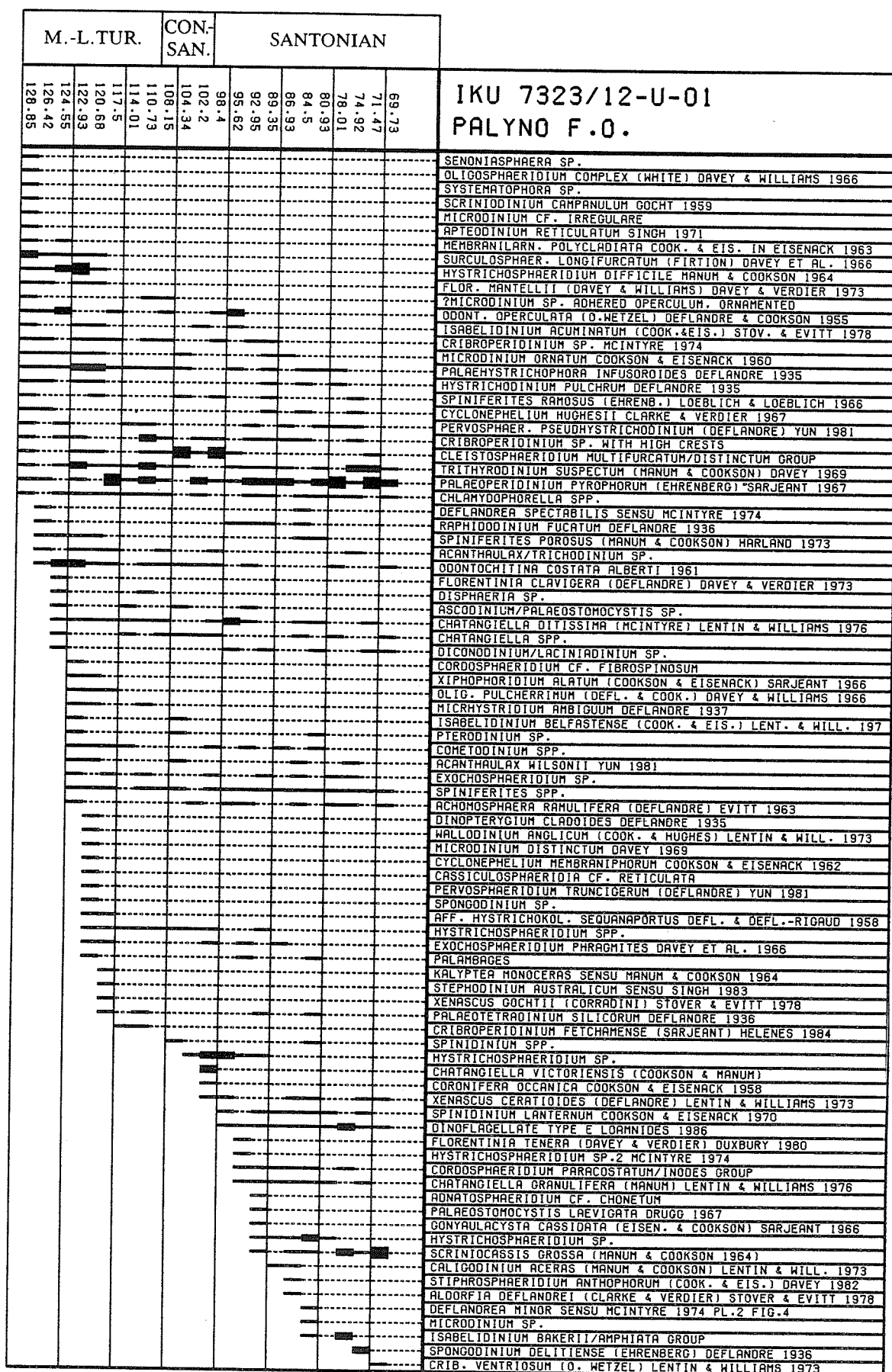


Figure 3.5.9 Palynological range chart of core 7323/12-U-01.
(Sorted according to first occurrence).

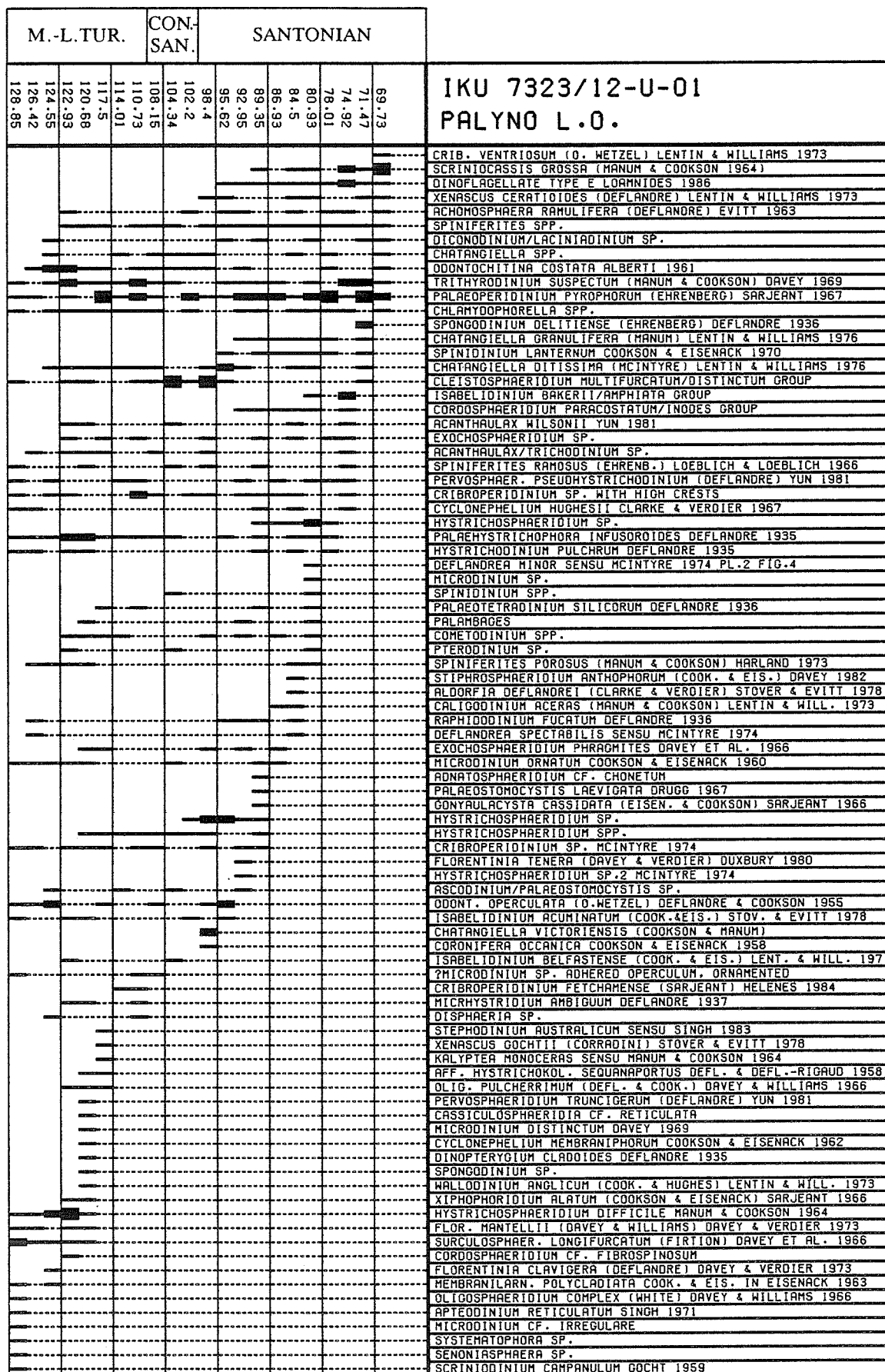


Figure 3.5.10 Palynological range chart of core 7323/12-U-01.
(Sorted according to last occurrence).

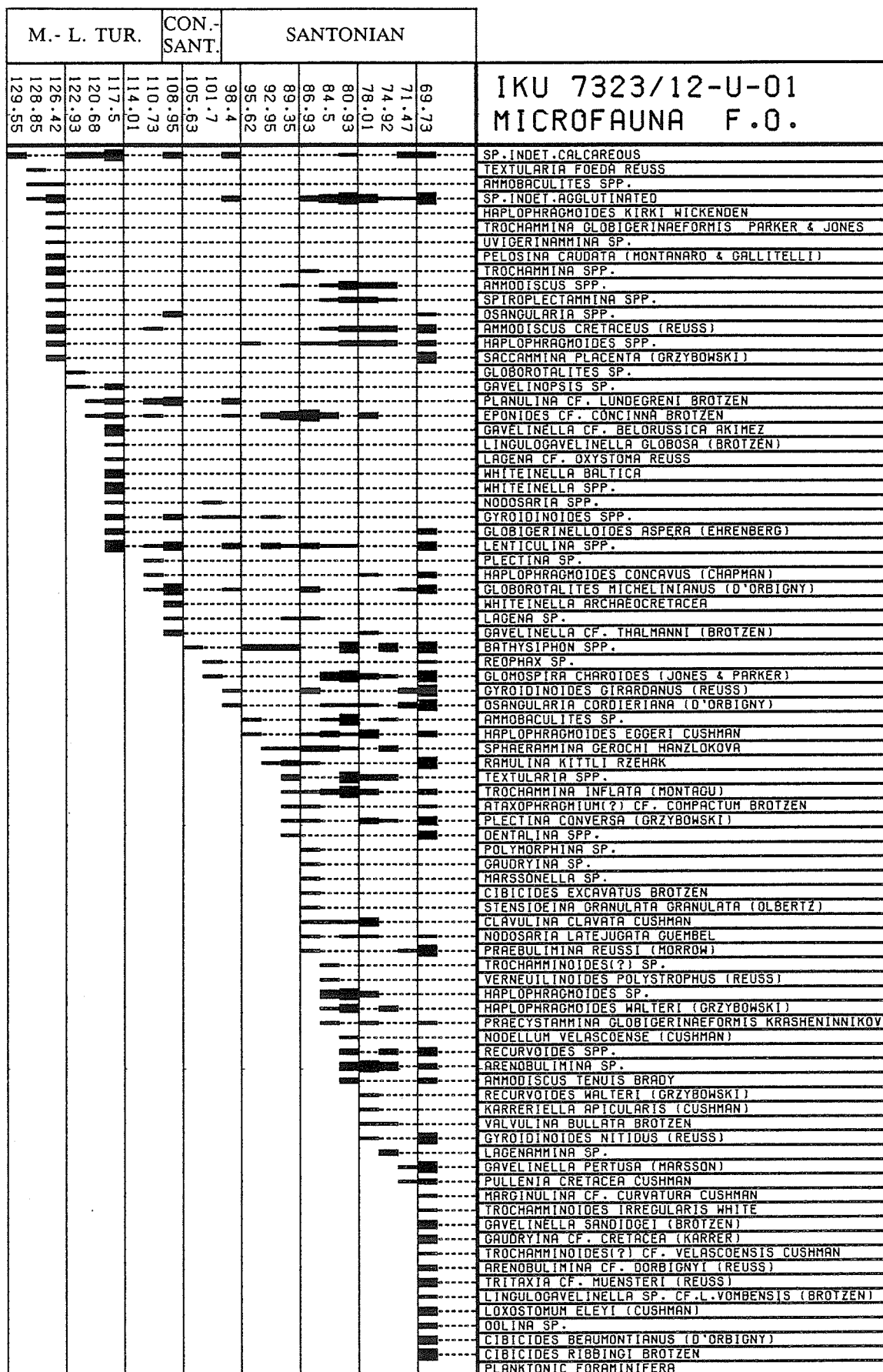


Figure 3.5.11 Foraminiferal range chart of core 7323/12-U-01.
(Sorted according to first occurrence).

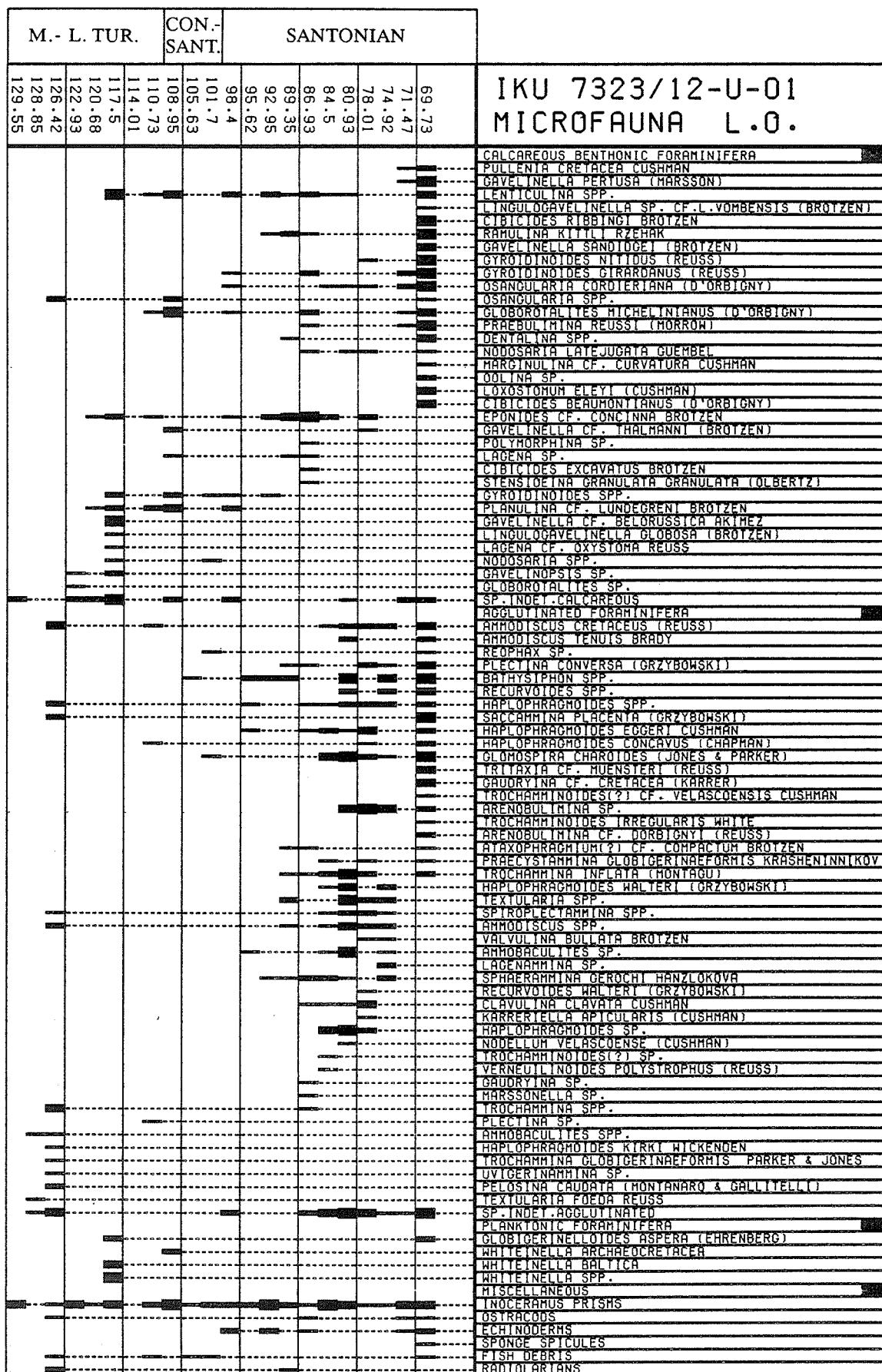


Figure 3.5.12 Foraminiferal range chart of core 7323/12-U-01.
(Sorted according to last occurrence).

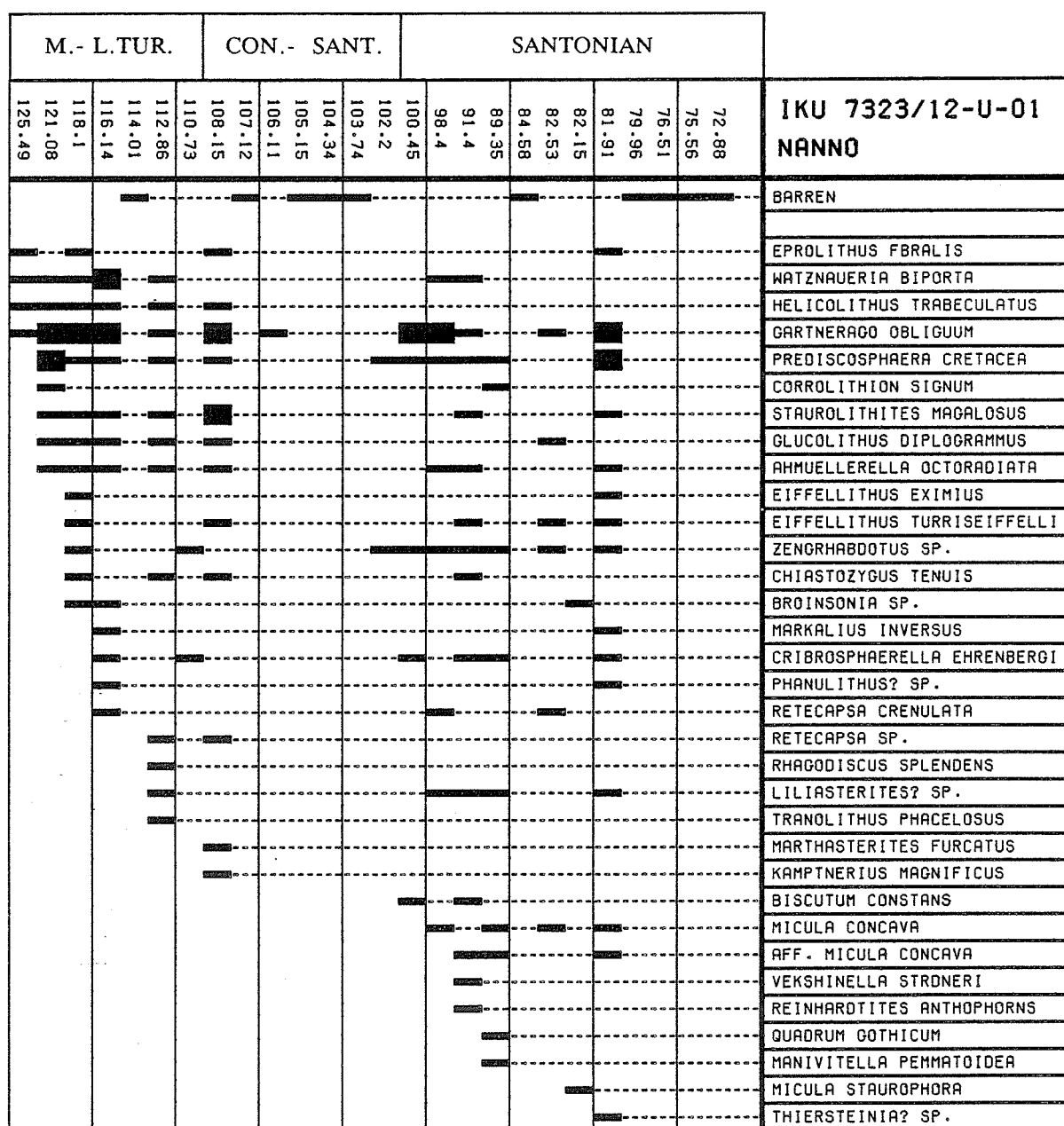


Figure 3.5.13 Calcareous nannoplankton range chart of core 7323/12-U-01.
(Sorted according to first occurrence).

3.5.5 Organic geochemistry

The organic geochemical data figures and tables are presented in a separate volume of the report. Only summary figures will be presented in this section.

Seventeen canned samples were analysed for headspace and occluded gas. The concentrations of gaseous hydrocarbons are between 6,000 and 75,000 $\mu\text{l/kg}$ rock. The headspace fraction usually contains only methane (max. 57,000 $\mu\text{l/kg}$ dry rock) and trace amounts of ethane. Methane also predominates in the occluded gas, although most of the samples contain compounds up to C_{5+} in very minor concentrations (Figure 3.5.14). The low wetness (<1%) of the total gas (headspace + occluded), the occurrence of alkenes in samples with low gas yields, and the relatively high $i\text{-C}_4/n\text{-C}_4$ -ratios of 1.3 to 2.4 characterize this gas as immature and probably containing a biogenic contribution.

The samples from this predominantly sandy-carbonatic core contain between 0.37 and 0.73 % TOC, and the organic matter belongs to the hydrogen-poor type IV according to the extremely low hydrogen index values (3–20 mg HC/g TOC; Figure 3.5.15). This is in complete agreement with the reworked and oxidised appearance of the organic matter in the microscope and the considerable bioturbation of these sediments. Most of the oxygen index values are strongly elevated due to the carbonate-rich nature of the rocks and should therefore not be used for kerogen characterization.

Also the production index (Rock-Eval $S1/(S1+S2)$) shows extremely high values (0.3–0.9). They are considered unreliable because of the small peak areas. $S1$ values of less than 0.9 mg HC/g rock suggest that only very minor concentrations of free hydrocarbons can be expected in this core.

Reasonable Rock-Eval T_{max} values could not be obtained due to the poor $S2$ peaks. The strong reworking and oxidation of the organic material also precluded the determination of vitrinite reflectance. Green to greenish-yellow fluorescence colours of the liptinite and TAI values of 3 to 3.5, however indicate that the organic material is still immature.

Five samples (79.97, 91.40, 97.89, 110.73, 121.48 m) were extracted in order to examine the composition of any bitumen and to obtain biomarker data for the characterization of thermal maturity. Poor to fair EOM and

C_{15+} -hydrocarbon concentrations of 278-1111 and 44-126 ppm of rock weight, respectively, are in general agreement with the hydrogen-poor nature and low maturity of the organic matter, although even lower extract contents could be expected considering both the low content in organic matter and its extremely poor hydrocarbon potential (Figure 3.5.16). The bulk composition shows characteristic features of an immature bitumen, namely a predominance of non-hydrocarbons (60-80 % of EOM) and (usually) a high abundance of aromatic hydrocarbons relative to saturated hydrocarbons.

The gas chromatograms of the saturated hydrocarbon fractions usually show bimodal distributions with maximum n-alkane concentrations at carbon numbers around 22-24 and 29-31, respectively. A third mode around C_{18} - C_{19} occurs in the sample at 91.40 m. The prominent peaks at C_{29} and C_{31} and the well developed odd-over-even predominance indicate a considerable contribution by thermally immature higher land plant material to the hydrocarbons. The slight differences in the n-alkane distributions may perhaps be attributed to minor variations in organic input or local redistribution; however, the low fraction weights which favour evaporation losses suggest that the composition of the n-alkanes with lower molecular weight and the respective peak ratios (Figure 3.5.17) should be interpreted with great caution.

The samples at 110.73 m and 121.48 m show fairly different distributions of saturated steranes (m/z 217) and terpanes (m/z 191). The sterane mass fragmentogram at 110.73 m is dominated by regular steranes, among which the biologically preferred $14\alpha(H)$, $17\alpha(H)$ 20R isomers are most prominent (peaks j,p,t). The respective fragmentogram for the terpanes shows well developed peaks of the ubiquitous $17\alpha(H)$ -hopanes (B,C,E). A clear predominance of the 22R- over the thermally stable 22S-isomer of the C_{31} - and C_{32} -extended hopanes (G/H, J1/J2) suggests that the extractable organic material has not reached thermal maturity. This is also indicated by the incomplete (80 %) conversion of $17\beta(H)$, $21\alpha(H)$ -hopane (= moretane; peak F) into $17\alpha(H)$, $21\beta(H)$ -hopane (E). Usually a conversion of 90 to 100 % is attained before maturity approaches the oil window.

A low maturation stage is also suggested by the predominance of $17\alpha(H)$ -trishnorhopane (T_m) over $18\alpha(H)$ -trishnorhopane (T_s), although this ratio may be influenced by the organic facies as well. The overall distribution pattern of the steranes and terpanes suggests that this extract has a maturity comparable with the one of the extract from 80.22 m in core 7324/07-U-01.

The biomarker distribution at 121.48 m reflects a slightly more advanced stage of maturation. This is suggested by the appearance of rearranged steranes (diasteranes, peaks a-g,k,n in m/z 217), the relative increase of the thermally stable 20S-isomer of the C₂₉-steranes (q,s) relative to the 20R-configurations (r,t), and a slightly reduced predominance of the 22R-extended hopanes. Also the somewhat increased concentration of tricyclic terpanes (P-S in m/z 191) may be interpreted in terms of more advanced maturation or local redistribution of hydrocarbons. It should, however, be emphasized that the maturity of this extract is still far below oil window maturity.

In conclusion, it can be said that core 7323/12-U-01 is extremely poor in organic matter, which belongs to the hydrogen-poor kerogen type IV and lacks any significant hydrocarbon generation potential. Vitrinite reflectance and Rock-Eval Tmax values could not be obtained from this core due to the strong reworking and oxidation of the organic material, however, thermal alteration indices of 3-3.5 suggest that this material is thermally immature. The analysed samples contain poor to fair amounts of hydrocarbons with a somewhat variable, but generally immature composition. No strong indications of migrated hydrocarbons have been found in this core, but considering its low organic content and poor hydrocarbon potential, the immigration of trace amounts of immature hydrocarbons cannot be completely ruled out.

7323/12-U-01

C1-C4 HYDROCARBONS C5+ HYDROCARBONS WETNESS (%)

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

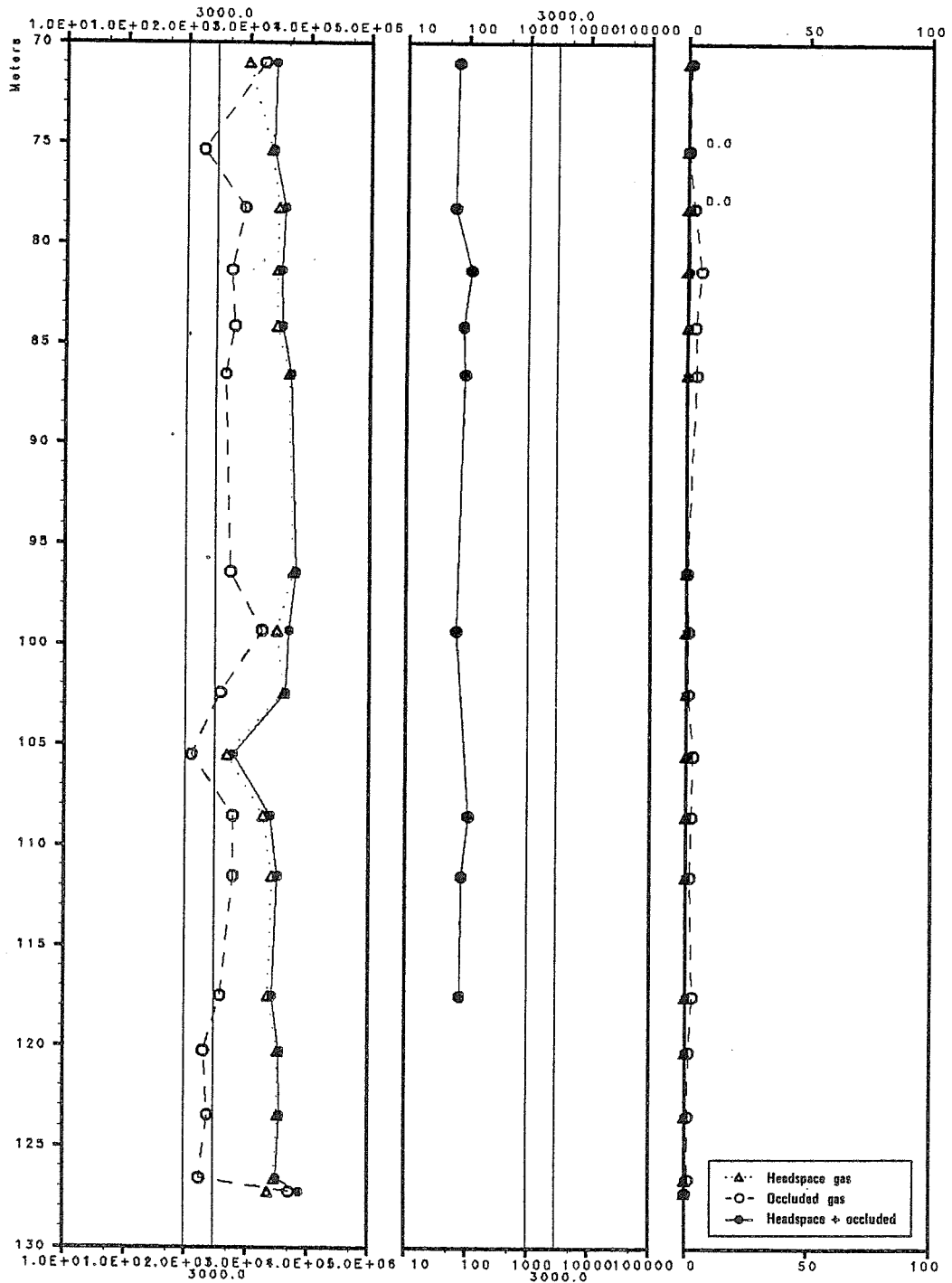


Figure 3.5.14 Yield and composition of headspace/occluded gas of core 7323/12-U-01.

7323/12-U-01

ROCK-EVAL PYROLYSIS DATA

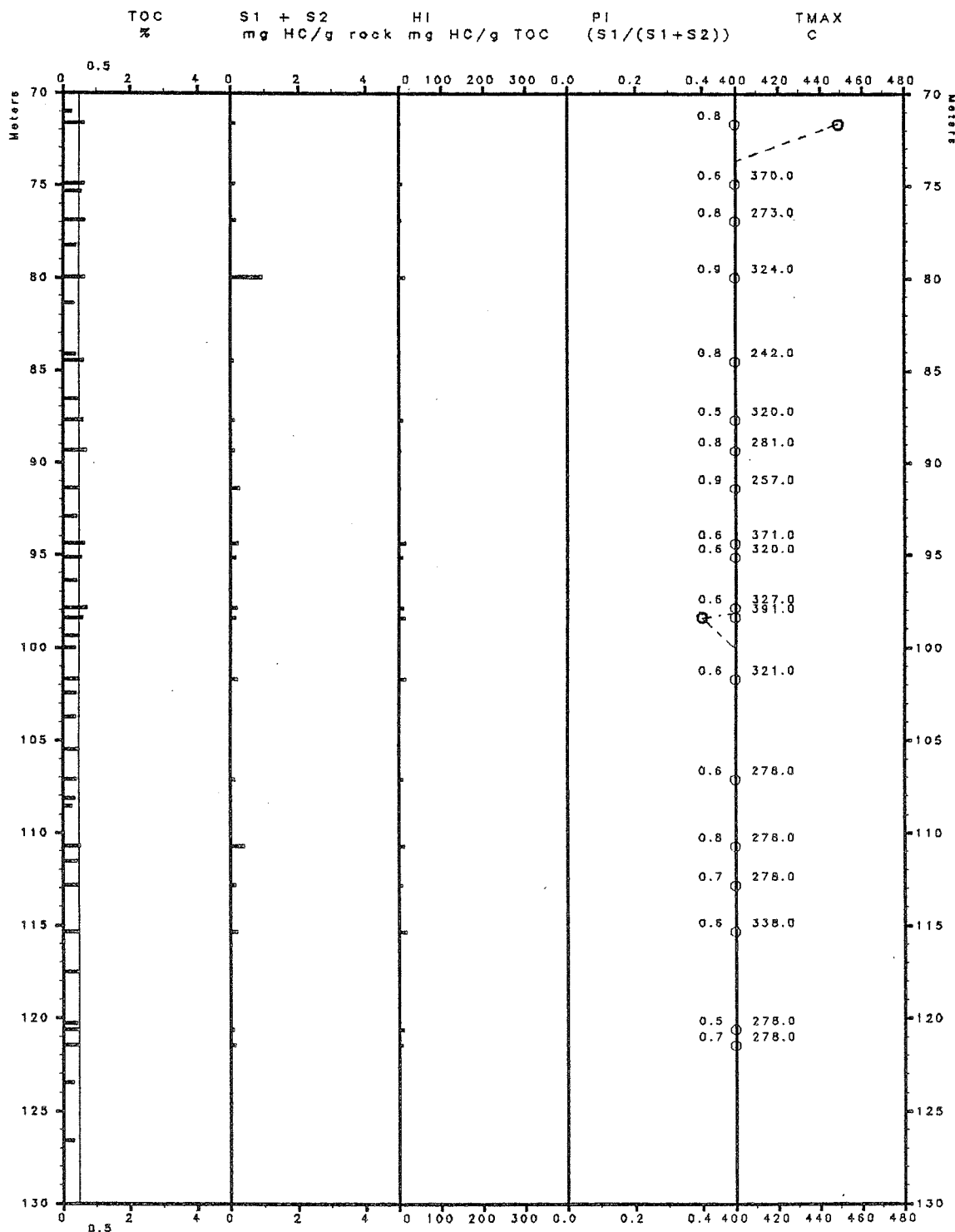


Figure 3.5.15 Total organic carbon content and Rock-Eval data of core 7323/12-U-01.

7323/12-U-01

EXTRACTABLE ORGANIC MATTER

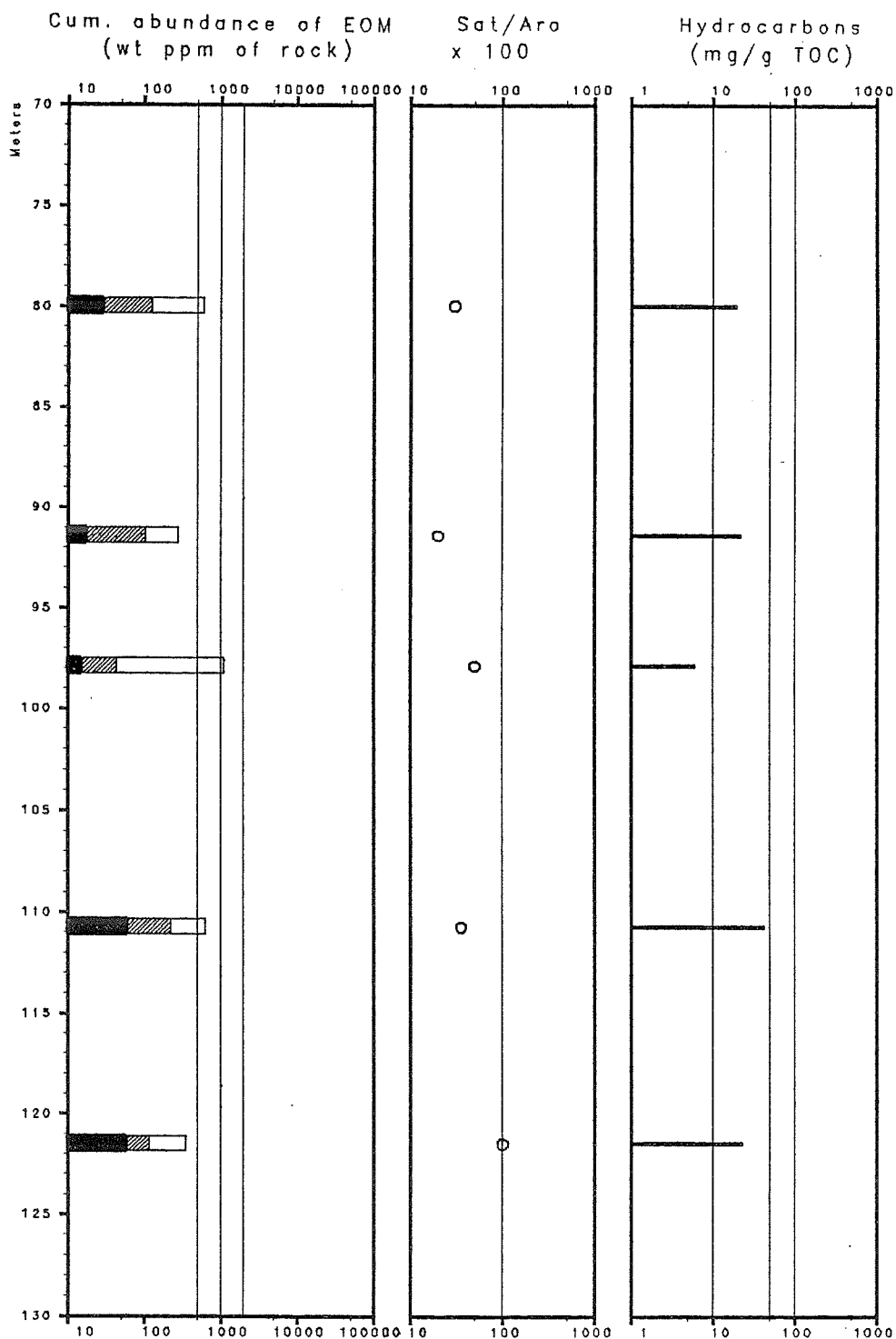


Figure 3.5.16 Extract data for core 7323/12-U-01.

7323/12-U-01

GAS CHROMATOGRAPHIC RATIOS

CPI 2

Pristane/Phytane

Pristane/n-C17

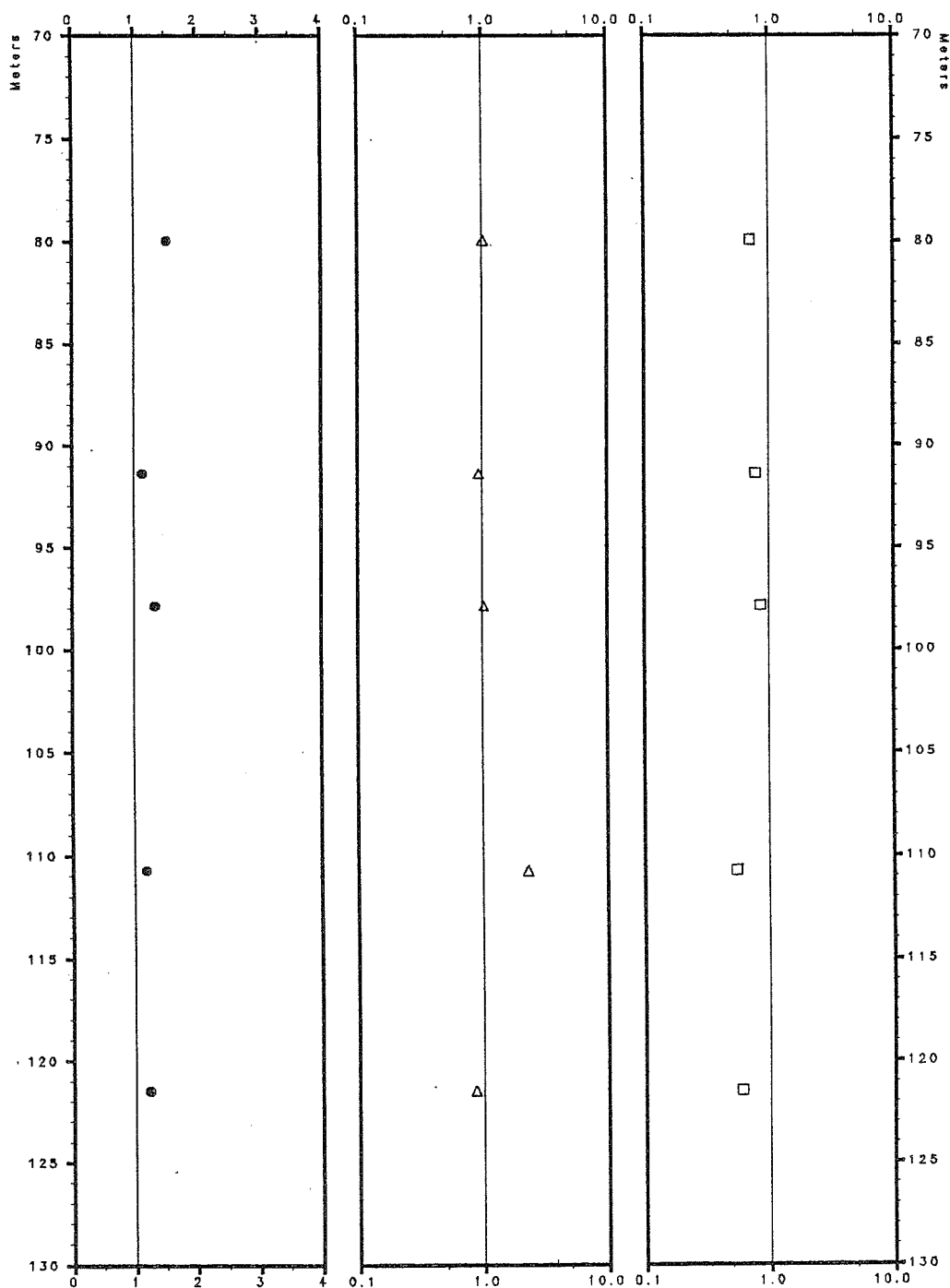


Figure 3.5.17 Compound ratios from gas chromatograms of saturated hydrocarbon fractions from core 7323/12-U-01.

3.5.6 Depositional environment

The core is dominated by limestone, marl, greenstones (glaucanites) and mudstones, and contains a diverse macro-, micro- and ichnofauna. The microfauna and palynoflora indicate normal marine depositional environments under open shelf conditions.

Unit A shows very abundant glauconite grains, and the upper part of the unit is dominated by this mineral. Formation of glauconite is most abundant under shelf conditions between 50 and 500 metres (Odin & Matter 1981), an environmental setting which corresponds well with the lack of micritization of fossil shells and the presence of trace fossils as *Zoophycos*. The gradual transition from claystone in the lower part, upwards to greensand/-glauconitic packstone/wackestone with scattered clastic grains in the upper part, indicates lowered sedimentation rate.

Unit B shows strong decrease in the glauconite content which may indicate increased sedimentation rate as also indicated by the increase in clay content towards the top of the unit.

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APPENDICES

A.1 Drilling operation - field statistics

A.1.1 General

Main contractor for the field operations was Offshore Support Services A/S in Oslo, using the drill ship M/S "Bucentaur" (Figure A.1.1). The bedrock coring machine was purchased from Diamant Boart, Belgium/Norway, and Dia-Team, Norway provided diamond drilling staff.

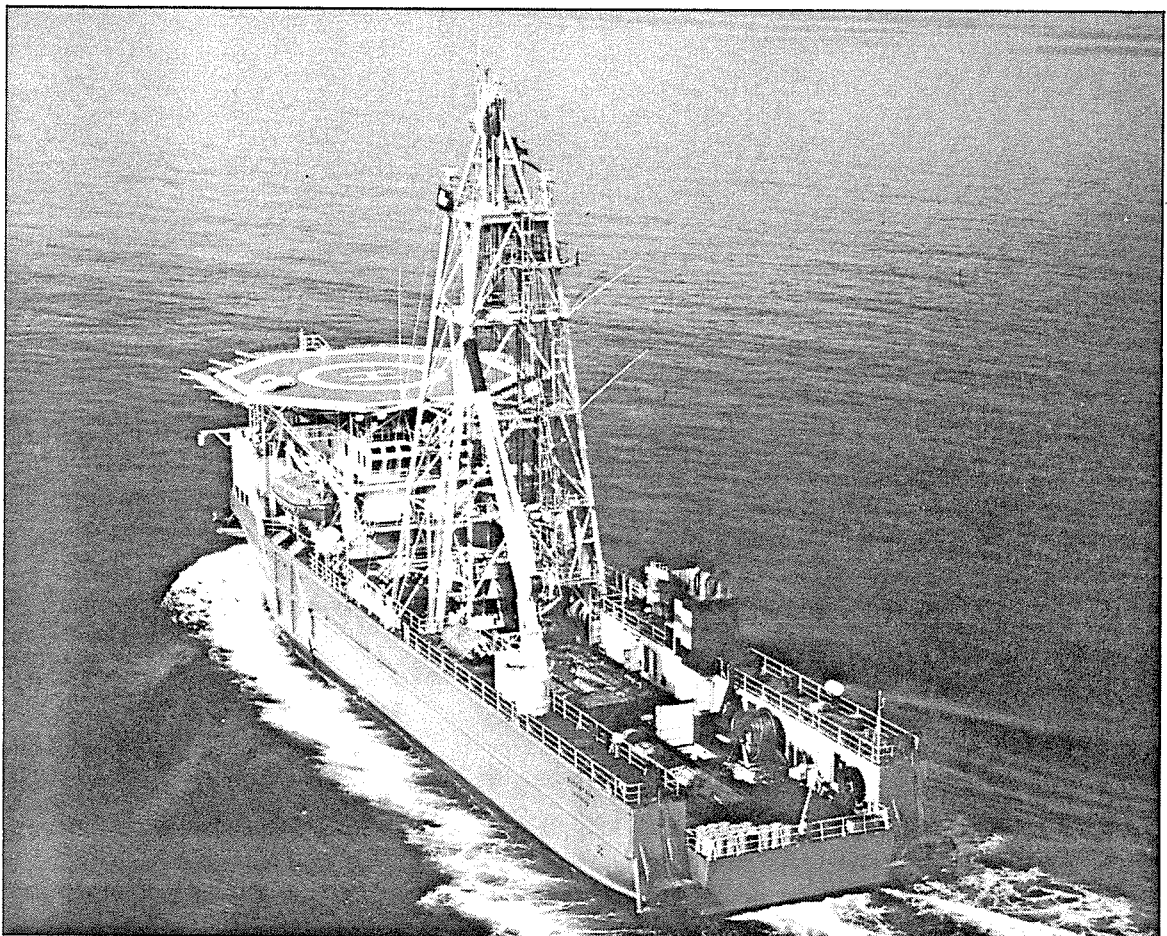


Figure A.1.1. The drill ship M/S "Bucentaur".

A.1.2 Technical data

Drill ship M/S "Bucentaur"

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-Elliott 2050 computer, video display and joystick. Positioning reference by deep water tautwire system and by Simrad HPR T209 hydro-acoustic system.

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 5 1/2" 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 51/2" x 51/2", 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 51/2" tool joints, 4" I.D.

Drill collars: Sixteen, each 5 m long, 7" O.D. and 4" I.D. with 51/2" 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 drill rods O.D. 69.9 mm, I.D. 60.3 mm.

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

Core diameters: HR triple tube 54.2 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 (Figure A.1.2)

(a) M/S "Bucentaur" moves onto position and sets the dynamic positioning system (D.P.) in operation.

- (b) Seabed re-entry template is lowered to the seabed, and constant tension applied to the template cables via the template heave compensation system.
- (c) The 5" drill pipe with open centre bit is lowered on a guided template cable rider to the seabed.
- (d) The Quaternary overburden is penetrated until the drillbit is drilled into rockhead. Hammer samples of main Quaternary units are recovered during drilling.
- (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 5" drill string is clamped to the template by using the hydraulic template clamp.
- (f) The coring pipe and wireline 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. Coring continues for 1-2 days. The coring pipe and subsequently the 5" drill pipe are pulled and stored on the deck.
- (h) The seabed template is hoisted into the moonpool, D.P. is disengaged and the vessel proceeds to the next location.

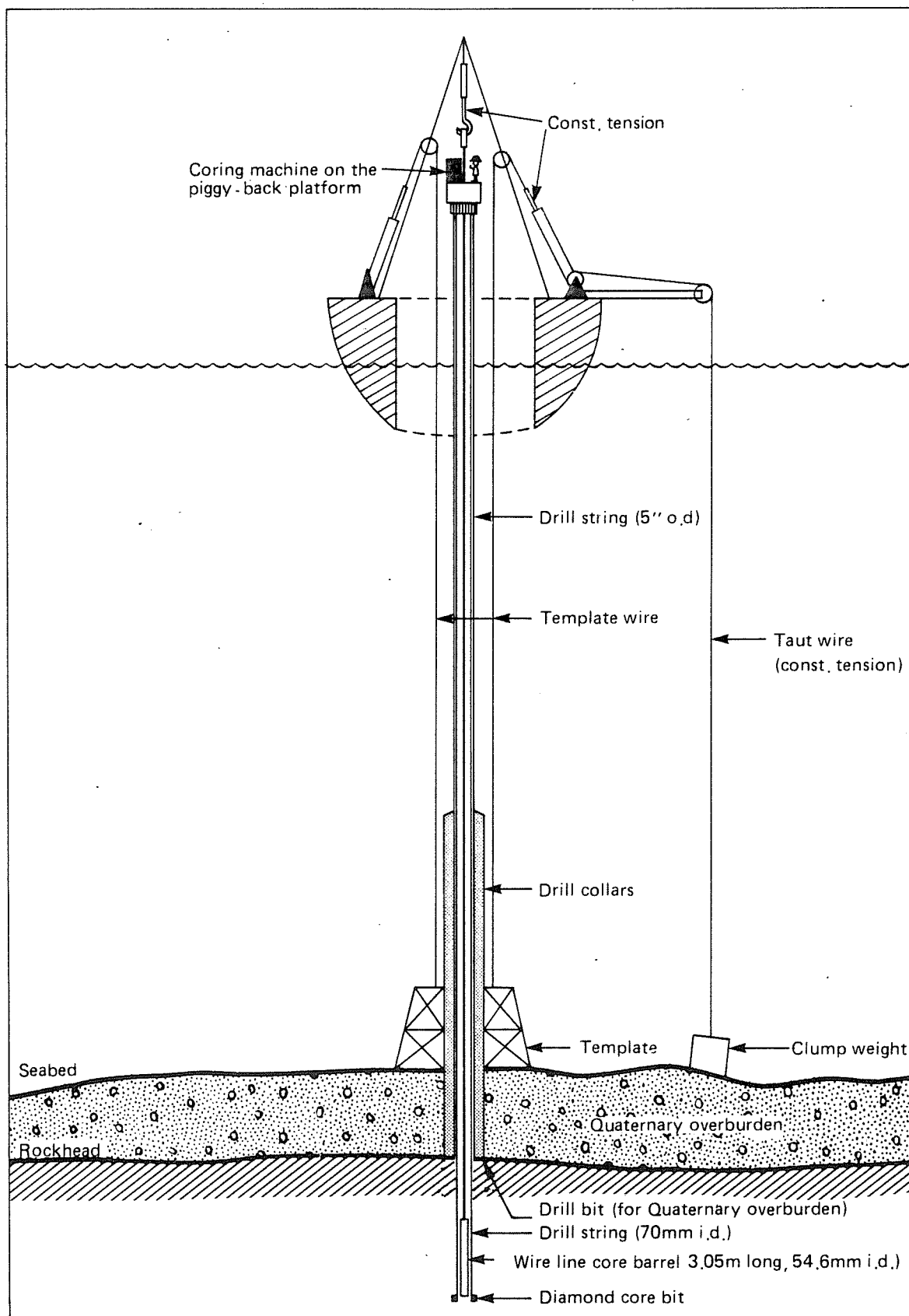


Figure A.1.2 Sketch showing the drilling operation for M/S "Bucentaur".

A.1.4 Field operation

The field operations started with mobilization of the ship and a technical test drilling off Kristiansund July 17-18 1987. This season IKU performed heat flow measurements at three sites in the Nordkapp Basin and shallow drilling at eight sites in addition to the five drillings in the present project. The field work started off in Honningsvåg 22 July and lasted for 49 days until demobilization in Honningsvåg September 9.

In order to save sailing time and money the field work of the different projects was mixed. For the present project drilling of the three sites in the Nordkapp Basin was performed in the period August 22-28 and of the two sites at the Dia-Structure in the period August 29 - September 5. The mobilization cost, technical breakdown time and time for sailing to and from Honningsvåg were split between the three projects, depending on the duration of the field operation.

The time spent in this project was as follows:

Working	11.1 days
Steaming	1.5 days
Weather standby	0 days
Share of technical breakdown time	<u>0.5 days</u>
Total	<u>13.1 days</u>

This demonstrates that a minimum of time was lost due to technical breakdown and that we were lucky to have no weather standby. The time spending expressed as percent of total time is shown in the diagram in Figure A.1.3.

A total of 5 holes were drilled, all of them about 50-60 m into bedrock. Total penetration in bedrock was 281 m, and the total recovered core length was 265 m, which gives an average core recovery of 94.5 %. Compared to the planned penetration of 20 m into the bedrock for three of the holes and 30-50 m for two of the holes, this is twice as much as planned, and the actual average penetration per hole was about 56 m. Further key data of each borehole is given in Table A.1.1.

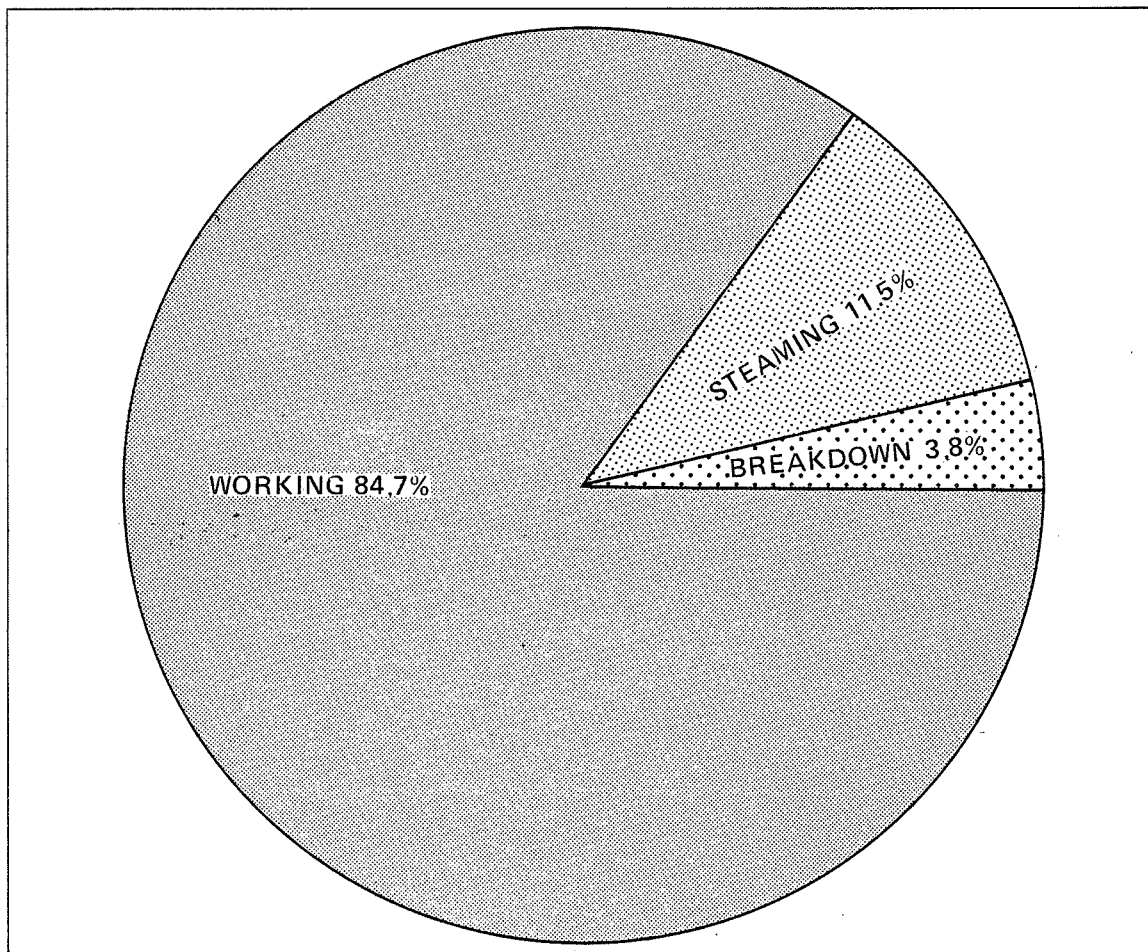


Figure A.1.3 Duration of field work activities for the present project.
Total operation time was 13.1 days.

Table A.1.1 Key data of the boreholes.

Core no.	Seismic line	Shotp.	Water depth	Quat. overburden	Penetration in bedrock	Core length	Core recovery	Tot. penetr. below seabed
7231/01-U-01	IKU-310730-87	2130.7	278 m	36.3 m	56.5 m	55.7 m	98.6 %	92.8 m
7231/04-U-01	IKU-310730-87	2246.3	280 m	37.7 m	59.7 m	58.0 m	97.3 %	97.4 m
7230/05-U-09	IKU-302230-87	1186.1	294 m	20.0 m	55.1 m	42.7 m	77.5 %	75.1 m
7324/07-U-01	IKU-21-87	1106.8	401.7 m	75.4 m	49.0 m	48.4 m	98.8 %	124.4 m
7323/12-U-01	IKU-21-87	411.1	402 m	69.2 m	60.6 m	60.6 m	100 %	129.8 m
				Σ238.6 m	Σ280.9 m	Σ265.4 m	Av. 94.5 %	Σ519.5 m

We would like to mention that the very good result is due to various factors:

- Good weather conditions most of the time and no weather downtime.
- Most of the rocks were easy to drill.
- Several minor, but important technical improvements were made since last year.
- We had the same crew as in previous years.

Only minor drilling problems were encountered, and action has been taken to improve the equipment.

A.2 NAVIGATION - FINAL POSITIONS

A.2.1 General

Bentech A/S in Troms was operator of the navigation chains in the Barents Sea, and they provided equipment and personnel for positioning of the drilling vessel.

Hyperfix was used as the main system, with Navstar GPS as a backup system during the about 8 hours a day this system provided navigation coverage. The Hyperfix was calibrated using a Syledis navigation chain. This chain has a range of about 100 km, and calibration was done every time the vessel approached the coastal area.

A.2.2 Chain performance and final positions

The general survey activity in the area was moderate this year, and the Hyperfix chain was therefore available in range-range mode all the time. We also had access to the same station combination as during the seismic survey. The best possible navigation accuracy was therefore achieved during the whole survey. From comparison between the seismic data and the core there are reasons to believe that the accuracy is within ± 10 m.

The final positions are listed in Table A.2.1.

Table A.2.1 Final positions (ED 50). Note the two different central meridians for the UTM coordinates.

LOCATION	Latitude 72° 45' 12.45" N Longitude 31° 07' 30.21" E		
	7231/01-U-01	Northing 8 077 891.7 m Easting 636 418.1 m	UTM 27°
LOCATION	Latitude 72° 44' 16.31" N Longitude 31° 07' 28.94" E		
	7231/04-U-01	Northing 8 076 155.2 m Easting 636 526.0 m	UTM 27°
LOCATION	Latitude 72° 37' 22.44" N Longitude 30° 22' 31.41" E		
	7230/05-U-09	Northing 8 061 797.7 m Easting 612 471.4 m	UTM 27°
LOCATION	Latitude 73° 18' 56.92" N Longitude 24° 08' 21.22" E		
	7324/07-U-01	Northing 8 138 574.7 m Easting 600 560.4 m	UTM 21°
LOCATION	Latitude 73° 14' 17.81" N Longitude 23° 57' 00.65" E		
	7323/12-U-01	Northing 8 129 626.3 m Easting 594 935.6 m	UTM 21°

A.3 Analytical methods

A.3.1 Core description and sampling

Detailed core description was undertaken on board the ship (as time permitted) as well as all subsampling. Both core description and sampling were completed 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 1-3 m intervals.

A.3.2 X-ray diffraction analysis

Two fractions, whole rock and $<4 \mu\text{m}$, from each sample were analysed according to the following procedure.

1. The samples were gently crushed and split in two parts.
2. One part was ground in ethanol to a fine powder and sucked onto millipore filters for whole rock analyses.
3. The other part was disaggregated by use of an ultrasonic sound dispergator in order to avoid the production of fine powder from the silt and sand grains. The $<4 \mu\text{m}$ fraction was separated by use of settling tubes and sucked onto millipore filters for analysis.
4. Most of the clay samples were glycol saturated in order to determine whether smectite was present. To obtain good results, the samples were placed in glycol vapor in a desiccator for 24 hours at 40°C .

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

LITHOLOGY , SEDIMENTARY STRUCTURES & FOSSILS

	Quaternary		Increasing bioturbation
	Claystone / shale		Teichichnus
	Siltstone		Zoophycos
	Sand		Fecal pellets
	Limestone		Sparse
	Dolomite		Abundant
	Siderite		Mudstone clast
	Calcite cement		Pyrite
	Dolomite cement		Glauconite
	Siderite cement		Bryozoa
	Phosphorite		Fossils in general
	Concretion		Unspecif. fossils fragments
	Erosion		Bivalve
	Horizontal lamination		Inoceramus
	Ripple lamination		Brachiopod
	Wave ripples		Gastropod
	Hummocky cross stratification		Ammonite
	Trough cross stratification		Belemnite
	Horizontal burrows		Foraminifera
	Vertical burrows		Ostracoda
			Fish remains
			Spicule
			Calcsphere
			Plant fragment
			Algae
			Borings

Figure A.3.1 Legend to the sedimentological columns.

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

Smectite	(Smec):	(14Å - 4.7Å) x 0.35
Mixed layer minerals	(Mix) :	10 to 14Å x 0.55
Muscovite/Illite	(M/I) :	10Å x 1.0 or 10Å x 1.4 (illite)
Chlorite	(Chl) :	4.74Å x 3 x 0.7
Kaolinite	(Kao) :	7Å x 0.7 - Chl
Quartz	(Qtz) :	4.26Å x 1
K-feldspar	(Alk) :	2.24Å x 0.5
Plagioclase	(Plag):	3.19Å x 0.5
Calcite	(Cal) :	3.04Å x 0.25
Dolomite	(Dol) :	2.89Å x 0.20
Siderite	(Sid) :	2.79Å x 0.25
Pyrite	(Pyr) :	2.71Å x 0.7

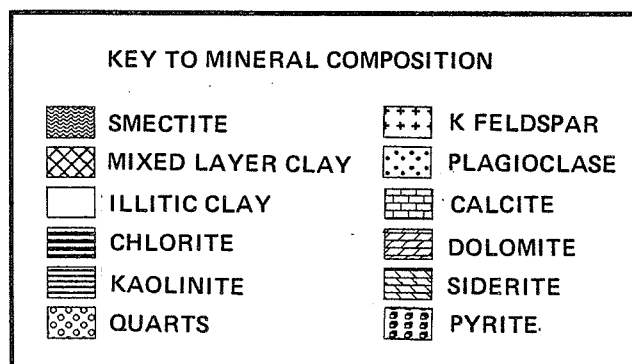


Figure A.3.2 Legend to the semiquantitative mineralogy plots.

A.3.3. Sound velocity measurements

Sound velocity measurements, horizontal and vertical, were carried out on board 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 measurements were carried out on board using a 5" x 5" NaI-detector connected to a 4048 channel analyser 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 600 sec (10 minutes). 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:

- 1) K-40: 1.460 MeV
- 2) U-238 via Bi-214: 1.764 MeV
- 3) Th-232 via Tl-208: 2.615 MeV

The results are presented as counts per 10 minutes. The logs show the relative amount of radiation and not the absolute abundance 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 3 m intervals, leaving reference material at all levels. In lithologies with poor recovery an extra set of samples was later processed.

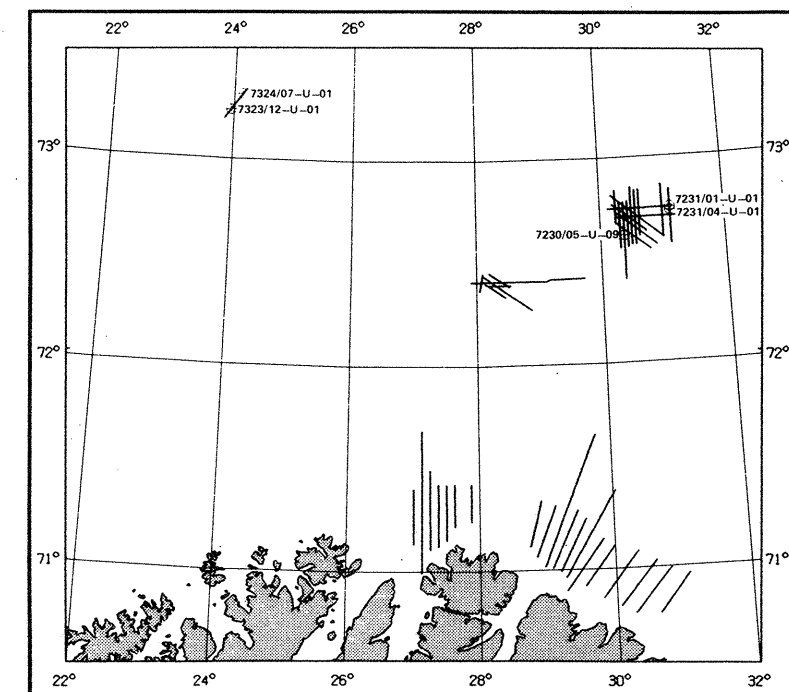
Slides were prepared of; the total residues, unoxidized sieved residues, and oxidized residues at various stages.

Microfauna

Samples were prepared at approximately 3 m intervals. The samples were soaked in water for some days after being dried. The fraction $>125\mu$ was analysed with respect to foraminifera, ostracods and macrofossil debris. The fraction $125-63\mu$ was analysed with respect to radiolarians.

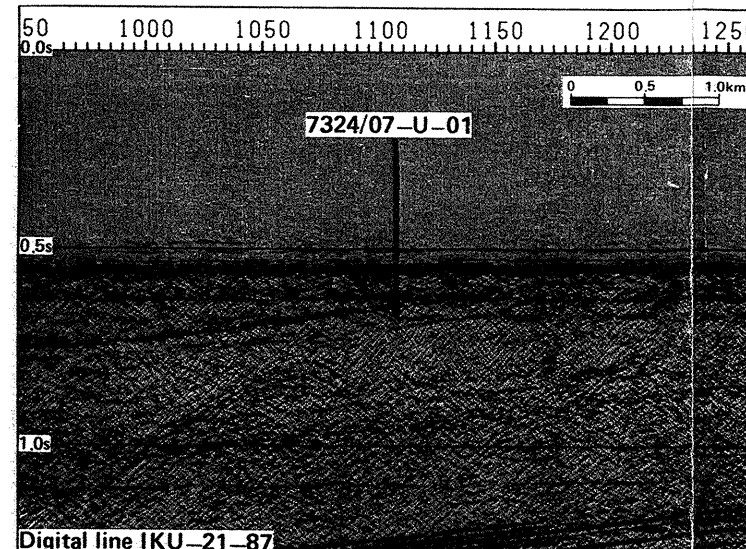
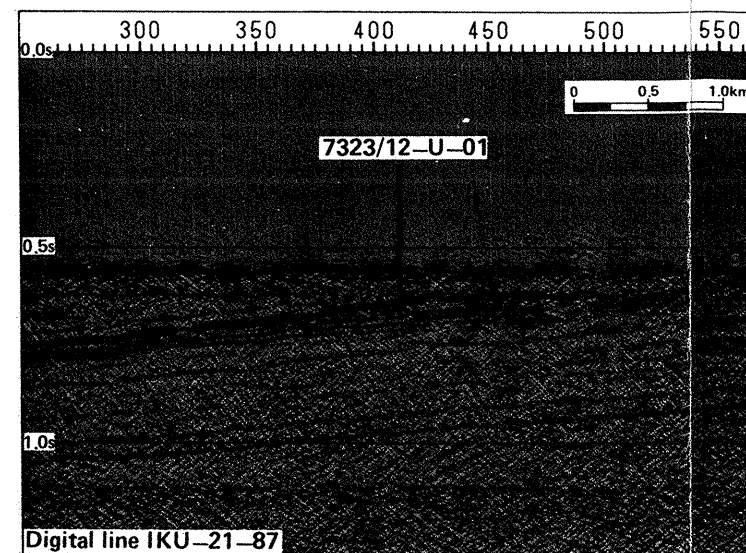
A.3.7 Organic geochemistry

See separate Appendix volume.

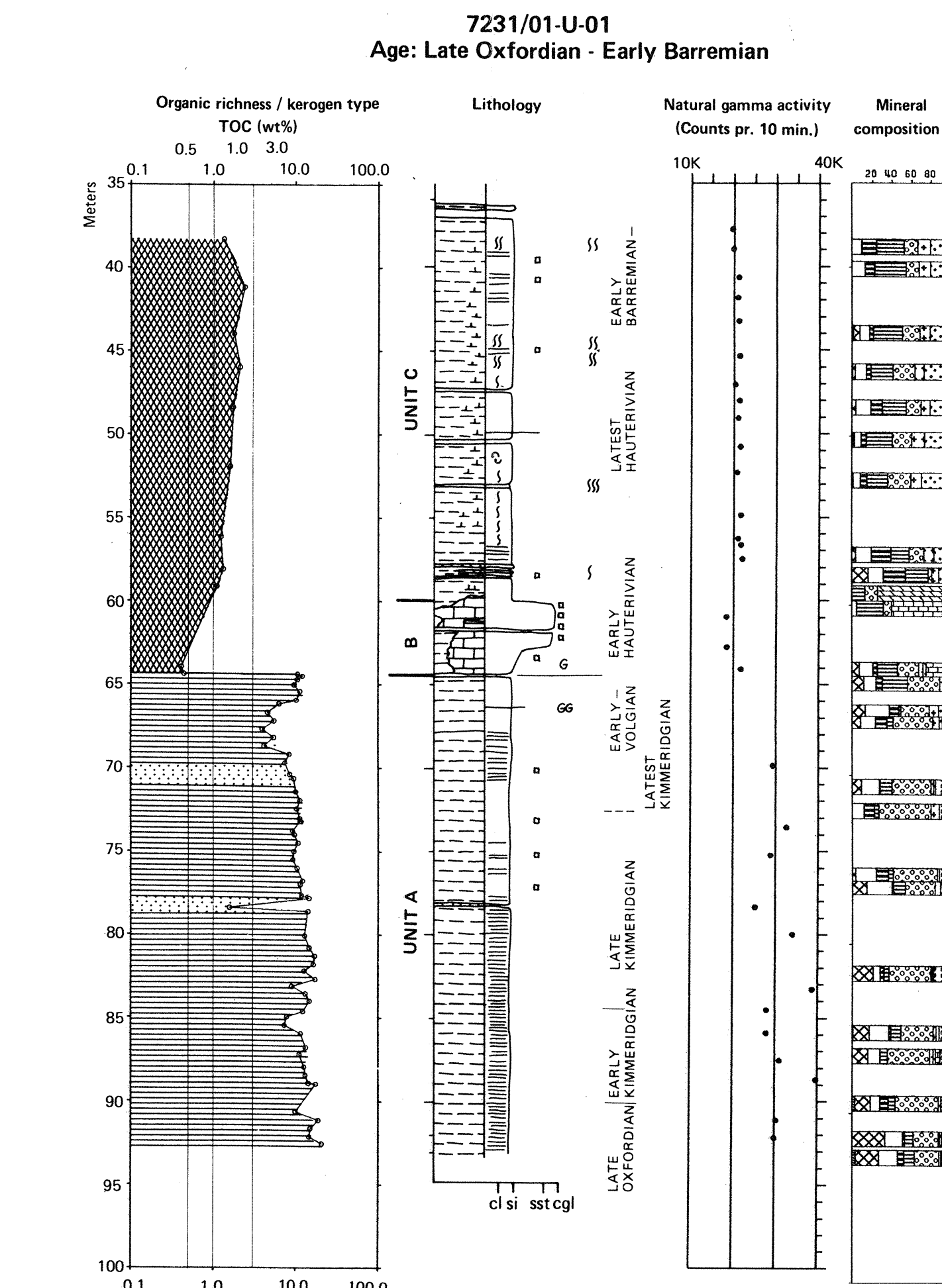
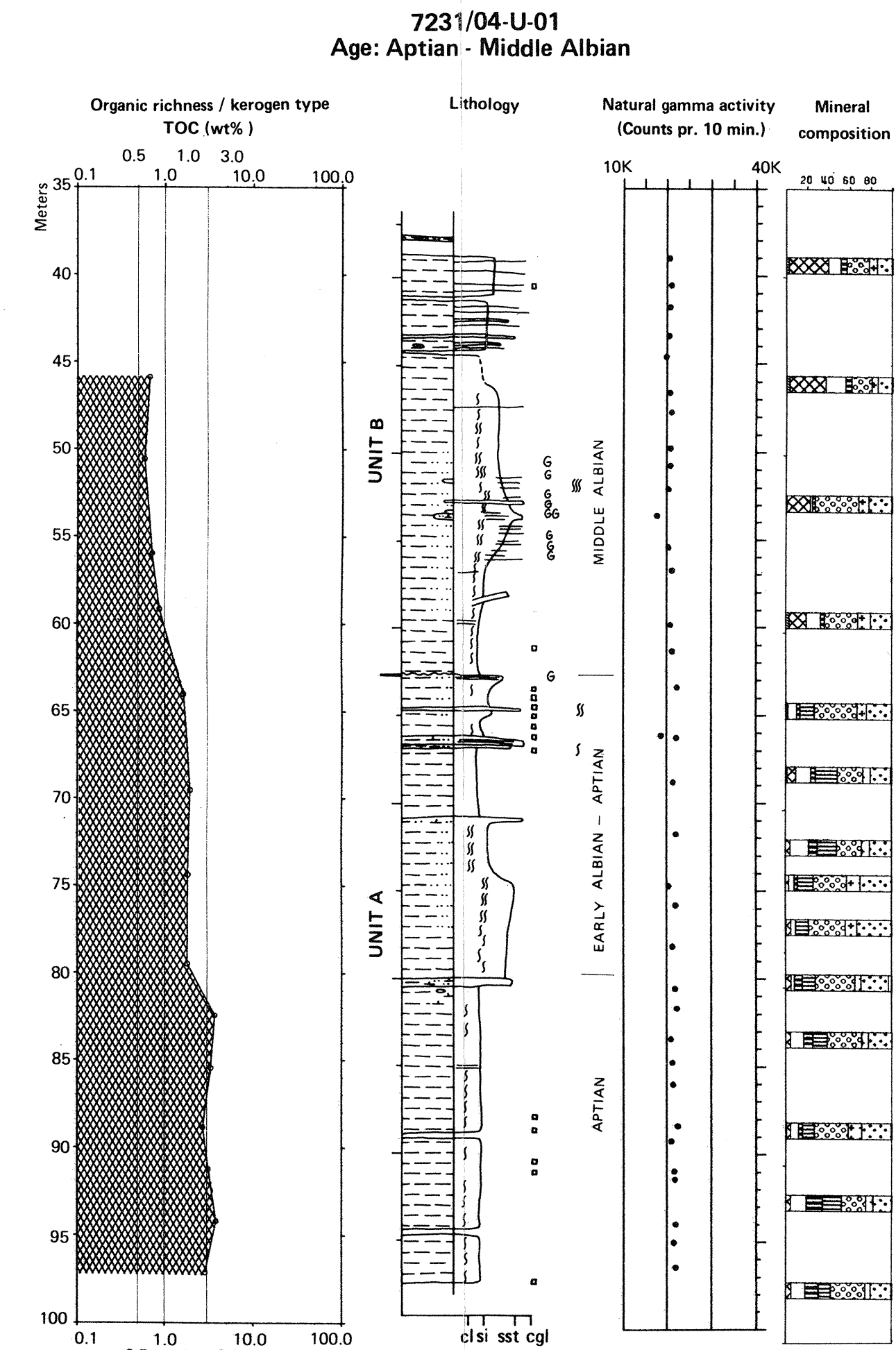
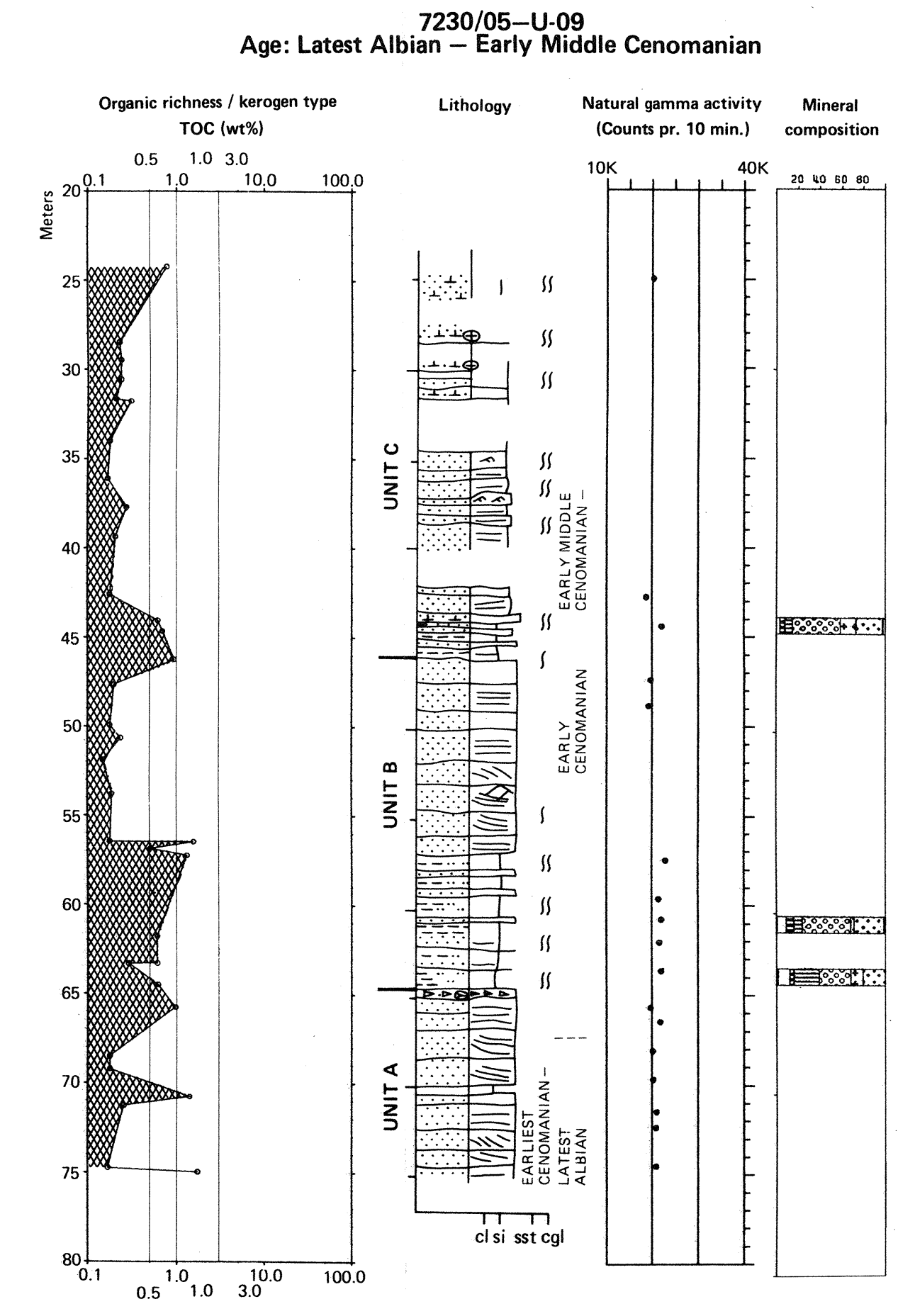
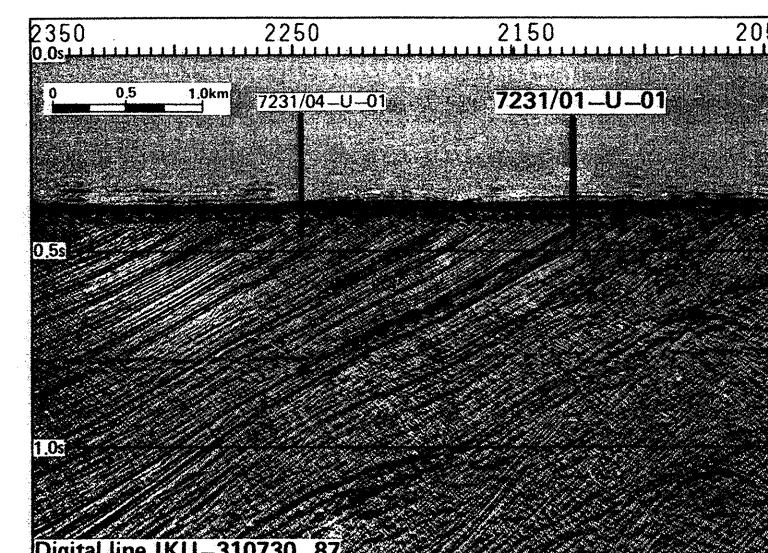
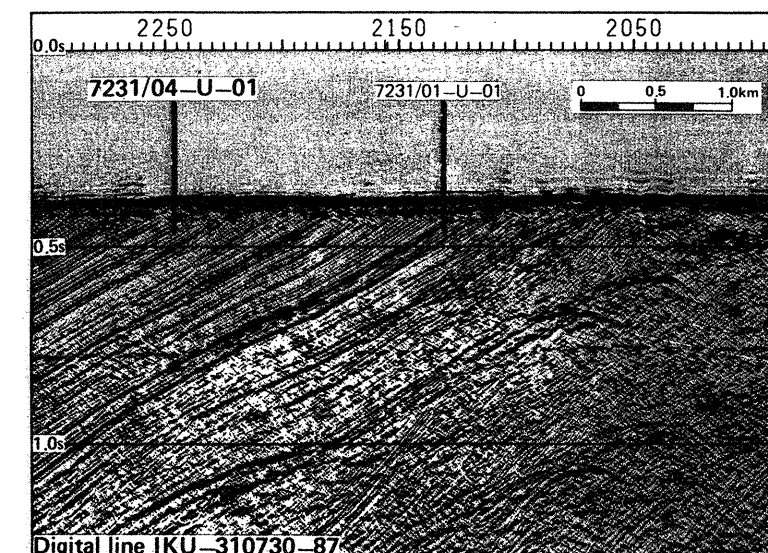
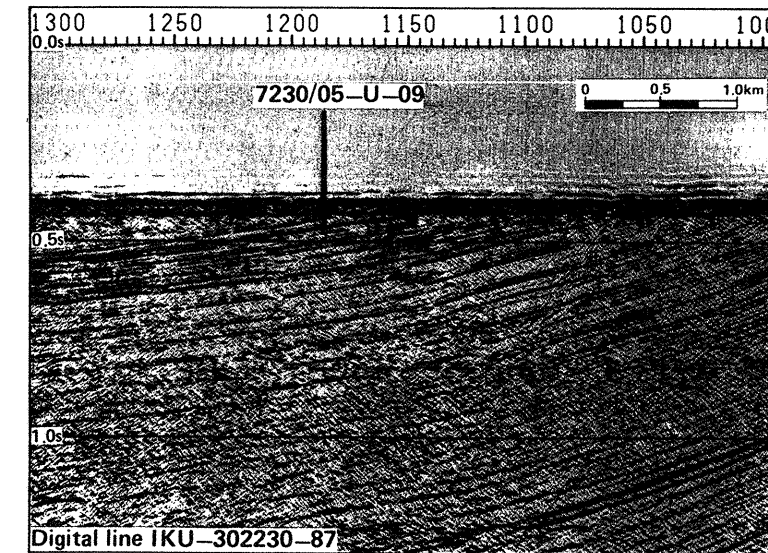
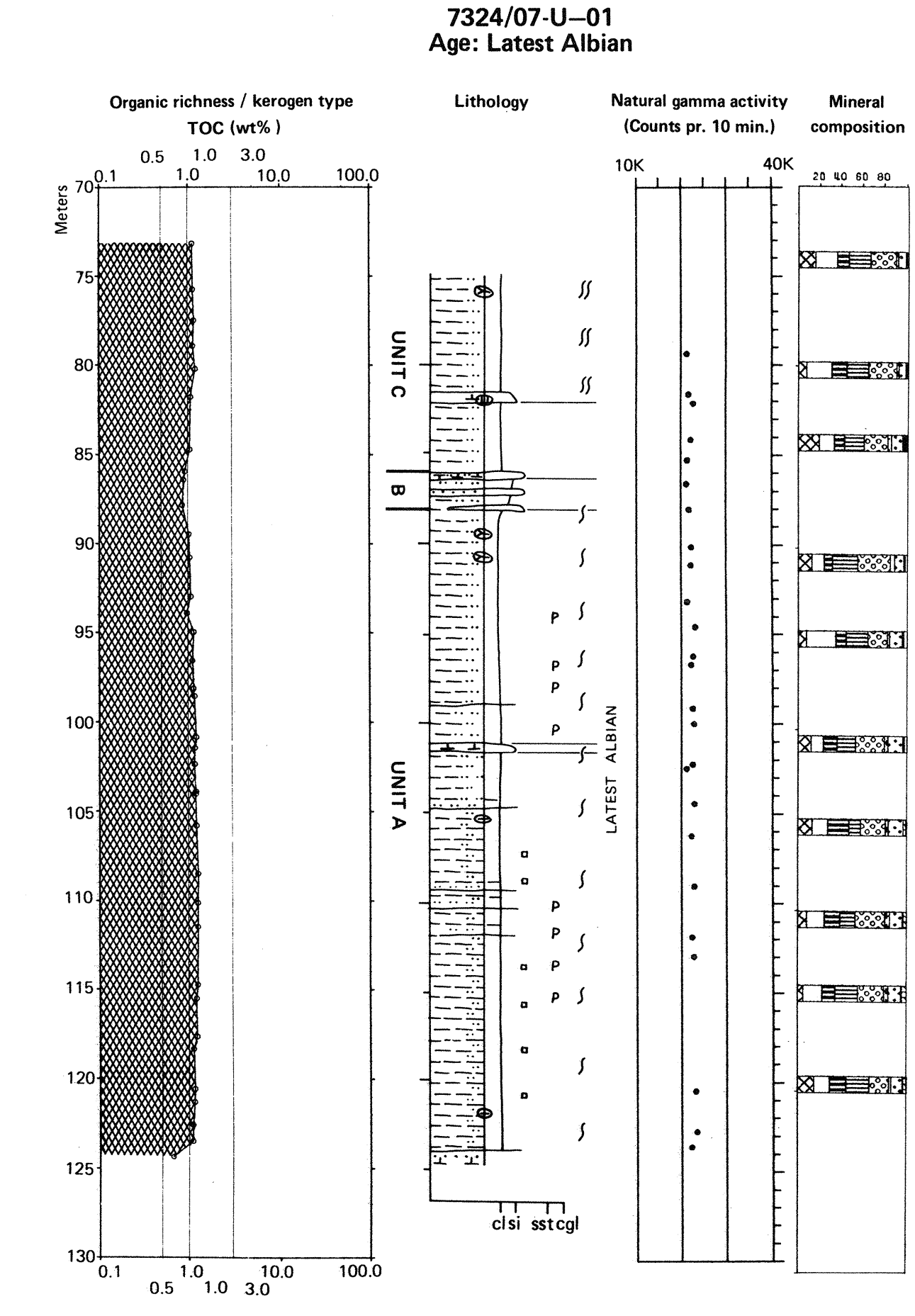
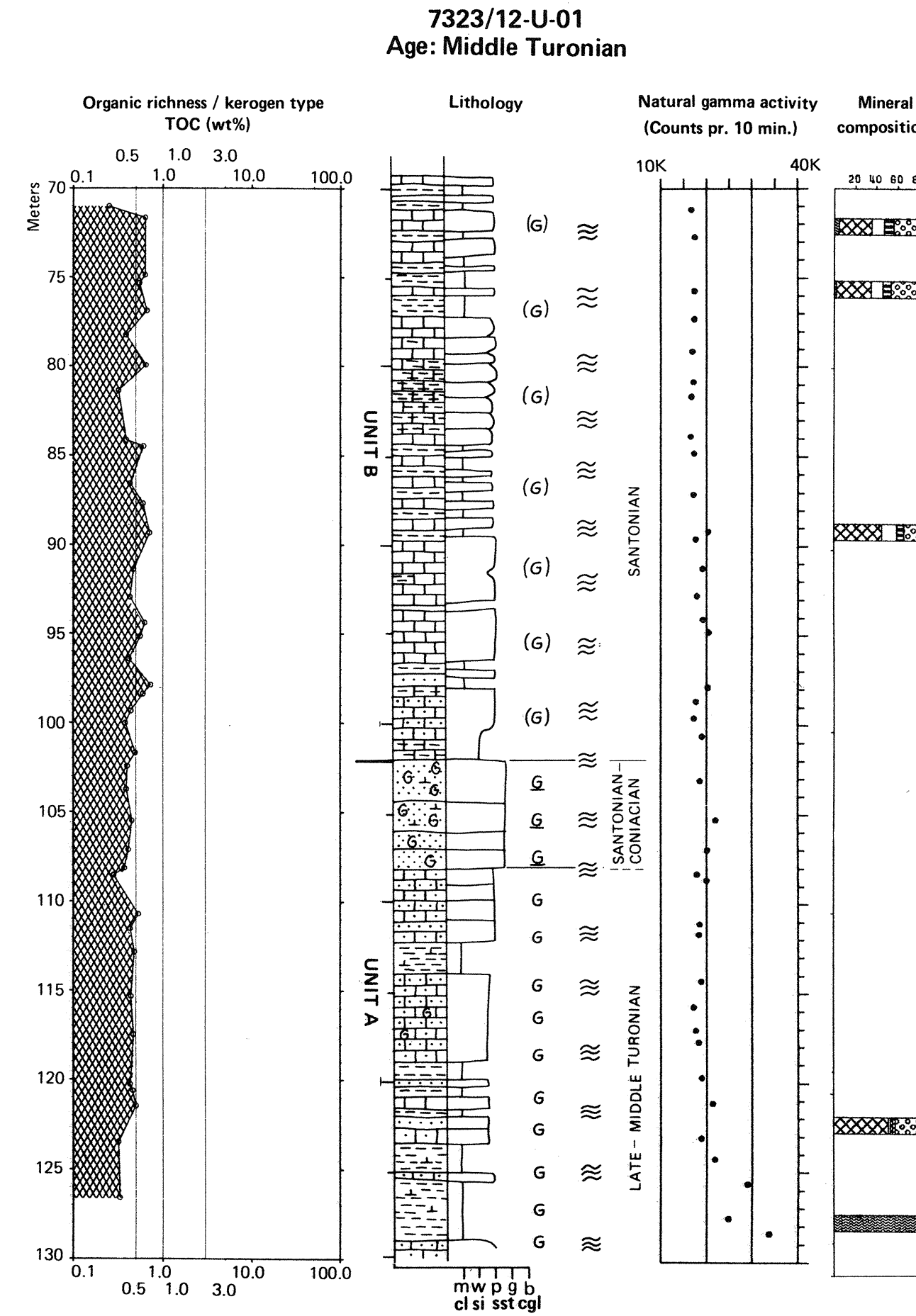


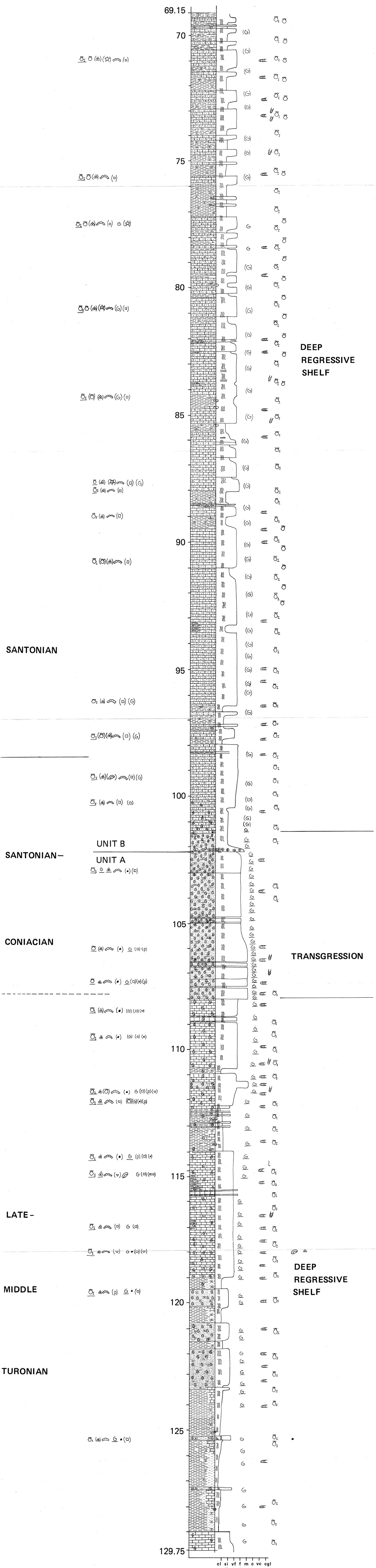
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H.M. Weiss and T.L. Leith
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IKU
SINTEP-GRUPPEN

KEY TO KEROGEN TYPE
Type I (HI > 600 mg/g TOC)
Type II (HI = 400-600 mg/g TOC)
Type II/III (HI = 200-400 mg/g TOC)
Type III (HI = 50-200 mg/g TOC)
Type IV (HI < 50 mg/g TOC)

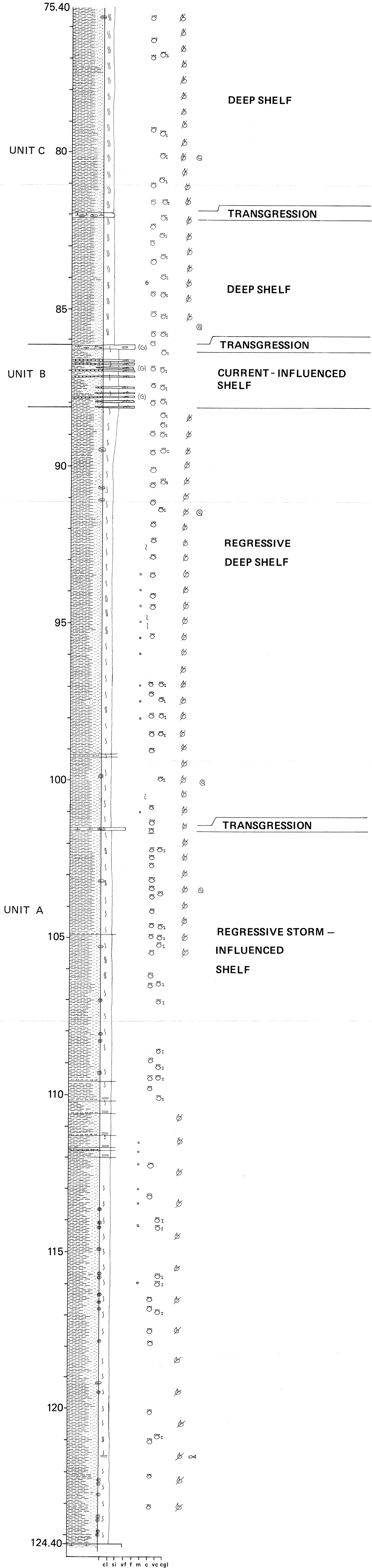


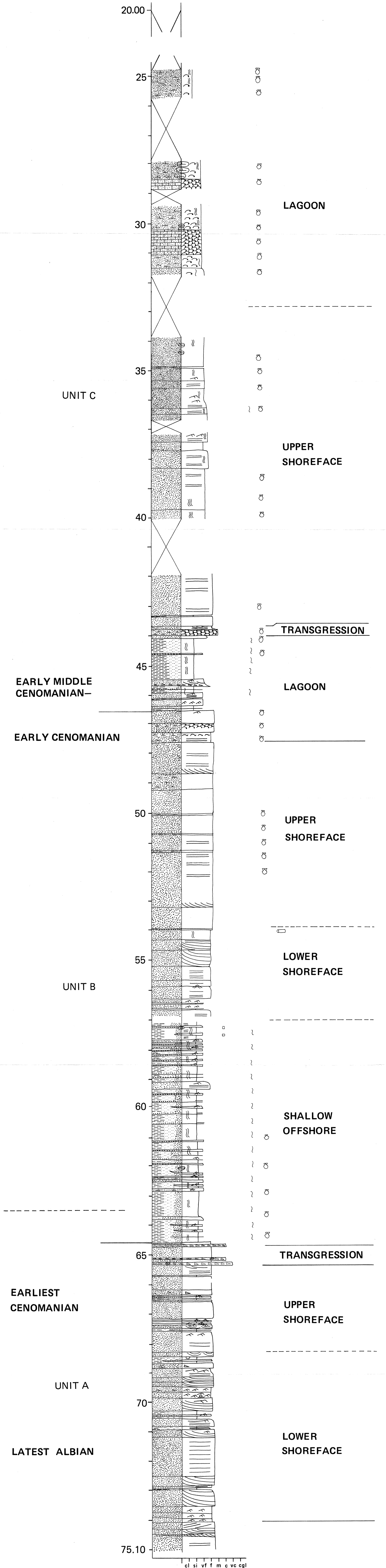
KEY TO MINERAL COMPOSITION
SMECTITE
MIXED LAYER CLAY
ILLITIC CLAY
CHLORITE
KAOLINITE
QUARTZ
K FELDSPAR
PLAGIOCLASE
CALCITE
DOLOMITE
SIDERITE
PYRITE

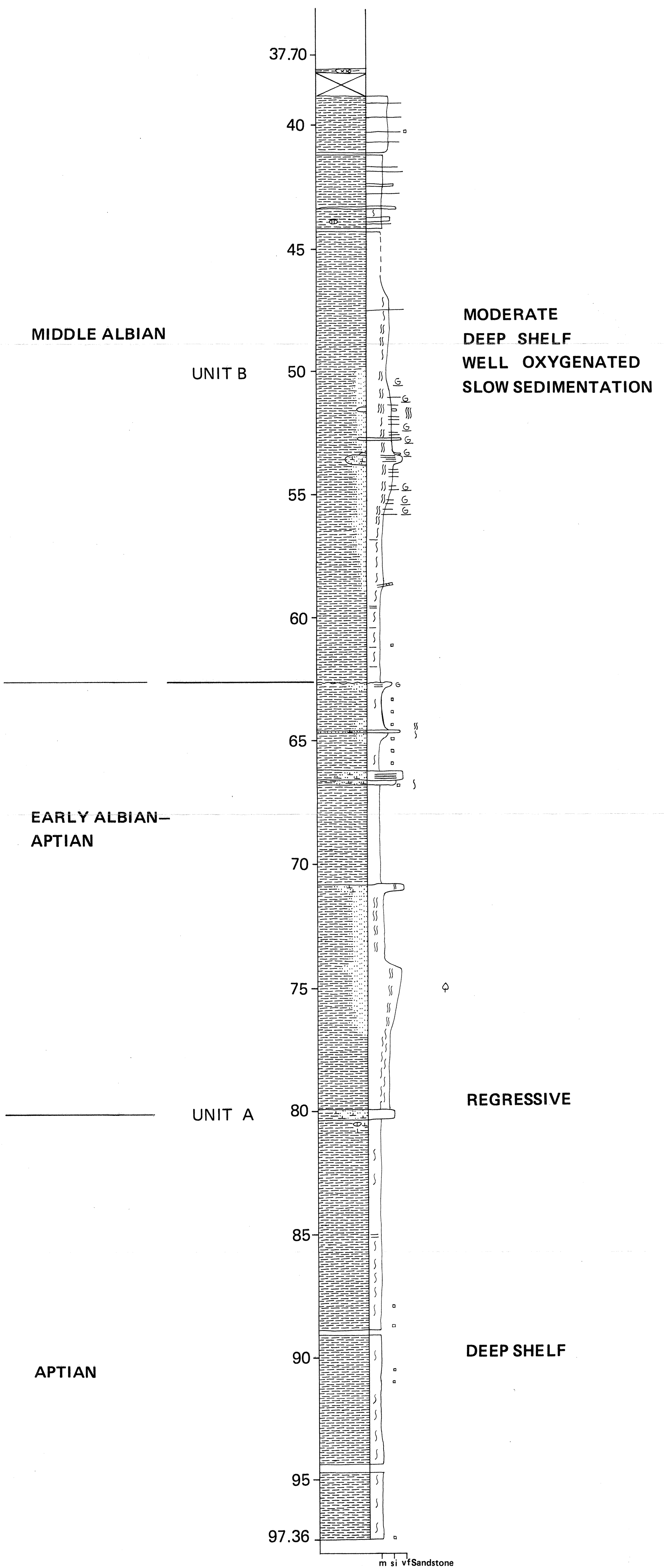


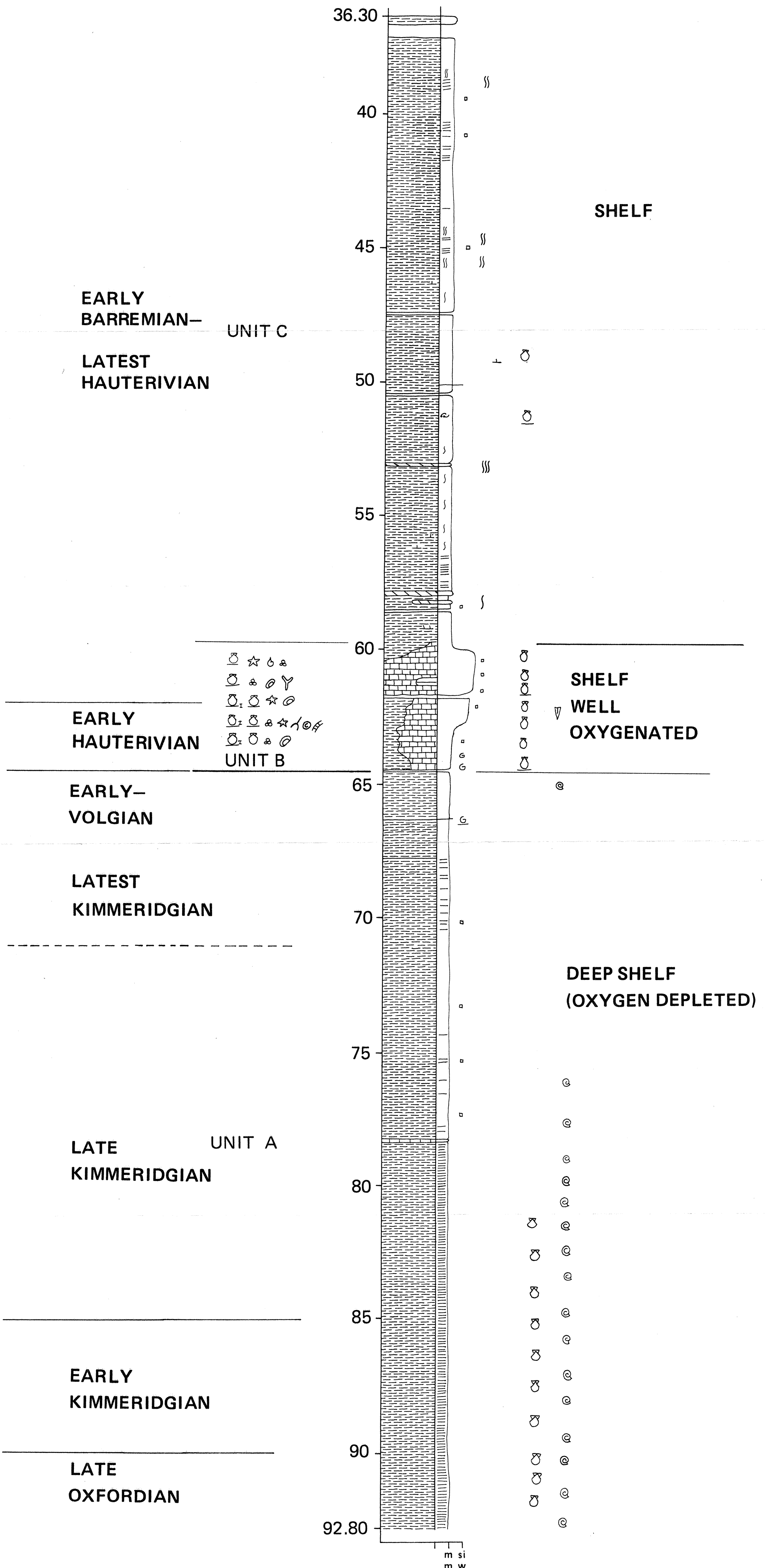


LATEST
ALBIAN









Shallow Drilling Elf Aquitaine/Norsk Hydro/Statoil Barents Sea 1987

Main data report



SINTEF

GROUP