Conoco Norway Inc.

Environmental Surveys of the

Heidrun Field

Supplementary Baseline Survey 1992

HEIDRUN

NIVA

IKU SINTEF-GRUPPEN

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Abstract:

The present survey is a re-investigation of the sea bottom sediments at six sites in the Heidrun oil and gas field, May 1992. Petroleum hydrocarbons and heavy metals were at background levels. Compared to the baseline survey in 1988 values of hydrocarbons and barium were decreased. The sediment fauna was sparse with low numbers of species and individuals. Densities were strongly reduced and diversity decreased compared to 1988. There is no indication of anthropogenic factors or other large scale disturbances in the area to explain the faunal changes, which may reflect a large natural variation in the sediment fauna.

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3. Kjemiske parametre
4. Bunnfauna

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For the Administration

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ENVIRONMENTAL SURVEYS OF THE HEIDRUN FIELD

Supplementary Baseline Survey 1992

Grimstad, 8th February 1993

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Preface

This report presents the results of the re-investigation of selected environmental monitoring sites in the area of the future installations for oil and gas production at the Heidrun field, block 5607/7 at Haltenbanken, Mid-Norway.

NIVA was awarded the contract for the work by Conoco Norway Inc. (CNI) on 13 May 1992 (Service Order Hei-6181). The contract work has been performed as a joint effort by the following research institutions:

- Continental Shelf and Petroleum Technology Institute (IKU), Trondheim
- Norwegian Analytical Center A/S (NAC), Oslo
- Norwegian Institute for Water Research (NIVA), Oslo/Grimstad

IKU has been responsible for the sampling, analyses and reporting of chemical parameters, except for analysis of heavy metals, which has been performed by NAC. NIVA has been responsible for sampling, analysis and reporting of biological parameters and sediments for grain size distribution.

NIVA has coordinated the project and is responsible for the final report.

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Grimstad, 8th February 1993

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EXECUTIVE SUMMARY

Conclusions

The *physical* and *chemical* conditions in the Heidrun field bottom sediments had changed somewhat since the main baseline survey in 1988, but not to a degree beyond what may be natural fluctuations. The changes did not indicate any man-made or other disturbances.

The sediments had a silt/clay content of 24-36 % with a carbon content (TOC) of about 0.50 %. Total hydrocarbons (THC) varied from 0.74 to 2.45 mg/kg dry sediment and concentrations of selected aromatic compounds (NPD) from 53 to 118 µg/kg dry sediment. Decalines/bicyclanes varied from 14 to 55 µg/kg. The values were within the range of background values in North Sea sediments except for NPD which was somewhat higher. The distribution of alkylated homologes of NPD suggested a petrogenic source.

The results of the heavy metal analyses showed values typical for an uncontaminated area. Barium was significantly reduced since 1988 with values of 45-296 mg/kg dry sediment. Mercury was not detected.

The sea-bed *fauna* was extremely sparse and had changed dramatically since 1988. The number of taxa varied from 11 to 30 pr. 0.5 m^2, and the number of individuals from 31 to 93 pr. 0.5 m^2. Compared to 1988 the number of species was about a third and the number of individuals about a fifth. There were no major changes in species composition, however. Diversity was moderate to low. There are good reasons to believe that the changes were natural, although the information necessary to identify the causes were lacking.

The results of the two surveys in the Heidrun field, the main baseline in 1988 and the present supplementary baseline in 1992, should form a good basis for future monitoring. The *chemical analyses* have documented consistently low and generally stable levels of contaminants in the bottom sediments. It is also assumed that the *biological analyses* constitute a good basis for monitoring despite the large and unexpected changes in the fauna. It should be emphasized that the fauna both in 1988 and in 1992 was homogeneous and showed neither haphazard variation nor marked trends across the field. Any effects due to oil production activities after the installation of a platform in the field are expected to lead to directional gradients in the fauna.

Objective of the survey

The present survey is a re-investigation of selected environmental monitoring sites at the Heidrun oil and gas field at Haltenbanken NW of Trøndelag on the coastal Norwegian shelf. The survey comprises physical characteristics of the sediments, contents of major organic and inorganic trace elements and a quantitative description of the seabed fauna. A baseline environmental survey of the Heidrun field was carried out in 1988. The analyses of the present samples allow a comparison to determine if significant changes in the field have occurred.

Selected sites and sampling

A total of six sites were sampled. With reference to the 1988 baseline survey the stations selected for re-sampling were stn. 7, 14, 17, 21 and 23 at the platform site and the reference station, st. 24. The stations were positioned along the four axes previously defined around the platform site.

At all stations samples were taken for particle size distribution, total organic carbon (TOC), total hydrocarbons (THC), heavy metals and macrofauna. In addition core samples from st. 7 were sectioned for vertical distribution of hydrocarbons in the sediment. This site lies between the two sites (8 and 10) selected for the same analysis in 1988. At stn 7, 23 and 24 (reference) samples were also taken for selected aromatics (NPD and 2-6 ring aromatics) and bicyclanes/decalines.

Sampling was performed in the period 5-6 May 1992 from the vessel 'Svanaug Elise'. Station positions were located by use of the Decca GPS Shipmate RS 4000 cc navigator. During sampling date, time and water depth was logged every time the sampling gear reached the bottom.

Sampling procedure and field measurements

Samples for physical and chemical characterization of the sediment were taken with a 0.1 m^2 Smøgen box corer enabling sediment surface subsampling on undisturbed samples. Samples for biological analysis were taken by use of a long armed 0.1 m^2 Van Veen grab.

The standard sampling programme for each station consisted of:

- three box core samples, accepted when having undisturbed surface, depth greater than the thickness of the oxidised layer (> 5 cm) and no sediment wash-out. Each box core sample was transferred to a plastic tray for control and six subsamles were withdrawn from the topmost 0-5 cm for analysis of particle size distribution, and from 0-1 cm for analysis of total organic carbon (TOC), hydrocarbons and metals.

- five Van Veen grab samples, accepted when having a minimum volume of 10 liters and no sign of sediment wash-out. The sample was transferred to a hopper table and washed by gentle water jet onto a 1 mm sieve. The residues from the screen were preserved for analysis of macrofauna.

In addition to the standard sampling programme the following was performed:

- At station no. 24 (reference station) two additional box core samples were collected making the total of five samples for chemical analysis. Similarly five additional Van Veen grab samples were collected making the total of ten samples for macrofauna analysis.

- At station no. 7 a sediment core subsample was taken to study vertical distribution of hydrocarbons.

Each box core was immediately characterized by colour (Munsell colour code) and apparent main sediment composition.

Sample treatment on board

The subsamples for particle size distribution were taken from the grab with a nylon spatula, packed individually in double plastic bags and stored frozen at -20°C.

The subsamples for TOC and hydrocarbon analysis were taken with a nylon spatula and wrapped individually in clean aluminium foil. The core sample was taken with a perspex cylinder of 100 mm diameter, wrapped in aluminium foil, and frozen in a standing position. Sectioning of the sample were performed in the laboratory after slight thawing.

The samples for metal analysis were taken with a nylon spatula, transferred individually to labelled plastic bags and stored frozen.

The sieve residues for macrofauna analysis retained on the 1 mm sieve was transferred to plastic buckets, preserved in 4 % formaldehyde solution with rose bengal stain, and kept cool.

Particle size analysis

The particle size distribution was determined by dry sieving of the fraction above 63 µm and electronic particle counting for the finer fractions. The weight of each size fraction (φ-intervals of 0.5) was determined to the nearest 0.001 g. From the weight distributions were calculated particle diameter, φ %-fractiles, median particle diameter, φ standard deviation, φ skewness and φ kurtosis.

The values for sediment φ median ranged from 2.843 (fine sand) at st. 24 to 3.485 (very fine sand) at st. 17. The average φ median for the six sampled stations was 3.178 (very fine to fine sand). The φ standard deviation and φ skewness indicated poor sorting of the sediment and a displacement of the size distribution towards the finer grains. The % silt/clay or 'mud' content ranged between 24.8-36.4 %. Compared to the 1988 baseline survey a decreased φ-median value and lower % mud content suggest a change towards a coarser and slightly better sorted sediment. The differences, however, may be due to local variations in sediment characteristics, sampling conditions or analytical procedures. Changes caused by water movements (sediment resuspension, transport and redeposition) or large-scale geological processes are not likely.

Chemical analyses

Sediment samples were analysed for the content of total hydrocarbons (THC) (6 stations), selected aromatic compounds (naphthalenes, phenanthrenes, dibenzothiophenes (NPD) and 2-6 ring aromatics) (3 stations), bicyclic aliphatic compounds (C_5-C_8 decalines) (3 stations) and the trace metals iron, copper, zinc, lead, barium, cadmium and mercury (6 stations).

The core sample at st. 7 was analysed for THC and selected hydrocarbon compounds (aromatics and decalines) in the 0-1 cm, 1-3 cm and 3-6 cm layers.

THC is defined as the nonpolar fraction of the total extractable organic matter. This fraction was isolated by saponification, followed by liquid-liquid extraction and adsorption chromatography. The THC content in the boiling-point range nC_{12}-nC_{35} was determined by gas-chromatography/flame ionization detection (GC/FID). The concentrations of selected aromatic compounds and decalines were determined by coupled gas-chromatography/mass-spectrometry (GC/MS).

The trace metal analyses were done in accordance with the Norwegian Standard NS 4770.

Analysis of total organic carbon content (TOC) was done on three replicate samples from each station. TOC was determined by combustion after acid treatment to remove the carbonates.

Chemical characterization

The results from the TOC analyses ranged from 0.38% (site 17) to 0.60% (site 14) with an average of 0.50±0.046%. There was no significant difference between the mean TOC values from the two baseline surveys at Heidrun; 0.52±0.047% (1988) and 0.50±0.046% (1992).

The THC-level varied from 0.74 mg/kg (site 7 and 24) to 2.45 mg/kg (site 23) dry sediment with an average of 1.16±0.36 mg/kg for the whole field. This is within the range of background values in North Sea sediments. The gas-chromatograms verifies the observation of the Heidrun field as homogenous.

The THC-values from this years baseline survey is lower than the reported values from 1988. The observed decrease in THC-values could be due to the work-up procedure/analytical technique or to natural variations as a change in the fauna. The internal quality control program should control the first possible cause.

The concentration of NPD was somewhat higher than normal background values in the North Sea. The NPD concentration ranged from 53.3 µg/kg (site 24) to 118 µg/kg (site 23) dry sediment with an average of the whole field as 77.8±20.6 µg/kg. The distribution of alkylated homologues of NPD at the reference site (site 24) indicates a petrogenic source.

The sum of 2-6 ring aromatics verifies the observation of the Heidrun field as uncontaminated. The mean concentration of PAH of the whole field was 111±41 µg/kg dry sediment.

The content of C_5-C_8 decalines/bicyclanes varied from 14.0 µg/kg (site 24) to 55.0 µg/kg (site 23) dry sediment with a mean concentration of 36.9±14.3 µg/kg. This background level is normal compared with other fields in the North Sea the last years. Decalines were not detected in quantifiable amounts during the 1988 baseline survey.

The report "Heidrun intercalibration and method study" concluded that no direct comparison of NPD, decalines and 2-6 ring aromatics were possible, and that new limits of significant contamination had to be calculated. New limits are given in Table I.

At site 7, the vertical sectioning of THC, NPD, decalines and 2-6 ring aromatics were analysed. There was no significant difference between the THC-values from the different layers (0-1 cm, 1-3 cm and 3-6 cm) and the values were in the same range as for the other locations. The concentration of decalines decreased with increasing depth, but the values were similar to the other 0-1 cm layers analysed. The concentrations of NPD and 2-6 ring aromatics were lower in the 1-3 cm and 3-6 cm layers, while the concentration in the 0-1 cm layer was in accordance with the other data.

The results of the heavy metal analyses showed normal background values typically of an uncontaminated area. New limits of significant contamination were calculated (see Table II). The values are in accordance with the limits calculated during the survey in 1988 except for barium. Mercury was not detected in quantifiable amounts.

The content of barium varied from 45.9 mg/kg (site 7) to 296 mg/kg (site 17) dry sediment with an average of 90.3±58.7 mg/kg. At the reference site (site 24) the mean content of barium was low (51.7±1.6 mg/kg) and this was in accordance with the previous baseline survey. The mean barium content decreased from 164±80 mg/kg in 1988 to 90.3±58.7 mg/kg in 1992, and the decrease is significant ($p > 0.99$).

Biological analyses

All animals, except for foraminiferans and nematodes, were picked out from the samples under a dissection microscope. The animals were identified to the lowest taxon possible, usually species level, and counted. The animals were transferred to 70 % alcohol for storage.

Based on the species lists the following attributes have been calculated:

- Total number of species (taxa)
- Total number of individuals
- Diversity expressed by the Shannon-Wiener index
- Eveness expressed by the Pielou J-index
- Grouping of stations by cluster and ordination (MDS) analyses

Biological characterization

The number of species was low. Altogether 73 taxa were identified, with the number of taxa for each station varying from 11 (st. 14) to 30 (st. 17). At the reference station (st. 24) a total of 24 species were found. The numbers of individuals were low, in many samples extremely low. Total densities ranged from 31 (st. 23) to 93 (st. 7) specimens/0.5 m^2. The reference station had particularly low densities with a total catch of 45 individuals for the 10 replicates (1.0 m^2). A summary of community parameters is given in Table III.

Curves of species numbers versus area showed increasing trends indicating that further sampling (more replicates) would have produced more species. Diversity was low to moderate with values of H' (log_2) ranging from 2.78-4.57 (Table III). The lowest values were calculated for the stations with the lowest species numbers. Evenness (J) was high and stable among the stations. This result expresses that there were no strongly dominating species in the area. Calculation of other indices, rarefaction curves and log-normal distributions was omitted because of the very low numbers of species and individuals.

The bristles worms (Annelida: Polychaeta) constituted the most important group with the bivalves (Mollusca: Bivalvia) the second most important. Other important groups were the sipunculids and sponges (Porifera). The most abundant species were the polychaetes *Lumbrineris* sp., *Onuphis fiordica* (= *Sarsonuphis fiordica*), *Onuphis quadricuspis* (= *Sarsonuphis quadricuspis*) and *Paramphinome jeffreysi*, the bivalves *Abra longicallus*, *Limopsis minuta* and *Nucula tumidula*, the isopod crustacean *Cirolana borealis* (abundant in one grab sample only) and the sipunculan *Onchnesoma steenstrupi*. A summary of species occurring among top ten dominants on the stations are shown in Table IV. *Onuphis fiordica* was top ranked on three stations (7, 14, 17) and second ranked on the reference station (24). *Lumbrineris* sp. was top ranked on the reference station and one of the other stations (23) and second ranked on one station (17).

Compared to the 1988 Heidrun baseline survey there were rather dramatic reductions in numbers of species and individuals. In 1992 the number of species was about a third (15-53 %) and the number of individuals about a fifth (7-32 %) of the numbers recorded in 1988. However, there were no major changes in species composition (Table IV). During a survey of the Haltenbanken in 1985, however, very low numbers of species and individuals were recorded in the northernmost areas, including the Heidrun field.

Assessment of the results

The chemical and biological analyses gave rather different results compared to the 1988 Heidrun baseline survey. While the chemical results indicated stable and environmentally good conditions, the biological results would suggest that some changes might have occurred. The number of species and densities recorded in the present survey were far below what would be considered normal. The results, however, are far from conclusive.

The chemical analyses showed that the sediments in the Heidrun field were uncontaminated with values for hydrocarbons (THC) and heavy metals at background level. The grain size distribution analyses, which showed a more coarse sediment than in 1988, could indicate some physical/mechanical disturbance of the bottom, but the differences are more likely due to local variations in sediment characteristics, sampling or analytical procedures. The chemical and sedimentological parameters thus do not indicate any anthropogenic factors which could be the reason for the sparse fauna.

There is nothing to indicate gear malfunction or incorrect routines during the biological sampling. As far as can be ascertained the van Veen grab worked properly. Actually this is supported by the consistent and similar results of the samples. Errors in sampling or processing procedures would generally be expected to lead to great variation among the samples.

The possibility therefore exists that the results represent a large and unexpected, though natural, variation in the bottom fauna of the area. It should also be notet that the 1988 samples were taken ultimo June which is at the time of recruitment of most species. This may explain the high number of species and high diversities, but abundances were not particularly high in 1988. It is therefore unlikely that recruitment conditions is the only cause of the differences between the 1988 baseline survey and the present study.

Table I *Heidrun Baseline Study 1992. Field mean concentrations of TOC, THC, NPD, decalines and 2-6 rings aromatics. Limit of significant contamination (LSC) was calculated based on a Student T-test with (p>0.95) and (p>0.99) confidence levels.*

Parameter	Mean ± SD	LSC (p>0.95)	LSC (p>0.99)
TOC[1)]	0.50 ± 0.046	0.58	0.63
THC[2)]	1.16 ± 0.360	1.78	2.19
NPD[3)]	77.8 ± 20.6	115	143
C_5-C_8 decalines[3)]	36.9 ± 14.3	63.1	83.4
2-ring aromatics[3)]	6.35 ± 3.45	12.6	17.3
3-ring aromatics[3)]	7.48 ± 3.46	13.7	18.4
4-ring aromatics[3)]	16.7 ± 10.0	34.8	48.4
5-ring aromatics[3)]	47.3 ± 15.5	75.4	96.4
6-ring aromatics[3)]	36.0 ± 12.3	58.3	75.0

Legend:
1) - results in % of dry weight
2) - results in mg/kg dry weight
3) - results in µg/kg dry weight

Table II *Heidrun Baseline Study 1992. Field mean concentrations of selected heavy metals. Limit of significant contamination (LSC) was calculated based on a Student T-test with (p>0.95) and (p>0.99) confidence levels.*

Parameter	Mean ± SD[1)]	LSC (p>0.95)	LSC (p>0.99)
Cd	0.075 ± 0.013	0.097	0.11
Cu	7.94 ± 0.71	9.17	9.97
Pb	15.9 ± 2.95	21.0	24.3
Zn	41.5 ± 3.50	47.6	51.5
Fe	14200 ± 1136	16200	17500
Ba	90.3 ± 58.7	192	258
Hg	-	-	-

Legend:
1) - results in mg/kg dry weight

Table III *Heidrun survey 1992. Community parameters for the benthic macrofauna: area sampled, number of species (taxa), number of individuals, Shannon-Wiener diversity (H') and Pielou evenness (J).*

Station no	Area sampled, m^2	Number of taxa	Total number of individuals	H' (ln)	H' (log_2).	J
7	0,5	27	93	2,73	3,93	0,83
14	0,5	11	23	1,93	2,78	0,80
17	0,5	30	72	2,95	4,25	0,87
21	0,5	29	51	3,17	4,57	0,94
23	0,5	16	31	2,47	3,56	0,89
24	1,0	24	45	2,87	4,13	0,90

Table IV *List of most abundant species in the Heidrun survey 1992. Species are ranked according to number of registrations on top ten lists for the stations. Number of registrations in the 1988 Heidrun baseline survey (1 mm fraction) are shown for comparison.*

	Number of registrations on top-ten lists	
	1992 (6 stations)	1988 (25 stations)
Lumbrineris sp.	5	24
Onuphis fiordica	4	25
Onuphis quadricuspis	4	6
Paramphinome jeffreysii	4	11
Onchnesoma steenstrupi	4	7
Nucula tumidula	3	13
Limopsis minuta	2	13
Abra longicallus	2	14
Clymenura borealis	1	7
Ophelina sp.	1	-
Maldanidae ind.	1	-
Cirolana borealis	1	-
Molgulidae ind.	1	14

UTFYLLENDE SAMMENDRAG

Konklusjoner

De sedimentfysiske og -kjemiske forholdene på Heidrun-feltet hadde forandret seg noe siden basisundersøkelsen i 1988. Forandringene var imidlertid ikke større enn normale variasjoner og tydet ikke på menneskeskapte påvirkninger eller andre forstyrrelser.

Sedimentene hadde et silt/leire-innhold på 24-36 % og verdier for organisk karbon (TOC) omkring 0.50 %. Totalmengde hydrokarboner (THC) varierte fra 0.74 til 2.45 mg/kg tørt sediment og utvalgte aromatiske forbindelser (NPD) fra 53 til 118 µg/kg tørt sediment. Dekaliner/bisyklaner varierte fra 14 til 55 µg/kg. Verdiene var innenfor normale bakgrunnsverdier for sedimenter i Nordsjøen med unntak for NPD som var noe høyere. Fordelingen av alkylerte homologer av NPD indikerte at aromatene stammer fra en petrogen kilde.

Resultatene for tungmetallene var innenfor normale bakgrunnsverdier for uforurensede områder. Barium var signifikant redusert siden 1988 og hadde verdier på 45-296 mg/kg tørt sediment. Kvikksølv ble ikke påvist.

Faunaen i bunnsedimentene var svært fattig og viste en dramatisk forandring siden 1988. Antall arter (taxa) varierte fra 11 til 30 pr. 0.5 m^2 og antall individer fra 31 til 93 pr. 0.5 m^2. Sammenlignet med 1988 var artstallene omkring en tredel og individtallene omkring en femdel av tallene som ble funnet i 1988. Det var imidlertid ingen vesentlige endringer i artssammensetningen. Det er grunn til å anta at forandringene var naturlige selv om det ikke var mulig å peke på noen klar årsak til disse.

Resultatene fra de to undersøkelsene på Heidrun, basisundersøkelsen i 1988 og den supplerende undersøkelsen i 1992, gir et godt grunnlag for fremtidig overvåking i området. De *kjemiske analysene* har påvist lave og generelt stabile verdier for sporelementer i bunnsedimentene. Det må også forutsettes at de *biologiske analysene* gir et godt grunnlag for overvåking på tross av de store og uventede forandringene i fauna. Det bør understrekes at både i 1988 og i 1992 var faunaen homogen og viste hverken tilfeldig variasjon eller markerte trender over området. Mulige effekter fra produksjon eller annen oljerelatert aktivitet etter at en plattform er installert, vil ventelig gi seg utslag i retningsbestemte gradienter i faunaen.

Mål for undersøkelsen

Foreliggende rapport gir resultater fra en supplerende basisundersøkelse på Heidrun-feltet på Haltenbanken nordvest for Trøndelag. Undersøkelsen omfatter sedimentfysiske forhold, organiske og uorganiske sporelementer i bunnsedimentene og bunnfauna. I 1988 ble det utført en basisundersøkelse på Heidrun-feltet. Ved foreliggende undersøkelse er det foretatt ny prøvetaking på utvalgte stasjoner for å avgjøre om det har funnet sted endringer i området.

Valg av stasjoner og prøvetaking

I alt ble det tatt prøver på seks stasjoner. Med referanse til undersøkelsen i 1988 tilsvarer disse stasjonene 7, 14, 17, 21 og 23 ved posisjonen for plattformen og referansestasjonen, st. 24. Stasjonene ligger på de fire hovedaksene rundt plattform-posisjonen som tidligere er definert.

På alle stasjonene ble det tatt prøver for partikkelfordeling, totalt organisk karbon (TOC), hydrokarboner (THC), tungmetaller og makrofauna. I tillegg ble en kjerneprøve fra stasjon 7 seksjonert for analyse av vertikalfordeling av hydrokarboner i sedimentet. Denne stasjonen ligger mellom stasjonene 8 og 10 hvor de samme analysene ble utført i 1988. På stasjon 7, 23 og 24 (referanse) ble det også tatt prøver for utvalge aromatiske forbindelser (NPD og 2-6 rings aromater) og bisykliske alifater/dekaliner.

Prøvetakingen ble foretatt 5-6 mai 1992 med fartøyet 'Svanaug Elise'. Posisjonene for stasjonene ble lokalisert ved bruk av Decca GPS Shipmate RS 4000 cc navigator. Under prøvetakingen ble dato, klokkeslett og dyp notert for hver prøve som ble tatt.

Prøvetakingsprosedyre

Prøver for sedimentfysiske/-kjemiske parametre ble tatt med en 0.1 m^2 'Smøgen boxcorer' som gjør det mulig å ta delprøver av overflatesediment fra uforstyrrede prøver. De biologiske prøvene ble tatt med en 0.1 m^2 van Veen bunngrabb.

Standard innsamlingsprogram for hver stasjon besto av:

- tre prøver med boxcorer, godkjent når sedimentoverflaten var uforstyrret, prøven var dypere enn tykkelsen av det oksyderte laget (> 5 cm) og det ikke var tegn til utvasking av sedimentet. Hver prøve ble overført til en plastbakke for kontroll. Seks delprøver ble tatt fra det øverste 0-5 cm sedimentsjikt for analyse av partikkelfordeling, og fra 0-1 cm for analyse av totalt organisk karbon (TOC), hydrokarboner og metaller.

- fem van Veen grabbprøver, godkjent når prøvevolumet oversteg 10 liter og det ikke var tegn til utvasking av sediment. Prøvene ble overført til et spylebord og vasket med lett spyletrykk på 1 mm sikt. Sikteresten fra spylingen ble konservert for analyse av bunnfauna.

I tillegg til standardprogrammet ble følgende utført:

- På stasjon 24 (referansestasjonen) ble det tatt to ekstra prøver med boxcorer for kjemiske analyser. Tilsvarende ble det tatt 5 ekstra prøver med van Veen grabb for analyse av bunnfauna.

- På stasjon 7 ble det tatt en kjerneprøve for analyse av vertikalfordeling av hydrokarboner.

Hver boxcorer-prøve ble karakterisert etter Munsell fargekode og visuell sammensetning av sedimentet.

Prøvebehandling i felt

Delprøvene for partikkelfordeling ble tatt med en nylonspatel, pakket i doble plastposer og oppbevart frosset ved -20 °C.

Delprøvene for TOC og hydrokarboner ble tatt med en nylonspatel og pakket individuelt i renset

aluminiumsfolie og merkede plastposer. Kjerneprøven ble tatt med en perspex sylinder med 100 mm diameter, pakket i aluminiumsfolie og frosset i vertikal stilling. I laboratoriet ble prøven seksjoner etter delvis tining.

Prøvene for analyse av metaller ble tatt med en nylonspatel, overført til merkede plastposer og oppbevart frosset.

Siktematerialet for analysene av bunnfauna ble overført til plastbøtter, fiksert i 4 % formaldehyd løsning med bengalrosa og oppbevart nedkjølt.

Analyse av partikkelfordelingen

Kornstørrelsesfordelingen ble bestemt ved tørrsikting av fraksjonen over 63 µm og elektronisk partikkeltelling for finere fraksjoner. Vekten av hver størrelsesklasse (φ-intervaller på 0.5) ble bestemt til nærmeste 0.001 g. Fra vektfordelingene ble det beregnet verdier for partikkeldiameter, φ %-fraktiler, median partikkeldiameter, φ standard avvik, φ skjevhet og φ kurtosis.

Verdiene for midlere partikkeldiameter (φ-middel) varierte fra 2.843 (fin sand) på stasjon 24 til 3.485 (svært fin sand) på stasjon 17. Den midlere verdi for φ-median for de seks stasjonene var 3.178 (svært fin til fin sand). φ standardavvik og φ skjevhet viste at sedimentet var dårlig sortert med en hale i finfraksjonen. Innholdet av finsediment (silt/leire) varierte fra 24.8 til 36.4 %. Sammenlignet med basisundersøkelsen i 1988 var det lavere φ-median verdi og lavere prosentandel av finsediment som tyder på en forandring mot et noe grovere og bedre sortert sediment. Forskjellene skyldes imidlertid mest sannsynlig variasjoner i sedimentforhold, prøvetaking og analyser. Forandringer som kan tilskrives vannbevegelser (resuspensjon, transport og nedfall) eller stor-skala geologiske prosesser er ikke sannsynlige.

Kjemiske analyser

Sedimentprøvene ble analysert for totalt hydrokarboninnhold (THC) (6 stasjoner), utvalgte aromater (naftalener, fenantrener, dibenzotiofener (NPD) og 2-6 rings aromater) (3 stasjoner), bisykliske alifater (C_5-C_8 dekaliner) (3 stasjoner) og elementene jern, kobber, sink, bly, barium, kadmium og kvikksølv (6 stasjoner)

Kjerneprøven fra st. 7 ble analysert med hensyn på THC og utvalgte forbindelser i lagene 0-1 cm, 1-3 cm og 3-6 cm.

THC er definert som den upolare fraksjonen av det totale ekstraherbare organiske materialet. Denne fraksjonen ble isolert ved forsåpning, etter-fulgt av væske-væske-ekstraksjon og adsorbsjonskromatografi. Innholdet av THC, definert ved kokepunkts-området nC_{12} - nC_{35}, ble bestemt ved gasskromatografi/flammeionisasjons-deteksjon (GC/FID). Konsentrasjonen av utvalgte aromater og dekaliner ble bestemt ved koblet gasskromatografi/massespektrometri (GC/MS).

Norsk standard NS 4770 ble benyttet ved elementanalysene.

Innholdet av totalt organisk karbon (TOC) ble i tillegg bestemt i tre paralleller fra hver stasjon ved forbrenningsanalyse etter fjerning av karbonater med saltsyre.

Kjemisk karakterisering

Resultatene fra TOC analysene varierte fra 0.38% (stasjon 17) til 0.60% (stasjon 14) med et gjennomsnitt på 0.50±0.046%. Det var ingen forskjell mellom den gjennomsnittlige TOC verdien beregnet for hele feltet ved undersøkelsene i 1988 og 1992. TOC verdiene var henholdsvis 0.52±0.047% (1988) og 0.50±0.046% (1992).

THC-nivået varierte fra 0.74 mg/kg (stasjon 7 og 24) til 2.45 mg/kg (stasjon 23) tørt sediment med et gjennomsnitt på 1.16±0.36 mg/kg for hele feltet. Dette er typiske bakgrunnsverdier for Nordsjø-sedimenter. Gass-kromatogrammene viser at sammensetningen av THC i området er homogen.

THC-verdiene fra denne undersøkelsen er lavere enn de rapporterte verdier fra 1988. Dette kan være forårsaket av naturlige variasjoner som sammensetningen av fauna eller av opparbeidingsprosedyre/analyseteknikk. Sistnevnte skal være tatt vare på gjennom det interne kvalitetssikringsprogrammet.

Konsentrasjonen av NPD var noe høyere enn normale bakgrunnsverdier i Nordsjøen. NPD-konsentrasjonen varierte fra 53.3 µg/kg (stasjon 24) til 118 µg/kg (stasjon 23) tørt sediment med en gjennomsnittsverdi for hele feltet på 77.8±20.6 µg/kg. Fordelingen av serien av alkylerte homologer ved referansestasjonen (stasjon 24) indikerer at aromatene stammer fra en petrogen kilde.

Summen av 2-6 rings aromater indikerer et uforurenset sediment. Den gjennomsnittlige konsentrasjonen av PAH for Heidrun-feltet var 111±41 µg/kg tørt sediment.

Innholdet av C_5-C_8 dekaliner/bisyklaner varierte fra 14.0 µg/kg (stasjon 24) til 55.0 µg/kg (stasjon 23) tørt sediment med et gjennomsnitt på 36.9±14.3 µg/kg. Dette er normale bakgrunnsverdier som er rapportert fra andre felter i Nordsjøen de siste årene. Dekaliner ble ikke påvist ved basisundersøkelsen i 1988.

Rapporten "Heidrun intercalibration and method study" viste at NPD, dekaliner og 2-6 rings aromater ikke kunne sammenlignes direkte, og at nye grenser for signifikant kontaminering måtte beregnes ved senere undersøkelser. Nye grenseverdier er vist i Tabell I.

På stasjon 7 ble den vertikale fordelingen av henholdsvis THC, NPD, dekaliner og 2-6 rings aromater analysert. THC-verdien mellom de ulike lagene viste ingen signifikant forskjell, og verdiene var innenfor området for de rapporterte verdier fra de andre stasjonene. Dekalin-innholdet avtok med økende dybde, men verdiene var lik de andre målte verdiene fra 0-1 cm. For NPD og 2-6 rings aromater var konsentrasjonen noe lavere i 1-3 cm og 3-6 cm lagene, mens konsentrasjonen i 0-1 cm laget var innenfor verdiene målt ved de andre stasjonene.

Resultatene av tungmetall-analysene viser normale bakgrunnsverdier for et uforurenset område. Nye grenseverdier for signifikant kontaminering ble beregnet (se Tabell II). De fleste viser overensstemmelse med verdiene beregnet ved basisundersøkelsen i 1988, med unntak for barium. Kvikksølv ble ikke påvist i 1988 eller 1992.

Konsentrasjonen av barium varierte fra 45.9 mg/kg (stasjon 7) til 296 mg/kg (stasjon 17) tørt sediment med et gjennomsnitt på 90.3±58.7 mg/kg. Barium-innholdet ved referansestasjonen (stasjon 24) var lav (51.7±1.6 mg/kg) og denne observasjonen var i samsvar med resultatet fra 1988. Den gjennomsnittlige konsentrasjonen av barium avtok fra 164±80 mg/kg i 1988 til 90.3±58.7 mg/kg i 1992, og reduksjonen var signifikant ($p > 0.99$).

Analyser av bunnfauna

Alle dyr i prøvene, med unntak for foraminiferer og nematoder, ble plukket ut under binokulærlupe. Dyrene ble identifisert til lavest mulige taxon, vanligvis artsnivå, og telt. Materialet ble overført til 70 % alkohol for lagring.

Basert på artslistene ble følgende størrelser beregnet:

- totalt antall arter (taxa)
- totalt antall individer
- diversitet utrykt ved Shannon-Wiener indeks
- jevnhet beregnet ved Pielou J-indeks
- gruppering av stasjoner ved clusteranalyse og ordinasjonsanalyse (MDS)

Karakterisering av bunnfauna

Artstallet i prøvene var lavt. Tilsammen ble 73 taxa identifisert, med antall taxa for hver stasjon varierende fra 11 (st. 14) til 30 (st. 17). På referansestasjonen (st. 24) ble det funnet tilsammen 24 arter. Individtallene var også lave, tildels ekstremt lave. Totale individtettheter for stasjonene varierte fra 31 (st. 23) til 93 (st. 7) individer/0.5 m^2. På referansestasjonen var det særlig lave tettheter med totalt 45 individer i de 10 parallelle prøvene (1.0 m^2). En sammenfatning av parametre for bunnfaunaen er gitt i Tabell III.

Kurvene over antall arter mot innsamlet areal viste stigende trend for alle stasjoner og indikerte at ytterligere prøvetaking ville gitt flere arter. Diversitetene var lave til moderate med verdier for H' (log_2) på 2.78 - 4.57 (Tabell III). De laveste verdiene ble funnet på stasjonene som hadde færrest arter. Jevnheten (J) var høy og stabil for alle stasjonene. Resultatet uttrykker at det ikke var noen tydelige dominanter i området. Beregning av andre indekser, diversitetskurver ('rarefaction'-kurver) og log-normalfordelinger ble ikke utført på grunn av de lave arts- og individtallene.

Mangebørstemarkene (Annelida: Polychaeta) utgjorde den største gruppen med muslinger (Mollusca: Bivalvia) som den nest største. Andre viktige former var sipunculider og svamp. De viktigste artene var børstemarkene *Lumbrineris* sp., *Onuphis fiordica* (= *Sarsonuphis fiordica*), *Onuphis quadricuspis* (= *Sarsonuphis quadricuspis*) og *Paramphinome jeffreysi*, muslingene *Abra longicallus*, *Limopsis minuta* og *Nucula tumidula*, krepsdyret *Cirolana borealis* (tallrik bare i en grabbprøve) og sipunculiden *Onchnesoma steenstrupi*. En oversikt over artene som forekommer blant de ti dominerende på stasjonene er gitt i Tabell IV. *Onuphis fiordica* var den individrikeste arten på tre stasjoner (7, 14, 17) og nummer to på referansestasjonen (24). *Lumbrineris* sp. var individrikest på referansestasjonen og en av de andre (23) og nummer to på en stasjon (17).

Sammenlignet med basisundersøkelsen i 1988 var det betydelige reduksjoner i arts- og individtallene. I 1992 var artstallene omkring en tredel (15-53 %) og individtallene omkring en femdel (7-32 %) av tallene som ble funnet i 1988. Det var imidlertid ingen vesentlige endringer i artssammensetningen. Ved en undersøkelse på Haltenbanken i 1985 ble det også funnet lave arts- og individtall i de nordligste områdene som omfatter Heidrunfeltet.

Vurdering av resultatene

De kjemiske og biologiske analysene ga ganske forskjellige resultater sammenlignet med basisundersøkelsen på Heidrun i 1988. Mens de kjemiske undersøkelsene indikerte stabile og gode

miljøforhold, kunne resultatene fra bunnfaunaprøvene tyde på at forandringer i miljøet hadde funnet sted. Arts- og individtallene som ble funnet var langt lavere enn hva som blir betraktet som normalt. Resultatene er imidlertid ikke entydige.

De kjemiske analysene viste at bunnsedimentene var uforurenset med verdier for hydrokarboner (THC) og tungmetaller på bakgrunnsnivå. Kornstørrelsesanalysen, som viste et noe grovere sediment enn i 1988, kunne indikere en fysisk/mekanisk forstyrrelse av bunnen, men det er mer sannsynlig at resultatene gjenspeiler lokale variasjoner i sedimentet, prøvetaking eller forskjeller i analysene. De fysisk/kjemiske undersøkelsene indikerer derfor ingen antropogene faktorer som kunne være årsak til den fattige faunaen.

Det er ingen ting som tyder på redskapsfeil eller dårlige rutiner under den biologiske prøvetakingen. Så langt det kan verifiseres har van Veen grabben fungert tilfredsstillende. Faktisk taler den lave variasjonen mellom de enkelte prøvene for at lave tettheter var et virkelig forhold og ikke en følge av mangelfull prøvetaking.

Muligheten er tilstede for at resultatene representerer en stor og uventet, men allikevel naturlig variasjon i bunnfaunaen i området. I 1988 ble prøvetakingen foretatt i slutten av juni som er tidspunkt for rekruttering for mange arter. Dette kan gi forklaring til høy artsrikhet og høy diversitet, men tetthetene var ikke spesielt store i 1988. Forhold ved rekruttering til bestandene av bunnfauna kan derfor ikke være eneste grunn til forskjellene mellom basisundersøkelsen i 1988 og foreliggende undersøkelse.

Tabell I *Basisundersøkelsen på Heidrun 1992. Midlere konsentrasjoner av TOC, THC, NPD, dekaliner og 2-6 rings aromater over hele feltet. Grense for signifikant kontaminering (LSC) ble beregnet basert på en Student T-test med konfidensnivå på (p>0.95) og (p>0.99).*

Parameter	Middel ± SD	LSC (p>0.95)	LSC (p>0.99)
TOC[1)]	0.50 ± 0.046	0.58	0.63
THC[2)]	1.16 ± 0.360	1.78	2.19
NPD[3)]	77.8 ± 20.6	115	143
C_5-C_8 dekaliner[3)]	36.9 ± 14.3	63.1	83.4
2-rings aromater[3)]	6.35 ± 3.45	12.6	17.3
3-rings aromater[3)]	7.48 ± 3.46	13.7	18.4
4-rings aromater[3)]	16.7 ± 10.0	34.8	48.4
5-rings aromater[3)]	47.3 ± 15.5	75.4	96.4
6-rings aromater[3)]	36.0 ± 12.3	58.3	75.0

Forklaringer:
1) - resultater i % av tørrvekt
2) - resultater i mg/kg tørrvekt
3) - resultater i µg/kg tørrvekt

Tabell II *Basisundersøkelsen på Heidrun 1992. Midlere konsentrasjoner av tungmetaller og mineraler over hele feltet. Grense for signifikant kontaminering (LSC) ble beregnet basert på en Student T-test med konfidensnivå på (p>0.95) og (p>0.99).*

Parameter	Middel ± SD[1)]	LSC (p>0.95)	LSC (p>0.99)
Cd	0.075 ± 0.013	0.097	0.11
Cu	7.94 ± 0.71	9.17	9.97
Pb	15.9 ± 2.95	21.0	24.3
Zn	41.5 ± 3.50	47.6	51.5
Fe	14200 ± 1136	16200	17500
Ba	90.3 ± 58.7	192	258
Hg	-	-	-

Forklaringer:
1) - resultater i mg/kg tørrvekt.

Tabell III *Basisundersøkelsen på Heidrun 1992. Samfunnsparametre for bunnfauna: prøvetatt areal, antall arter (taxa), antall individer, Shannon-Wiener diversitet (H') og Pielou jevnhet (J).*

Stasjon	Areal prøvetatt, m^2	Antall arter (taxa)	Totalt antall av individer	H' (ln)	H' (log_2).	J
7	0,5	27	93	2,73	3,93	0,83
14	0,5	11	23	1,93	2,78	0,80
17	0,5	30	72	2,95	4,25	0,87
21	0,5	29	51	3,17	4,57	0,94
23	0,5	16	31	2,47	3,56	0,89
24	1,0	24	45	2,87	4,13	0,90

Tabell IV *Fortegnelse over de mest vanlige artene ved basisundersøkelsen på Heidrun 1992. Artene er rangert etter antall registreringer på lister over 10 dominerende arter for stasjonene. Antall registreringer fra basisundersøkelsen på Heidrun i 1988 (1 mm fraksjon) er vist for sammenligning.*

	Antall registreringer på lister over dominante arter	
	1992 (6 stasjoner)	1988 (25 stasjoner)
Lumbrineris sp.	5	24
Onuphis fiordica	4	25
Onuphis quadricuspis	4	6
Paramphinome jeffreysii	4	11
Onchnesoma steenstrupi	4	7
Nucula tumidula	3	13
Limopsis minuta	2	13
Abra longicallus	2	14
Clymenura borealis	1	7
Ophelina sp.	1	-
Maldanidae ind.	1	-
Cirolana borealis	1	-
Molgulidae ind.	1	14

1. INTRODUCTION

1.1 The objectives of the survey

The Heidrun oil and gas field is situated at Haltenbanken on the coastal shelf NW of Trøndelag about 175 km from the Norwegian coast. The field lies predominantly within Block 6507/7 with an extension into Block 6507/8. A production licence was in 1984 allocated to a group with Conoco Norway Inc. (CNI) as operator. A total of nine exploratory wells were drilled in the period 1984-1987. According to present field development plans drilling of platform wells may start in 1993 while the platform operations is scheduled to start in 1995 (CONOCO 1989).

A baseline environmental survey of the sea bottom of the Heidrun field was carried out in 1988 (Bakke et al. 1989). The survey comprised physical characteristics of the sediments, content of major organic and inorganic trace elements and quantitative description of the seabed fauna. The present survey is a re-investigation of a selected set of the sites studied in the main baseline survey. The aim of the study is to determine if significant changes have occurred since the main survey.

1.2 Description of the area, basic sedimentology and oceanography

The Heidrun field lies about 100 km NW of the shallowest part of Haltenbanken. The western area of Haltenbanken has a fairly gentle topography with waterdepths between 200 and 300 m. The Heidrun field lies in the northern part of this submarine plain. North, east and west of Heidrun the submarine topography is more varied with ridges and troughs. North of Heidrun there is a wide trough, reaching depths of more than 400 m about 5.5 km north of the field.

Much of the surface sediments of Haltenbanken is characterized by silt/clay with various amounts of sand, gravel and occasionally pebbles and boulders. The sediments comprise glacial till or drift deposited as a consequence of several glaciations during the last 1.5-2 million years. The last glaciation was at its height about 18 000 years before present. During the glacial retreat the edge of the ice reached Haltenbanken about 12 000 years ago. It is considered that icebergs were particularly abundant in the waters overlying the deglaciated shelf, and that shedding of icerafted material was a major factor in the supply of sediment in this region. This is particularly pertinent with respect to the coarser particles (sand, gravel and cobbles). Shedding of icerafted material lead to significant and erratic variations in the physical composition of the sediment (Bowler et al. 1986, Bakke et al 1989).

Lateglacial and postglacial modification, reworking and retransport has been modest. Exception are the shallowest parts of Haltenbanken, the slopes of the bank and the uppermost part of the continental slope. In the submarine plain, including the Heidrun area, the sediments show little or no postglacial or recent reworking. Some areas of Haltenbanken have also been heavily influenced by iceberg scouring. Scouring is observed at depths between 100-500 m. Subsequent to the formation of the ploughmarks the sediments in the furrows and at the edges may be modified from processes of erosion and infilling giving rise to local variations in grain-size characteristics (Bowler et al. 1986).

Inspections using remote operated vehicles (ROVs) indicate that the seabed in the Heidrun field area is generally featureless, with soft smooth sediments and cobbles and stones present. There are several small depressions or pockmarks present (< 2 m deep), evidence of partially infilled iceberg plough marks and indications of a moraine ridge (CONOCO 1989).

The water column in the Haltenbanken area is considered to comprise two main components, i.e. Atlantic water and the Norwegian coastal water. The Atlantic water mass is part of the North Atlantic Current flowing east/northeast from the Faroe-Shetland channel. The coastal water is less saline (salinity less than 35 ‰) and flows northwards following the coast. Several workers have suggested the existence of a gyre of Norwegian coastal water flowing clockwise around Haltenbanken. If correct it would imply that the water masses caught in the gyre would stay for a long time over Haltenbanken.

1.3 Previous investigations in the area

The Heidrun baseline environmental survey performed in 1988 gives a detailed account of physical conditions in the sediments (particle size distribution, redox conditions), chemical parameters (total organic carbon (TOC), total hydrocarbons (THC), aliphatics, aromatics, bicyclanes, heavy metals) and benthic macrofauna for 25 sites in the Heidrun area (Bakke et al. 1989). For the faunal samples both 1 mm and 0.5 mm sives were used. The total area sampled for each station was 0.5 m^2.

In 1985 a baseline survey comprising 38 stations across the Haltenbanken was performed (Bowler et al. 1986). The sites were located in a grid format covering 19 concession blocks, with two stations located within each block. Sampling sites were approximately 14-18 km apart. Two of the stations (station numbers 3, 4) were in the Heidrun area and were resampled during the baseline survey in 1988. The survey comprised sediments, chemical parameters and bottom fauna.

Other investigations in the area comprise primary production, fish stocks, seabirds and marine mammals. A general overview is given by CONOCO (1989).

Geological investigations of the sediments of the Norwegian continental margin have been undertaken by IKU as a part of a regional mapping program. The results of the survey between latitudes 63 °N and 65 °N has been summarized by Bugge (1980). A detailed account of grain-size characteristics of the surface sediments in the Haltenbanken area is given by Holtedahl and Bjerkli (1982). In the Heidrun field a coring survey for description of near surface geology was conducted during June 1988 (Fugro-McClelland 1988).

1.4 Exploration activity prior to the survey

A total of nine exploratory wells have been drilled in the Heidrun area in the period 1984-87. All wells have been abandoned and surface wellhead equipment removed. Basic information on the wells is given by Bakke et al. (1989) and CONOCO (1989). No wells have been drilled after the baseline survey in 1988.

Other activities in the field include the use of coring devices for geotechnical purposes and description of near-surface geology.

There are no reports on other industrial activities in the field.

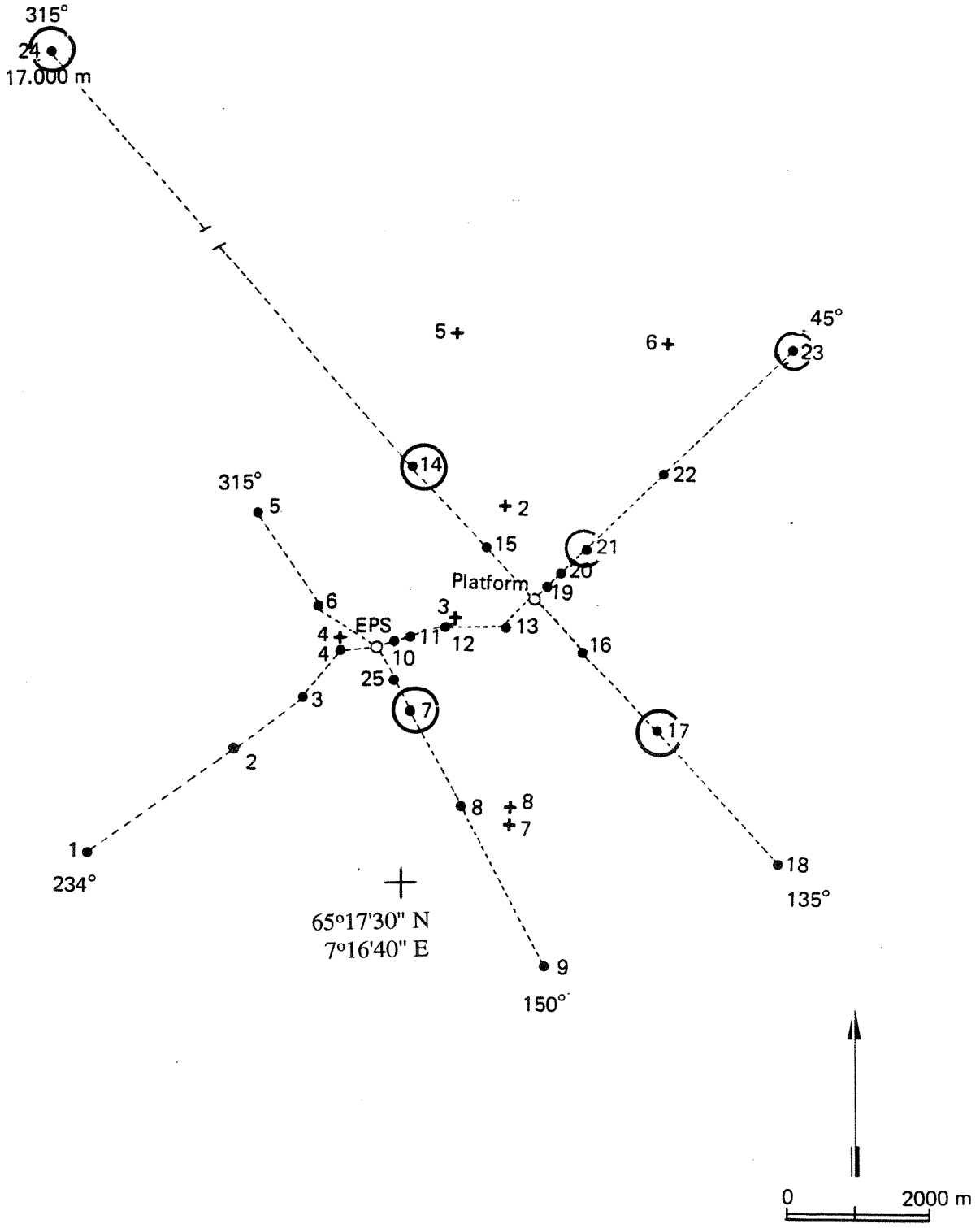


Fig. 1.1. *Map of the Heidrun field with positions for the previously planned early production system (EPS), the permanent platform, sampling transects for the 1988 baseline survey, sampling stations (•), and exploratory wells (+). The stations selected for the present re-investigation are encircled.*

1.5 Selection of sites and sampling program

A total of six sites were sampled in the present survey. Fig. 1.1 shows a map of the Heidrun field and the stations sampled during the baseline survey in 1988 (from Bakke et al 1989). The stations selected for the present re-sampling were stn 7, 14, 17, 21 and 23 at the platform site and the reference station, st. 24. The stations are positioned along the four axes previously defined around the platform site.

Stations 3 and 24 correspond to stn 4 and 3 respectively in Bowler at al. (1986).

At all stations samples were taken for particle size distribution, total organic carbon (TOC), total hydrocarbons (THC), heavy metals and macrofauna. In addition core samples from st. 7 were sectioned for vertical distribution of hydrocarbons in the sediment. This site lies between the two sites (8 and 10) selected for the same analysis in 1988. At stn 7, 23 and 24 (reference) samples were also taken for selected aromatics (NPD and 2-6 ring aromatics) and bicyclanes/decalines.

1.6 Background for the chemical analyses of the sediments

1.6.1 Total organic carbon - TOC

The TOC content of recent, unpolluted sediment is frequently related to the grainsize characteristics and generally, finer sediments contain higher levels of TOC than coarse sediments. The seabed sediments on the North Sea plateau mainly consists of medium and fine grained sand, which typically contain TOC concentrations of less than 1% (Dick 1976, Moore 1983, Oppenheimer 1977). At Haltenbanken (Bowler et al. 1986) the TOC content in sediments was found to vary from 0.25% to 0.56%, with an average of 0.40%.

The mean TOC value from the Heidrun survey in 1988 was 0.52 ± 0.047%. This was slightly higher than the 1985 values, but in 1985 the 0-2 cm layer was subsampled while the 0-1 cm layer was subsampled in 1988. Since the TOC content in general decreases with increasing depth, this may have affected the values. The values from the two common sites during the surveys showed the same trend; 0.51% versus 0.38% for site 3 (Station 4 in Bowler et al. 1986) and 0.51% versus 0.48% for site 24 (Station 3 in Bowler et al. 1986).

When oil-based drilling mud is discharged, the TOC concentration in the sediments close to the point of discharge may increase with several per-cent.

1.6.2 Total Hydrocarbons - THC

The term "total hydrocarbons", THC, used in environmental surveys is defined as the nonpolar hydrocarbon fraction of the extractable organic matter in sediments. The techniques accepted for extraction, isolation and analysis of THC are specified by the SFT Guidelines for environmental monitoring (SFT 1990). The guidelines include isolation by saponification, followed by liquid-liquid extraction and adsorption chromatography. The analysis of THC content is done by gas-chromatography/flame ionization detection (GC/FID).

Several analytical techniques have been employed for THC analysis in former environmental surveys. In the 1985 Haltenbanken survey, the THC content was determined by ultrasonic extraction followed by gravimetry/Iatroscan analysis (Bowler et al. 1986). Previous investigations have shown that this

method does not give accurate results for extremely low THC values (in the lower part of the background range, IKU unpublished results). This is because of certain linearity problems, connected to the Iatroscan detection. However, in this study, the results of the mean aliphatic/aromatic content (sum of aliphatic and aromatic hydrocarbons are defined as THC) of the extractable organic matter was more than 10 per-cent, meaning that the accuracy of the results in general was acceptable.

In the Heidrun survey in 1988, THC was determined by soxhlet extraction, isolation by adsorption chromatography and quantification of THC by gas chromatography/flame ionization detection (GC/FID). This method was in accordance with the SFT guidelines at that time.

A Heidrun intercalibration and method study (IKU 1990 a) concluded that results from THC analysis obtained by saponification extraction are directly comparable with the results from the soxhlet extraction system used in the baseline study.

Typical background values of THC in North Sea sediments are 0.50 - 20 mg/kg dry weight. Because of the different analytical techniques used in THC determination during the previous baseline and monitoring surveys, direct comparison of THC values from different North Sea areas may be difficult.

The average THC content measured in the Haltenbanken survey (1985) was 4.0 ±2.5 mg/kg dry weight. The average THC content found in the Heidrun survey in 1988 was slightly lower; 2.92 ± 1.35 mg/kg. No significant difference between these two data sets was detected, when the variation in the results was considered. As discussed above the values obtained during the Heidrun survey in 1988 probably give a more accurate measurement of the natural THC content. The area was regarded as homogenous.

1.6.3 Selected aromatics (NPD and 2-6 ring aromatics) and bicyclanes/decalines

The concentration of selected aromatic compounds (naphthalenes, phenanthrenes, dibenzothiophenes (NPD) and 2-6 ring aromatics) and bicyclanes/decalines in sediments are commonly determined in environmental surveys in the North Sea. These compounds are representative of base-oil but are present only at low levels in uncontaminated sediments. Coupled gas-chromatography/mass-spectrometry (GC/MS) is used for this analysis.

As discussed in chapter 1.6.2 several different extraction techniques have been used during previous surveys. The Heidrun intercalibration and method study (IKU 1990 a) concluded that no direct comparison of results from soxhlet and saponification are possible concerning NPD and 2-6 ring aromatics, and that new background values had to be established during future surveys.

The background level of NPD in North Sea sediments are typically in the range 3-50 µg/kg dry sediment. The mean NPD concentration reported from Veslefrikk was 21 µg/kg (Johnsen et al. 1988 a). The NPD concentration at Heidrun obtained by soxhlet extraction was in the range 3.7-30 µg/kg dry sediment (Bakke et al. 1989), which is in the range for a natural uncontaminated sediment. At Gullfaks the concentration of NPD was slightly lower; 7.4-13 µg/kg (Hasle et al. 1985). Other fields in the North Sea as Troll West and TOGI have reported quite high NPD values. The mean NPD content at Troll West I was 190 ± 37.5 µg/kg dry sediment which are 4 times higher than other fields in the North Sea (IKU 1989 a). The results are similar to results reported from TOGI (IKU 1989 b).

Concerning 2-6 ring aromatics and bicyclanes/decalines there are limited information about the background level in uncontaminated sediments in the North Sea. At Heidrun C_5 - C_8 decalines were not detected at all during the previous survey (Bakke et al. 1989). Results from the baseline survey at

Troll West II showed a background level of 47 ± 20 µg/kg dry sediment of C_5-C_8 decalines (IKU 1990b).

1.6.4 Heavy metals in sediments

Two methods have been used in determination of heavy metals in sediments. The total amount of heavy metals is determined by extracting the sediments with concentrated acid, while the bio-available amount is extracted from the sediments with diluted acid. A direct comparison between results obtained from these methods cannot be done. The comparison of these methods done at IKU, shows that the total amount of heavy metals will be higher than the bio-available amount, especially in undisturbed sediments. (IKU 1989c).

Barium is used as a weight agent in drilling fluids (barite) and this metal is commonly used as a tracer in monitoring the distribution of drilling fluids in the environment. It is a highly insoluble and biochemical stable compound. The concentration of barium in production water is also relatively high compared to seawater (MILJØPLAN 1987).

Strontium is found to be a component of drilling fluids, while the concentrations in production water is at the same level as seawater (MILJØPLAN 1987). Results from previous surveys at other fields have shown that strontium is not as good as barium in tracing drilling fluid contamination of sediments, (IKU 1988 b). Strontium is not required by SFT.

The remaining metals are included because they are of particular interest from an environmental/toxicological point of view.

The results from the 1988 baseline survey at Heidrun are given in Table 1.1 together with the limit of significant contamination (LSC) calculated for each metal at significance level p>0.99.

All sediment samples were regarded as undisturbed compared with other fields in the North Sea. The mean concentration of barium ranged from 58-410 mg/kg. The reference site (site 24) showed the lowest barium concentration (65 ± 5.1 mg/kg) and this may reflect natural variation in sediment composition.

There were no zones within the survey area with high concentrations of the other metals analysed. Mercury was not detected in quantifiable amounts.

Table 1.1. Result from the 1988 baseline survey at Heidrun. Mean concentrations and limit of significant contamination (LSC) of heavy metals. Result given in mg/kg.

Metal	Cd	Cu	Pb	Zn	Fe	Ba	Hg
Mean±SD	0.081±0.011	8.8±0.17	17±2.6	43±4.8	16800±1870	160±80	-
LSC	0.11	11.5	24	56	22000	370	-

\- below detection limit

No comparison with heavy metal analysis in the Haltenbanken environmental baseline survey were possible because of the different analytical methods used.

1.7 Background for the biological analyses of the sediments

Studies of the fauna inhabiting the bottom sediments is used routinely for monitoring of environmental quality. The bottom living animals must endure the conditions at the place where they live. The species assemblage are therefore considered to render an integrated picture of the environment. The assemblage is expected to remain stable, within certain limits, during normal conditions, but to react to disturbances by changes in species composition and abundances.

Samples of the fauna are taken with grabs or coring devices which usually take out 0.1 m^2 of the bottom surface. The sediment catch is sieved to separate the animals. It is routinely used sieves of 1 mm mesh size, which is also considered the lower size limit for 'macrofauna' , but in some studies 0.5 mm sieves have been used. The finer sieves catches species which are lost using 1 mm sieves, but very often also catches numbers of juveniles of larger species, which in many respects is a nuisance for the interpretation of the results. In the samples all animals are identified and the number of individuals per species registered. The species lists and abundances are the basis for description of parameters of the 'faunal communities', especially measurements of diversity and similarity.

Ideally the species composition and abundances on a fixed station should not vary. However, most bottom animals reproduce during spring and summer, giving rise to increases in both species numbers and abundances during summer. In the North Sea it is therefore recommended to collect samples not later than medio June. It is presumed that the populations vary least during winter and spring, when also the total numbers are at minimum.

It is recommended to take replicate samples covering a total surface of 0.5 m^2 per station. Comparisons among investigations indicate that both species numbers and abundances vary much from one area to another but 40-90 species and 200-2000 specimens could be considered as normal numbers. In the Heidrun baseline survey (Bakke et al. 1989) number of species (1 mm) were 48-90 and and number of specimens 150-450. In some deep areas lower numbers have been found. In the Troll Vest field in the North Sea species numbers was 31-64 and number of individuals 118-265 per 0.5 m^2 (IKU 1989a).

2. SAMPLING SURVEY

2.1 Sampling positions and position fixing

Sampling was performed in the period 5-6 May 1992 from the vessel ' Svanaug Elise'. The locations of the sampling stations are shown in Figure 1.1, and their basic features are given in Table 2.1. Station positions were located by use of the Decca GPS Shipmate RS 4000 cc installed and calibrated earlier this year. The navigation differ from the 1988 survey, where an ARGO radio link logging system was used.

During sampling date, time and water depth were logged every time the sampler reached the bottom. Further details of positioning is given in the Survey log (Appendix 1).

2.2 Sampling procedure and field measurements

Samples for physical and chemical characterization of the sediment were taken with a 0.1 m^2 Smøgen box corer enabling sediment surface subsampling on undisturbed samples. Samples for biological analysis were taken by use of a long armed 0.1 m^2 Van Veen grab without extra lead weights, except for sampling on station no. 14 and 17 where lead weights had to be used.

The standard sampling programme for each station consisted of:

- three box core samples, accepted when having undisturbed surface, depth greater than the thickness of the oxidised layer (> 5 cm) and no sediment wash-out. Each box core sample was transferred to a plastic tray for control and six subsamles were withdrawn fram the topmost 0-5 cm for analysis of particle size distribution, 0-1 cm for analysis of total organic content (TOC), hydrocarbons and metals.

- five Van Veen grab samples, accepted when having a minimum volume of 10 liters and no sign of sediment wash-out. The sediment volume was estimated as the difference between the total volume of a full grab and the measured sediment height in the grab sample. If acceptable, the whole sample was transferred to a hopper table and washed by gentle water jet onto a 1 mm sieve. The residues from the screen was preserved for analysis of macrofauna.

In addition to the standard sampling programme the following was performed:

- At station no. 24 (reference station) two additional box core samples were collected making the total of five samples for chemical analysis. Similarly five additional Van Veen grab samples were collected making the total of ten samples for macrofauna analysis. This was done to make an assessment of the number of species as a function of sampled area.

- At station no. 7 a sediment core subsample was taken to study vertical distribution of hydrocarbons.

Table 2.1. Sampling stations in the Heidrun Field, 1992: locations relative to position of production system, UTM coordinates, water depths and total sediment volumes sampled for faunal analyses.

Station no.	Target	Range m	Bearing deg °	UTM Position easting	UTM Position northing	Depth m	Fauna vol. sampled (l)
7	Platf.	2350	225	419916	7244468	341	72
14	Platf.	2500	315	419936	7247804	352	75
17	Platf.	2500	135	423374	7244176	336-340	75
21	Platf.	1000	45	422381	7246678	346.5	75
23	Platf.	5000	45	425282	7249429	352	75
24	Platf.	17000	315	411146	7260142	383-389	150[1]

1) Volume for 10 grabs.

Each box core was immediately characterized by colour (Munsell colour code) and apparent main sediment composition. These data are presented in Appendix 1.

2.3 Sample treatment on board

The subsamples for particle size distribution were taken from the grab with a nylon spatula, packed individually in double plastic bags and stored frozen at -20°C.

The subsamples for TOC and hydrocarbon analysis were taken with a nylon spatula and wrapped individually in clean aluminium foil. These samples were again packed in separate plastic bags and stored frozen. The core subsample from station no. 7 was taken with a perspex cylinder of 100 mm diameter, wrapped in aluminium foil, and frozen in a standing position. Sectioning of the sample was performed in the laboratory after slight thawing.

The samples for metal analysis were taken with a nylon spatula, transferred individually to labelled plastic bags and stored frozen.

The sieve residues for macrofauna analysis retained on the 1 mm sieve were transferred to plastic buckets, preserved in 4 % formalin solution with rose bengal stain, and kept cool.

3. PROCEDURES FOR LABORATORY ANALYSIS

3.1 Particle size analysis

The analysis for particle size distribution was performed by dry sieving of the fraction above 63 μm and electronic particle counting for the finer fractions. The samples were thawed and gently homogenized, and a subsample of approximately 65 ml was freeze dried for 48 hours. After weight determination the dry sample was shaken for 20 minutes through a nest of sieves with mesh sizes ranging from 1 mm to 63 μm at φ (phi: negative $\log_2$ of the particle diameter) intervals of 0.5 (Retsch Lab. Sieving Machine Vibro). The fraction on each screen was weighed to the nearest 0.001 g.

The fraction passing the smallest screen was suspended in a known volume of 0.9 % saline solution and the particles counted at volume intervals corresponding to spheric diameters from 2 μm up to 63 μm (φ intervals of 0.5) by use of a Coulter Counter mod. ZB. The % volume of each fraction was converted to % dry weight of the total sediment weight below 63 μm.

The weight of all size fractions were then used to construct cumulative % weight distribution tables for each station. From these tables the following quantities were calculated; particle diameter, φ % fractiles, median particle diameter, φ standard deviation, φ skewness and φ kurtosis.

3.2 Chemical characterization

3.2.1 Statistical methods

The results from each of the sampling sites were reported as mean concentrations ± standard deviation. This is in accordance with the SFT guidelines (Paris commission 1989). A Student T-test was used in calculating limits of significant contamination at a 95% and 99.5% significance level. Linear regression analysis was employed in determining the calibration curve for FID response versus concentration.

3.2.2 Analysis of total organic carbon

A subsample of the homogenized sediment (0-1 cm layer) from each station was analysed for total organic carbon content. 200 mg of dried sample were weighed into a LECO ceramic crucible and carbonate was removed by treatment with heated 10% HCl (40°C), followed by heating at 40°C on a hotplate. The content of total organic carbon was determined by combustion in a LECO CS244 carbon analyser.

3.2.3 Analysis of total hydrocarbons, aromatics and decalines

Figure 3.1 shows a flow chart of the total procedure for saponification/extraction, work up and analysis of THC, selected aromatic compounds and C_5-C_8 decalines. The different steps in the procedure are discussed in detail in the following chapters.

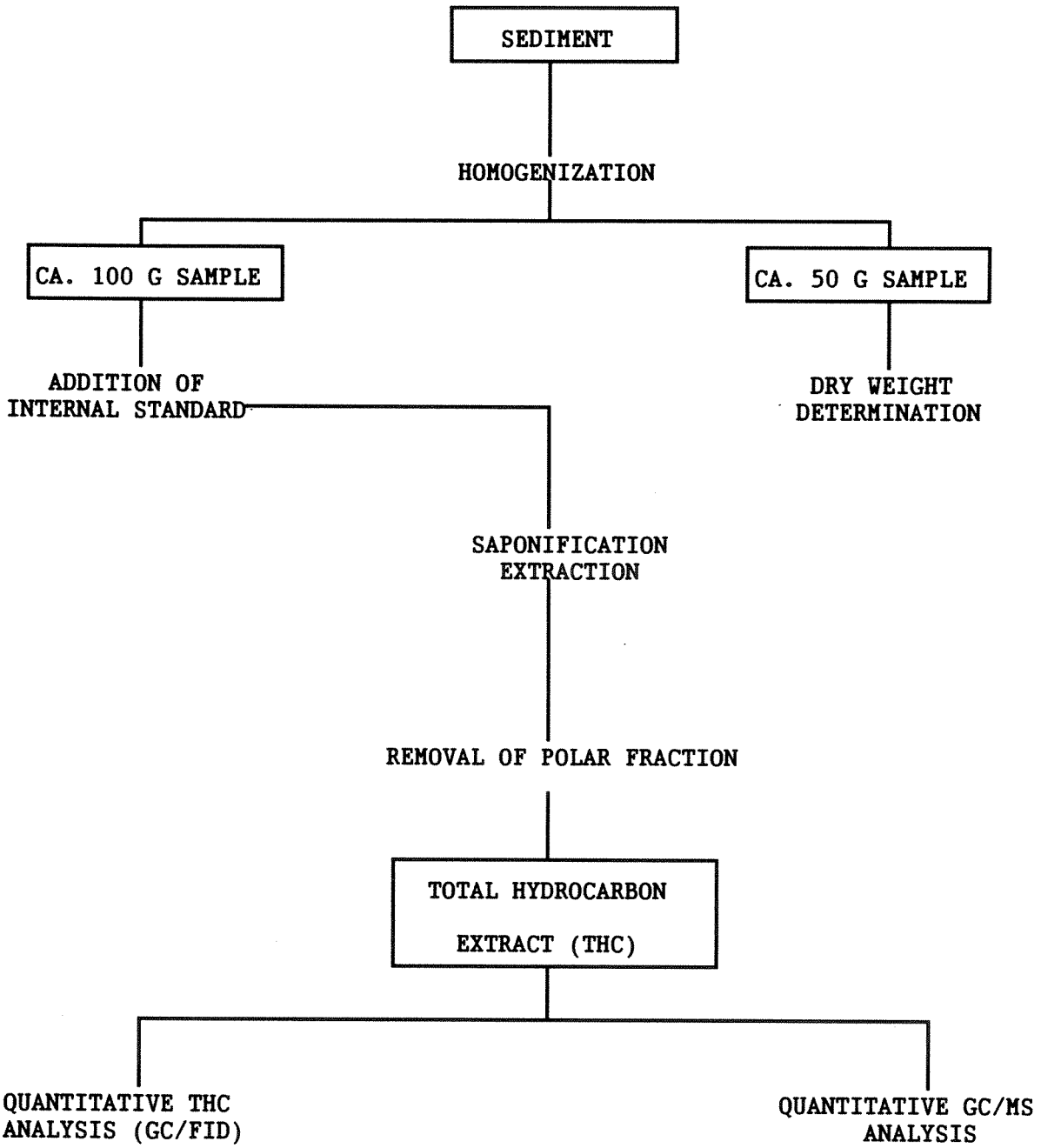


Fig. 3.1 Flow chart over the procedure of hydrocarbon analysis.

Table 3.1 Organic parameters and respective methods of analysis in the 1992 Heidrun baseline survey.

Parameter	Analytical method
Total hydrocarbon (THC) content	GC/FID
C_5-C_8 decaline content	GC/MS
Naphthalene, phenanthrene, dibenzothiophene (NPD) and their C_1-C_3 alkyl derivatives, other polyaromatic hydrocarbons (PAH)	GC/MS

Table 3.1 shows the different organic compounds analysed during the 1992 Heidrun baseline survey and the methods of analysis used.

Saponification and extraction

The sediment samples were homogenized and an aliquot of approximately 100 g was transfered to a 500 ml flask. Internal standards d_8-naphthalene, d_{10}-biphenyl, d_{10}-phenanthrene, d_{10}-pyrene, d_{12}-chrysene, d_{12}-perylene were added directly into the sediment. Sediment dry weight was determined for a 50 g sub-sample after overnight drying in an oven at 105°C.

Methanol (100 ml) and KOH (3.0 g), precleaned with dichloromethane, were added to the sample and the mixture was refluxed for two hours. After cooling, the sample was filtered through Whatman GF/C filters and washed with DCM (3 x 30 ml). The filtrate, DCM and methanol were transfered to a separator funnel and distilled water (50 ml) was added. The organic layer (DCM) was removed after vigorous shaking of the funnel for 2 min. and the remaining water phase was extracted with DCM (2 x 30 ml). The DCM from the three extractions were combined and washed with distilled water (50 ml). The remaining water was removed by drying with anhydrous Na_2SO_4, precleaned with DCM, for two hours. The sample volume was reduced on a rotavapor, followed by evaporation under a gentle stream of N_2 (last 5 ml) to approximately 0.5 ml, and n-hexane (2.0 ml) was added to the sample. All samples were stored at +4°C until the isolation step.

Isolation of non-polar fraction

The DCM was removed from the samples by reduction of the sample volume to 0.5 ml under N_2 atmosphere. Only a very small amount of DCM remains in the sample after evaporation. The remaining sample was transfered to a 500 mg Silica Bond Elut column and the non-polar fraction of the sample was eluded using n-hexane (3 x 2.0 ml). The resulting samples were concentrated or diluted with n-hexane to a suitable volume before GC/FID-analysis (depending on the expected hydrocarbon concentrations of the samples). All samples were stored at -22°C until the start of the analysis.

THC determination

The samples were analysed by GC/FID and quantification of THC was performed over a specified boiling point window (C_{12}-C_{35}) by the external standard method. The base oil from the Statfjord field

Table 3.2. Analytical equipment and conditions for THC determination.

Gas chromatograph:	Hewlett Packard HP 5890 Series II
Injector system:	HP 7673 automatic sampler - splitless in 40 sec.
Injector temperature:	280°C
Carrier gas:	H_2, 7 psi inlet pressure
Column:	Durabond DB-5 15 m x 0.25 mm id.
Detector:	FID 300°C
Temperature program:	40°C (2 min.) - 25°C/min - 300°C(15 min.)
Data system:	VG Multichrom, V.2.0 Vax-based

was used as external standard as no base-oil from Heidrun was available. The analytical equipment and conditions for the THC analyses are given in Table 3.2.

NPD, decalines and 2-6 ring aromatics

NPD, decalines and 2-6 rings aromatics were determined by GC/MS, using deuterated naphthalene, phenanthrene, pyrene, chrysene and perylene as internal standards. Relative response ratios were calculated by analysing a standard containing several of the compounds to be analysed. Some of the alkyl-homologues of NPD and all decalines are not commercially available. The relative response ratios for these compounds were estimated by using the observed relationships between relative response ratio and the number of carbons in the side chain. The molecular ions of the actual compounds were monitored. Peak detection/integration was performed automatically for well-resolved peaks like parent NPD and C_1-homologues. The remaining peaks, i.e. C_2 and C_3-homologues of NPD and decalines, were integrated manually by placing the cursor at the beginning and end of the actual peaks. A relative response factor of 10 is used for decalines (K. Uhrdal SI, personal communication).

Table 3.3 gives the analytical equipment and conditions for the GC/MS analysis, while the Selected Ion Monitoring program is given in Table 3.4.

Table 3.3 Analytical equipment and conditions for GC/MS analyses

GC:	Hewlett Packard 5890 with HP 7671 A
	Automatic sampler
MS:	VG TRIO 1 quadrupol
Computer:	VG LAB+BASE software on IBM compatible PC, AT 386
Analytical parameters:	
GC-conditions:	
Injection:	Splitless 280°C 0.60 min
Column:	Durabond DB -5, 30 m x 0.25 mm
Temp.prog.	60°C (2 min.) - 4°C/min - 310°C (5 min.)
Carrier gas:	Helium, 7 psi inlet pressure
MS-conditions:	
Ionization:	Electron Impact 70 eV
Source temp:	200°C
Source pressure:	10^{-5} Torr

Table 3.4 Monitored ions of NPD, decalines and 2-6 rings aromatic.

Compound	Fragment ion
Naphthalene	128.1
C_1-naphthalene	142.1
C_2-naphthalene	156.1
C_3-naphthalene	170.1
Phenanthrene	178.1
C_1-phenanthrene	192.1
C_2-phenanthrene	206.1
C_3-phenanthrene	220.1
Dibenzothiophene	184.1
C_1-dibenzothiophene	198.1
C_2-dibenzothiophene	212.1
C_3-dibenzothiophene	226.1
C_5-decaline	208.1
C_6-decaline	222.1
C_7-decaline	236.1
C_8-decaline	250.1
Acenaphthylene	152.1
Acenaphthene	153.1
Fluorene	166.1
Anthracene	178.1
Fluoranthene	202.1
Pyrene	202.1
Benzo(a)anthracene	228.1
Chrysene	228.1
Benzo(b/j/k)fluoranthene	252.1
Benzo(a)pyrene	252.1
Benzo(ghi)perylene	276.1
Indeno(1,2,3-cd)pyrene	276.1
Dibenzo(a,h)anthracene	278.1
Deuterated standards:	
d_8-naphthalene	136.1
d_{10}-biphenyl	164.1
d_{10}-phenanthrene	188.1
d_{10}-pyrene	212.1
d_{12}-chrysene	240.1
d_{12}-perylene	264.1

3.2.4 Quality assurance - hydrocarbon analysis

The quality assurance program for the hydrocarbon analysis is described in Appendix 4. The limits of detection (LOD) and quantification (LOQ) were determined from work-up and analysis of blank samples. In addition, the accuracy of the total analytical procedure was determined by recovery analysis of triplicate base oil-spiked sediment samples. The analytical precision was determined from the variation in the results of the recovery experiment and from repeatability tests of the GC/FID and GC/MS systems.

Table 3.5 Instrumentation and experimental conditions for analysis of heavy metals

ICP-AES:	Perkin Elmer Plasma II emission spectrometer		
	R.F. effect	:	1.0 kW
	Plasma gas	:	15 l/min.
	Nebulizer gas	:	1.000 l/min.
	Auxillary gas	:	1.0 ml/min.
	Pumping speed	:	1.0 l/min.
	Resolution	:	Monochromator A - ~0.007 nm
			Monochromator B - ~0.012 nm

Selected lines:

Element	Line (nm)	Background correction
Ba	455.40	Automatic
Cu	324.75	Automatic
Fe	238.20	Automatic
Zn	213.86	Automatic

EAAS:	Perkin Elmer 5100 with Zeeman HGA 600 Graphite furnace.		
Element	:	Pb	Cd
Lamp	:	Hallow cathode	Hallow cathode
Wavelength, nm	:	283.3	228.2
Slit, nm	:	0.7	0.7
Graphite tube	:	Pyrolytic with platform	
Matrix modifier	:	0.2% $(NH_4)H_2PO_4$	
Calibration	:	Standard curve	

CVAAS:	Perkin Elmer 2100 with continuous hydride/cold vapor system.	
Lamp	:	Hg-EDL
Wavelength, nm	:	253.7
Slit, nm	:	0.7

Hydride/cold vapor unit:		
Chanel 1	:	Sample (8 ml/min.)
Chanel 2	:	0.3% $NaBH_4$ + 0.5% NaOH (1 ml/min.)
Chanel 3	:	6 M HCl (1 ml/min.)

3.2.5 Heavy metal analysis

Heavy metal content in the sediment samples were determined by the procedure described by Norsk Standard 4770. Each sample was dried for 48 hours at 50°C and dry weight was determined. After homogenisation, the sample was siftet through a 500 µm sieve. Thereby, 1.0 g of the siftet sample was digested by HNO_3 (20 ml, 7 M) in a sealed Duranflask at 120°C in 30 minutes.

After cooling to ambient temperature, the sample was diluted to 100 ml and the precipitate was allowed to settle. The clear solvent layer was then transfered to polyethylene flasks. The extract was first analysed for the content of barium (Ba), copper (Cu), iron (Fe) and zinc (Zn) by inductive coupled plasma atomic emission spectrometry (ICP-AES). Due to low concentrations, the content of lead (Pb) and cadmium (Cd) was determined by electrothermal atomic adsorption spectrometry (EAAS) and the content of mercury (Hg) by using atomic adsorption spectrometry with cold vapor technique (CVAAS) Table 3.5 gives the instrumentation and experimental conditions for the heavy metal analysis.

3.2.6 Quality assurance - heavy metals

The quality assurance program of the heavy metal analysis is described in Appendix 4. The program involves testing of accuracy and precision by recovery and repeatability tests. International standard reference material was used.

3.3 Biological analyses

3.3.1 Processing of samples

In the laboratory each sample was washed through a fine-meshed sieve (250 µm) to remove formaldehyde and remaining fine sediment. All animals were picked out from the samples under a dissection microscope, except for foraminiferans and nematodes. The animals were identified to the lowest taxon possible, usually to species level, and counted. The animals were transferred to 70 % alcohol for storage.

3.3.2 Numerical methods

Based on the species lists the following attributes have been calculated:

- Total number of species (taxa)
- Total number of individuals
- Diversity expressed by the Shannon-Wiener index
- Evenness expressed by the Pielou J - index
- Grouping of stations by cluster analysis and ordination

Shannon-Wiener Index

This index, based on information theory, is generally considered an overall index of diversity incorporating both 'species richness' and 'evenness' in the measure. The index is given by the formula

$$H' = -\sum_{s} p_i \log_2 p_i$$

where p_i (= n_i/N) is the proportional abundance of species i out of the total number of individuals in the sample (N) and S = number of species. In species-rich communities the index is generally responsive to the abundance of dominant species, but in small samples the addition of rare species may strongly influence the values.

Pielou evenness

The index refers to the distribution of individuals among species in the community. Evenness is maximum when the abundances are equal for all species. The index is given by

$$J = H'/H_{max}$$

where H_{max} (= $\log_2 S$) is the maximum value for H'. Evenness is also the complement of dominance which is usually expressed by

$$D = 1 - J$$

Cluster analysis

Cluster analysis is a technique of multivariate analysis used to describe similarity among samples or stations based on faunal composition. The analysis proceeds in two steps: first the similarity between every pair of stations (samples) is calculated, and secondly a diagram expressing the similarity relationships is constructed. In the present analysis similarity was calculated according to the 'Bray-Curtis similarity index' and the diagram (dendrogram) was constructed according to the principle of 'group-average sorting'.

The Bray-Curtis similarity index is calculated by:

$$1 - \frac{\sum_{n=1}^{s} | X_{ni} - X_{nj} |}{\sum_{n=1}^{s} (X_{ni} + X_{nj})}$$

where s = number of species
x_{ni} = number of individuals of species n at station i
x_{nj} = number of individuals of species n at station j

The abundances were transformed by taking square-roots prior to analysis to balance between the number of species and abundances in the analysis.

Ordination analysis - multidimensional scaling (MDS)

The analysis performs an ordination - i.e. a plotting of points representing stations along right-angled axes - to illustrate the similarities among the stations. Like cluster analysis MDS proceeds in two steps,

first calculating a matrix of similarites between every pair of stations (samples) and secondly producing a plot to represent the calculated similarities. In the plot similarity, or actually dissimilarity, is represented by distance such that close-lying points show similar samples and distant points indicate dissimilar samples. In the present analysis the similarity matrix calculated in the cluster analysis (Bray-Curtis index, square-root transformed data) was used for the plotting procedure.

The calculations were performed on the PRIMER program package (Plymouth mar. lab.).

4. RESULTS

4.1 Particle size distribution

The results of the particle size analyses are summarised in Table 4.1. The complete grain size distribution data are given in Appendix 2.

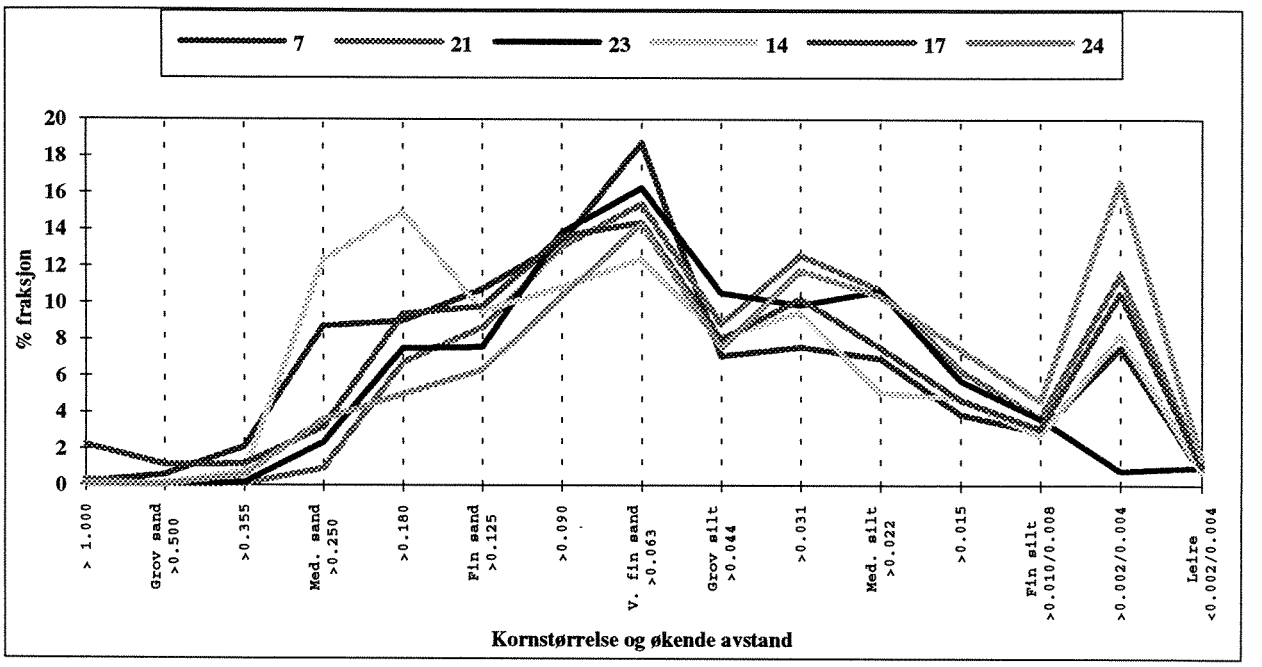
The values for sediment φ median ranged from 2.843 (fine sand) at st. 24 to 3.485 (very fine sand) at st. 17. The average φ median for the six sampled stations was 3.178 (very fine to fine sand). The φ standard deviation (sorting) ranged from 1.393 at st. 7 to 1.733 at st. 24 with an average φ standard deviation of 1.576. This indicates poor sorting of the sediment (values above 1). The φ skewness values (0.145-0.253) were all clearly positive showing a displacement of the size distribution towards the finer grains. The φ kurtosis values (0.862-1.051) which were fairly close to 1, indicated no serious deviation from a normal distribution of size classes. The main nature of the sediment is reflected in the low % silt/clay or 'mud' content ranging between 24.8-36.4 %.

Compared to the 1988 survey the average φ median value has decreased from 4.005 (coarse silt) to 3.178 in 1992 based on the six corresponding stations. The average φ standard deviation has changed from 1.741 in 1988 to 1.576 in 1992 indicating a slightly better sorted sediment, but the sediment is still poorly sorted. The changes, along with a decreased skewness and lower % mud content, suggest a change in the particle size distribution towards a coarser and slightly better sorted sediment. Based on the weight fraction percentages this may be explained either by an increase in the coarser fractions or by a decrease in the finer fractions. The changes are illustrated in Fig. 4.1 where curves of size distributions for the stations are compared.

The differences may be due to local variations in sediment characteristics, sampling conditions or analytical procedures. Changes caused by water movements (sediment resuspension, transport and redeposition) or large-scale geological processes, however, are not likely. In general there would be expected few natural changes in the overall sediment characteristics throughout post glacial time due to the great water depths (more than 300 m) and smooth bottom topography (slope angle less than 0.3 %). To initiate major slope processes (e.g. mud slides) influencing large areas at least an 5° angle is needed.

Table 4.1 Summary of sediment grain size characteristics in the Heidrun Field, 1992.

Station	φ-median	deviation	skewness	kurtosis	% mud
7	3.349	1.393	0.159	1.051	27,9
14	3.134	1.661	0.145	0.894	28.3
17	3.485	1.563	0.148	0.862	36,4
21	3.065	1.528	0.145	1.067	24.8
23	3.190	1.576	0.253	0.904	29.3
24	2.843	1.733	0.247	0.916	25.9



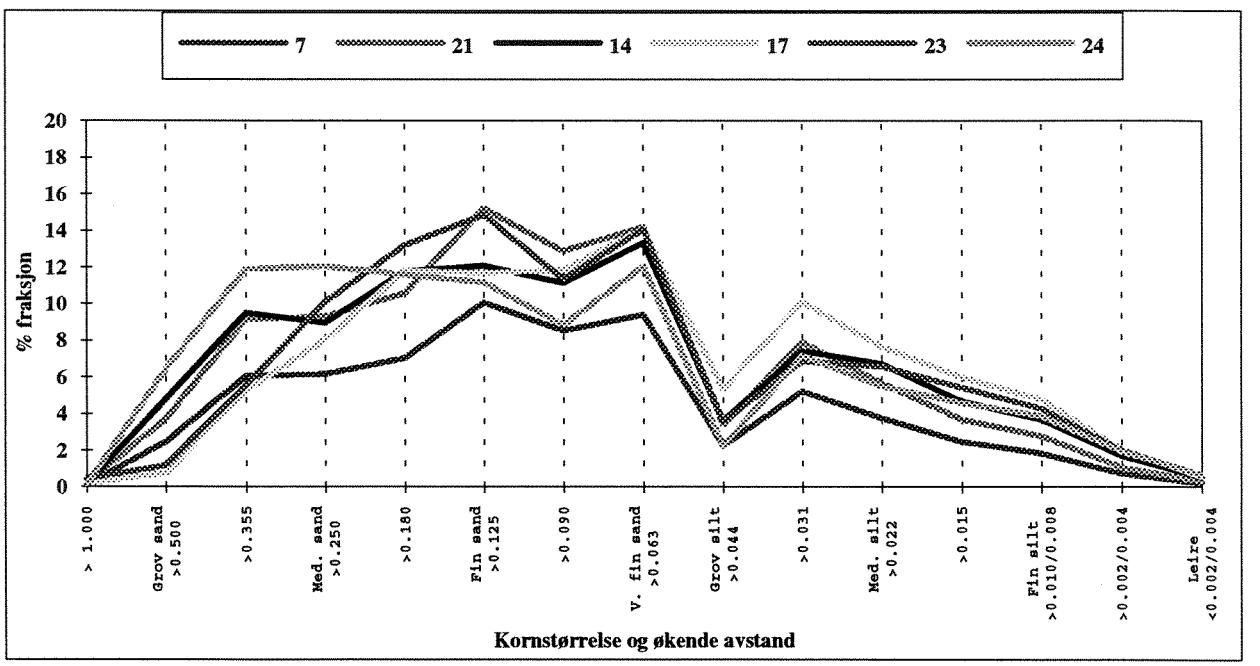


Fig. 4.1. Sediment characteristics in the Heidrun field: grain size distribution curves for the stations in 1988 (top) and 1992 (bottom).

The differences could be coincidental. In general the particle size distribution in glaciomarine sediment deposits vary randomly, especially the coarser fraction. Ice rafted particles have a patchy distribution (chapter 1.2). Further, there may be minor local sediment depressions over short distances, e.g. at sites of iceberg scouring (c.f. the variation in sampling depths at stn 17 and 24: Appendix 1). The values found are within the range, which actually was rather wide, of the 25 samples from 1988.

The notable difference in the fine silt/clay fractions (particles < 10 μm) (Fig. 4.1) could be due to the analytical techniques. During the drying process of the sediment clay particles may form coarse aggregates. There are also indications that the results of the particle counter may vary for the smallest particles. Even in situations when the same instrument and the same routines are used, as in this case, systematic differences may occur.

4.2 Chemical characterization of the sediments

4.2.1 Statistical methods - chemical analysis

From each selected site three replicates were analysed except for the reference site where five replicates were analysed. The mean value of the replicates together with the standard deviation are given for each site. The mean value and standard deviation for the whole field are also given.

Limit of significant contamination

The results from each site were compared with the limit of significant contamination (LSC). All samples with higher values than this value would be regarded as contaminated. The LSC values are calculated for the different contaminants by calculating mean and standard deviation from the results of the uncontaminated sediments. The standard deviation is then multiplied with a factor and the result are added to the mean value. The factor depends on the number of parallel measurements. Generally, the factor increases with decreasing number of parallel measurements. The probability that some of the values are outside the measured area decreases with increasing number of parallel measurements.

The factor is also depending on by which probability a value are representing a contaminated sediment or not. The limit of significant contamination (LSC) is calculated at two significance levels, $p>0.95$ and $p>0.99$. The current factor used is found in the literature (Samseth & Thorvaldsen 1981).

The method described assumes that the sediments from the measured area are representative of the whole area.

4.2.2 Total organic carbon (TOC) in sediments

The TOC results are given in Table 4.2. The TOC values ranged from 0.38% (site 17) to 0.60% (site 14) with an average value for the whole field of 0.50 ± 0.046%. Duplicate samples showed agreement within ± 8% (see Table 4.2).

Table 4.2 Total organic carbon (TOC) content in sediments (% weight) from the Heidrun field 1992.

Site		Location	Replicate no. 1	2	3	4	5	Mean ± SD
7	P	225°/ 2350 m*	0.48	0.45	0.50			0.48 ± 0.025
14	P	315°/ 2500 m	0.53	0.54	0.60			0.56 ± 0.038
17	P	135°/ 2500 m	0.38	0.47	0.56			0.47 ± 0.090
21	P	45°/ 1000 m	0.48/0.49**	0.50	0.51			0.50 ± 0.013
23	P	45°/ 5000 m	0.52	0.52	0.58			0.54 ± 0.035
24	P	315°/17000 m	0.48	0.49	0.48	0.50	0.50/0.54**	0.50 ± 0.022

* 7 = EPS 150°/1000 m (1988)
** Repeatability test. Duplicate analysis of selected samples.

P	Mean ± SD	0.51 ± 0.047
Field	Mean ± SD	0.50 ± 0.046

Limit of significant contamination: LSC = 0.63

The mean value for the Platform transects was 0.51 ± 0.047. Compared to the Heidrun survey in 1988 (see Table 4.3) there was no significant difference between the average TOC levels in this area; 0.52 ± 0.037% (1988) and 0.51 ±0.047% (1992).

The mean values for all sites obtained from the two surveys gave virtually identical results; 0.52 ± 0.047% (1988) and 0.50 ± 0.046% (1992).

4.2.3 Total hydrocarbons (THC) in sediments

Results from the total hydrocarbon (THC) analyses are given in Table 4.4 including mean concentrations and standard deviations. The THC content ranged from 0.74 mg/kg (site 7 and 24) to 2.45 mg/kg (site 23) dry sediment with an average of 1.16 ± 0.36 mg/kg. The mean THC content for the Platform transects was similar; 1.20 ± 0.37 mg/kg. These values are typical for undisturbed sediments in the North Sea. The standard deviation measured in parallel samples varied from 3% to 40%, which represent local variations. The greatest variation was seen on site 23 on the Platform transect.

Gas-chromatograms of all replicate samples from all sites are presented in Appendix 3, Figure 1-8. In the gas-chromatogram from site 23 of replicate 3, an unresolved hump of hydrocarbons in the range 10-14 minutes is seen. This agrees with the observation mentioned above at this site. The gas-chromatograms verifies the observations of the Heidrun field as an undisturbed area.

Table 4.3 Comparison of TOC content in Heidrun sediments from 1988 and 1992 (% dry weight).

Site		Location	1988	1992 Mean ± SD
1	EPS	230°/5000 m	0.49	-
2	EPS	234°/2500 m	0.45	-
3		234°/1300 m	0.51	-
4		234°/ 500 m	0.51	-
5	EPS	315°/2500 m	0.63	-
6		315°/1000 m	0.46	-
7	EPS	150°/1000 m (P 225°/2350 m)	0.47	0.48 ± 0.025
8		150°/2500 m	0.47	-
9		150°/5000 m	0.45	-
10	EPS	73°/ 250 m	0.55	-
11		73°/ 500 m	0.47	-
12		73°/1000 m	0.59	-
13		73°/1750 m	0.55	-
14	P	315°/2500 m	0.54	0.56 ± 0.038
15		315°/1000 m	0.57	-
16	P	135°/1000 m	0.52	-
17		135°/2500 m	0.54	0.47 ± 0.090
18		135°/5000 m	0.51	-
19	P	45°/ 250 m	0.58	-
20		45°/ 500 m	0.50	-
21		45°/1000 m	0.44	0.50 ± 0.013
22		45°/2500 m	0.51	-
23		45°/5000 m	0.52	0.54 ± 0.035
24	P	315°/17000m	0.53	0.50 ± 0.022
25	EPS	150°/ 500 m	0.54	-

\- not measured

EPS	Mean ± SD	0.51 ± 0.054	
P	Mean ± SD	0.52 ± 0.037	0.51 ± 0.047
Field	Mean ± SD	0.52 ± 0.047	0.50 ± 0.046
Limit of significant contamination:		0.64	0.63

Table 4.4 Total hydrocarbon (THC) content in Heidrun sediments 1992 given as mg/kg (dry weight).

Site	Location	Replicate no. 1	2	3	4	5	Mean ± SD
7 P	225°/2350 m*	0.95	0.74	1.04			0.91 ± 0.15
14 P	315°/2500 m	1.14	1.11	1.17			1.14 ± 0.03
17 P	135°/2500 m	1.58	0.98	1.05			1.20 ± 0.33
21 P	45°/1000 m	1.06	1.00	1.07			1.04 ± 0.04
23 P	45°/5000 m	1.33	1.25	2.45			1.68 ± 0.67
24 P	315°/17000 m	0.74	0.94	1.05	1.31	1.22	1.05 ± 0.23

* 7 EPS 150°/1000 m

P Mean ± SD 1.20 ± 0.37
Field Mean ± SD 1.16 ± 0.36

Limit of significant contamination: LSC = 2.19 mg/kg

Vertical sectioning

Site	Location		
7 P	225°/2350 m	0-1 cm	0.74
		1-3 cm	0.81
		3-6 cm	0.95

Comparing the mean THC values of the different sites from this years baseline survey with the last Heidrun survey in 1988 one by one, shows a decreasing THC content (see Table 4.5). The difference varies from 30% to 79%. The decreasing level of THC observed could have been caused by two factors:

1. Natural variations.
2. Work-up procedure or analytical technique.

The observed variations are most likely caused by natural variations. A change in the sediment fauna may have affected the THC content. An impoverished fauna, as observed in the present survey (Chapter 4.3), may give a lower contribution of natural hydrocarbons to the THC content. It should however be noted that there has not been presented any systematic scientific evidence of such an effect.

Table 4.5 Comparison of THC content in Heidrun sediments from baseline surveys in 1988 and 1992 given as mg/kg dry sediment.

Site	Location	1988 Mean ± SD	1992 Mean ± SD
1	EPS 230°/5000 m	2.29 ± 0.70	-
2	EPS 234°/2500 m	2.04 ± 0.37	-
3	234°/1300 m	1.94 ± 0.72	-
4	234°/ 500 m	5.91 ± 1.56	-
5	EPS 315°/2500 m	3.02 ± 0.83	-
6	315°/1000 m	3.44 ± 0.13	-
7	EPS 150°/1000 m (P 225°/2350 m)	2.63 ± 0.55	0.91 ± 0.15
8	150°/2500 m	1.48 ± 1.03	-
9	150°/5000 m	2.42 ± 0.60	-
10	EPS 73°/ 250 m	2.31 ± 0.67	-
11	73°/ 500 m	2.77 ± 0.39	-
12	73°/1000 m	2.40 ± 0.58	-
13	73°/1750 m	2.69 ± 0.27	-
14	P 315°/2500 m	3.05 ± 0.63	1.14 ± 0.03
15	315°/1000 m	3.72 ± 1.24	-
16	P 135°/1000 m	1.90 ± 0.72	-
17	135°/2500 m	2.00 ± 0.26	1.20 ± 0.33
18	135°/5000 m	1.85 ± 0.39	-
19	P 45°/ 250 m	2.65 ± 0.61	-
20	45°/ 500 m	2.85 ± 0.81	-
21	45°/1000 m	2.35 ± 0.64	1.04 ± 0.04
22	45°/2500 m	5.46 ± 3.18	-
23	45°/5000 m	4.05 ± 0.49	1.68 ± 0.67
24	P 315°/17000m	5.00 ± 0.65	1.05 ± 0.23
25	EPS 150°/ 500 m	3.54 ± 1.25	
-	not measured		
EPS	Mean ± SD	2.73 ± 1.14	
P	Mean ± SD	3.15 ± 1.52	1.20 ± 0.37
Field	Mean ± SD	2.92 ± 1.35	1.16 ± 0.36
Limit of significant contamination:		6.51	2.19

The other factor was controlled by the internal quality control program outlined in Appendix 4. In addition, the Heidrun intercalibration and method study mentioned in Chapter 1.6.2, showed high precision and accuracy in the extraction method especially concerning THC.

Vertical sectioning

From site 7 sediments from the 0-1 cm, 1-3 cm and 3-6 cm layers were analysed to map the vertical distribution of hydrocarbons. This site lies between site 8 and 10 which were analysed during the Heidrun survey in 1988. The results are presented in Table 4.4. There were no significant difference between the THC values from the different sediment layers, and all values were in the same range as for the other 0-1 cm sediments analysed. The same observation was done during the survey in 1988.

4.2.4 Selected hydrocarbons and bicyclanes/decalines

Naphthalenes, phenanthrenes and dibenzothiophenes - NPD

The results from the NPD analyses are given in Table 4.6 together with the limit of significant contamination of all sites. The total NPD content ranged from 53.3 (site 24) to 118 µg/kg (site 23) dry sediment with an average of 77.8 ± 20.6 µg/kg. These values are higher than normal background values in the North Sea, but high background levels have also been reported from other fields such as Troll West and TOGI (see chapter 1.6.3). In these fields, the NPD values were about 4 times higher than reported elsewhere in the North Sea. At Heidrun the NPD values are about 1.5 time higher than normal background values in the North Sea.

The amounts of naphthalenes and phenanthrenes in Heidrun sediments were quite similar while the dibenzothiophenes were about 0.1 time the content of naphthalenes/phenanthrenes. Similar distribution of NPDs have been reported from baseline surveys at Troll West and TOGI (IKU 1989 a, IKU 1989 b).

In Fig. 4.2, the relative alkyl-homologue distribution of NPDs at the reference station (site 24) is presented. The distributions were dominated by alkylated homologues which are typical for aromatics originated from a petrogenic source. Aromatics originated from combustion processes are dominated by unsubstituted compounds (C_0).

Decalines

Table 4.7 shows the concentration of C_5-C_8 decalines in the Heidrun sediments. The total decaline concentrations were in the range 14.0-55.0 µg/kg dry sediment at site 24 and 23 respectively, with an average of 36.9 ±14.3 µg/kg. These results are in accordance with values obtained from other fields in the North Sea, but a little lower than the mean value found at Troll West II (47 ± 20 µg/kg).

2-6 ring aromatics

The samples were analysed according to EPAs test method 610, Polynuclear Aromatic Hydrocarbons. A detailed list of the analysed compounds is given in Chapter 3.2.3. The sum of concentrations of 2-6 ring aromatics are given in Table 4.8 together with mean values of all sites, while Table 4.9 gives the results of each compound in detail. The limit of significant contamination (LSC) for the different 2-6 ring aromatics are presented in Table 4.10 together with the mean concentrations of each compound.

The sum of concentrations of 2-6 ring aromatics indicates an uncontaminated sediment and the results are in accordance with the results obtained from NPD and decalines. One sample from site 23 at the

Table 4.6 Concentration of total NPD in sediments from Heidrun 1992. Results are given in µg/kg dry weight.

Site	Location		N	P	D	Total NPD
7 P	225°/2350 m	1	29.5	26.0	3.94	59.4
		2	32.6	26.0	3.91	62.5
		3	68.1	31.9	4.83	105
Mean±SD						75.6±25.5
23 P	45°/5000 m	1	67.0	45.9	4.84	118
		2	58.9	23.1	2.52	84.5
		3	45.9	39.1	5.27	90.3
Mean±SD						97.6±17.9
24 P	315°/17000 m	1	48.1	21.3	2.16	71.6
		2	35.7	22.5	2.00	60.2
		3	33.5	29.2	3.83	66.5
		4	42.4	37.7	4.51	84.6
		5	30.0	21.0	2.32	53.3
Mean±SD						67.2±11.9
Field Mean ± SD						77.8±20.6

Limit of significant contamination: LSC = 143 µg/kg

Vertical sectioning

Site	Location					
7 P	225°/2350 m	0-1 cm	32.6	26.0	3.91	62.5
		1-3 cm	24.0	17.5	2.53	44.0
		3-6 cm	30.5	13.6	1.91	46.0

Table 4.7 Concentration of C_5-C_8 decalines in sediments from Heidrun 1992. Results are given in µg/kg dry weight.

Site	Location		C_5	C_6	C_7	C_8	Total
7 P	225°/2350 m	1	10.4	15.9	9.9	10.8	47.0
		2	11.3	15.8	12.7	11.6	51.4
		3	11.2	17.1	9.0	10.4	47.7
Mean±SD							48.7±2.36
23 P	45°/5000 m	1	8.7	11.8	10.0	6.4	36.9
		2	5.1	9.6	2.7	2.5	19.8
		3	9.4	15.9	16.3	13.4	55.0
Mean±SD							37.2±17.6
24 P	315°/17000 m	1	-	-	-	-	-
		2	7.5	10.2	2.9	-	20.6
		3	10.5	10.7	8.1	7.6	36.9
		4	10.2	14.2	7.1	7.9	39.4
		5	4.0	8.2	1.8	-	14.0
Mean±SD							27.7±12.4
Field Mean ± SD							36.9±14.3

Limit of significant contamination: LSC = 83.4 µg/kg

Vertical sectioning

Site	Location					
7 P	225°/2350 m	0-1 cm	11.3	15.8	12.7	11.6 51.4
		1-3 cm	7.85	15.1	8.42	7.12 38.5
		3-6 cm	6.82	10.0	1.86	1.27 20.0

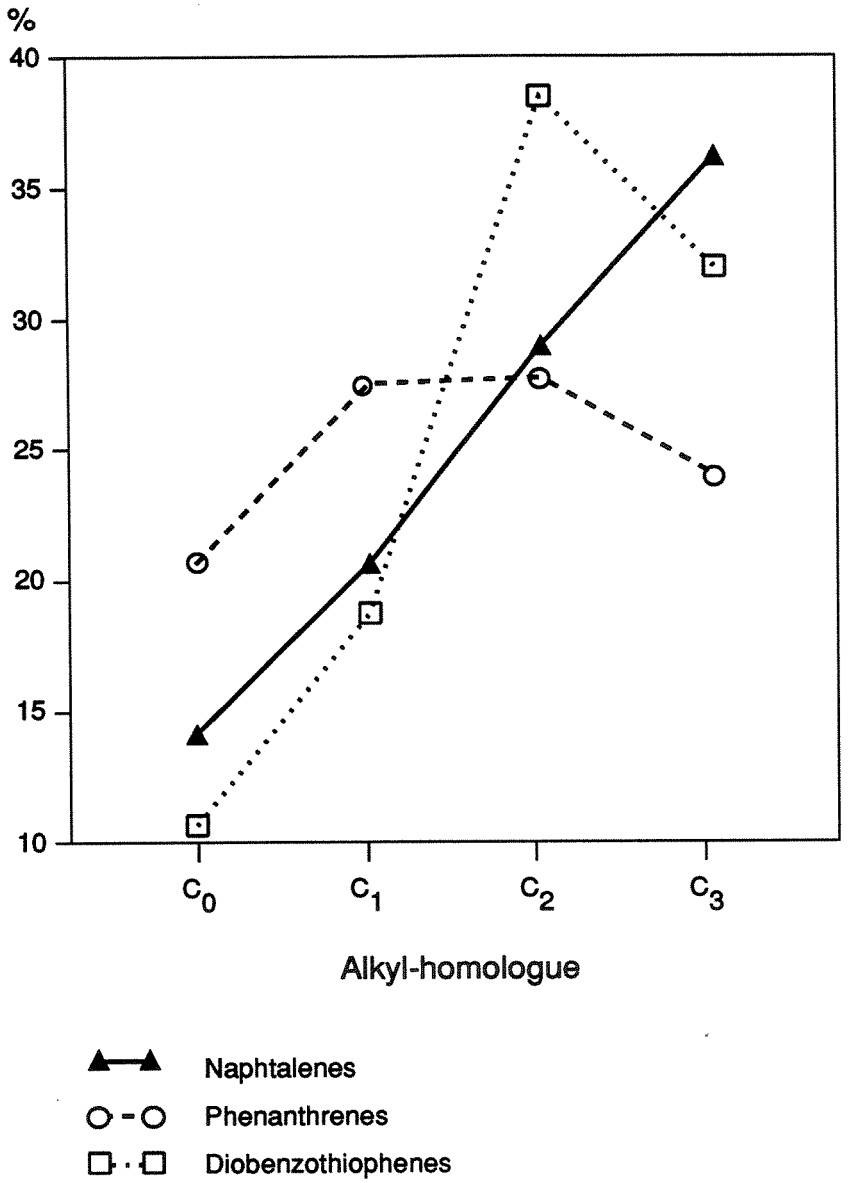


Fig. 4.2 Relative alkyl-homologue distribution of NPD at the reference site (site 24).

Platform transect show a somewhat higher concentration of 2-6 ring aromatics (192 µg PAH/kg) and the same observation is done according to the NPD (118 µg/kg). The mean concentration of the whole field is 111 ± 41 µg PAH/kg.

Vertical sectioning

The vertical variation in the sediment layers (0-1 cm, 1-3 cm, 3-6 cm) of selected aromatics and C_5-C_8 decalines was determined at site 7, and the results are given in Table 4.6-4.9. The total NPD concentration in the 0-1 cm sediment layer is similar to the values obtained from the other sites. There are no significant difference between the 1-3 cm and 3-6 cm layers, but the NPD concentrations are lower than in the 0-1 cm layer.

Table 4.8 Sum of concentration of 2-6 ring aromatics in Heidrun sediments 1992 given as µg/kg dry sediment.

Site	Location		2-ring	3-ring	4-ring	5-ring	6-ring	Sum PAH
7	P	1	3.10	4.91	12.6	43.3	31.7	95.6
225°/2350 m		2	4.17	5.09	11.9	34.7	27.5	83.4
		3	5.07	7.32	14.9	52.4	22.4	102
	Mean		4.11	5.77	13.1	43.5	29.6	93.7
	± SD		0.986	1.34	1.57	8.85	2.10	9.45
23	P	1	14.4	17.4	45.5	72.0	42.5	192
45°/5000 m		2	10.80	6.92	14.3	53.7	51.8	138
		3	5.76	8.22	19.3	67.0	48.4	149
	Mean		10.3	10.8	26.4	64.2	47.6	160
	± SD		4.34	5.71	16.8	9.46	4.71	28.5
24	P	1	7.57	6.24	8.81	19.8	-	42.4
315°/17000 m		2	6.74	6.44	12.1	39.0	27.9	92.2
		3	4.52	5.62	10.7	33.0	20.1	73.9
		4	3.84	7.90	17.5	47.2	33.5	110
		5	3.92	6.23	16.3	58.6	54	139
	Mean		5.32	6.49	13.1	39.5	33.9	91.4
	± SD		1.72	0.848	3.70	14.6	14.5	36.5
Field Mean			6.35	7.48	16.7	47.3	36.0	111
	± SD		3.45	3.46	10.0	15.5	12.3	41

Vertical sectioning

Site 7 Location P 225°/2350 m

0-1 cm	4.17	5.09	11.9	34.7	27.5	83.4
1-3 cm	2.97	3.24	8.70	22.7	13.7	51.3
3-6 cm	3.93	3.12	6.42	20.8	14.4	48.7

Table 4.9: Concentration of 3-6 ring aromatics in sediments from Heidrun 1992 given as µg/kg dry weight.

Site Location		Acenaphthylene m/z 152	Acenaphthene m/z 153	Fluorene m/z 153	Anthracene m/z 178
7 P 225°/2350 m	1	0.178	0.249	0.624	0.242
	2	0.198	0.259	0.590	0.223
	3	0.442	0.519	1.36	0.285
Mean		0.273	0.342	0.858	0.250
± SD		0.147	0.153	0.435	0.0318
23 P 45°/5000 m	1	0.214	2.11	2.53	0.531
	2	0.249	0.339	0.949	0.224
	3	0.235	0.442	0.976	0.370
Mean		0.233	0.964	1.490	0.375
± SD		0.0176	0.994	0.905	0.154
24 P 315°/17000 m	1	0.0899	0.201	0.910	0.167
	2	0.121	0.201	0.599	0.208
	3	0.102	0.202	0.749	0.192
	4	0.17	0.237	0.956	0.336
	5	0.132	0.0926	0.521	0.251
Mean		0.123	0.187	0.747	0.231
± SD		0.0309	0.0548	0.189	0.0663

Vertical sectioning

Site 7 Location P 225°/2350 m

0-1 cm	0.198	0.259	0.590	0.223
1-3 cm	0.102	0.165	0.412	0.130
3-6 cm	0.0948	0.166	0.385	0.089

Table 4.9 cont: *Concentration of 3-6 ring aromatics in sediments from Heidrun 1992 given as µg/kg dry weight.*

Site Location		Fluoranthene m/z 202	Pyrene m/z 202	Benzo(a) anthracene m/z 228	Chrysene m/z 228
7 P 225°/2350 m	1	2.68	3.37	1.50	5.09
	2	2.89	2.75	1.50	4.77
	3	3.81	3.43	1.84	5.79
Mean		3.13	3.18	1.61	5.19
± SD		0.601	0.376	0.196	0.472
23 P 45°/5000 m	1	12.2	9.32	6.94	17.0
	2	2.76	2.84	1.52	7.17
	3	5.07	3.75	2.10	8.37
Mean		6.68	5.30	3.52	10.8
± SD		4.92	3.51	2.98	5.36
24 P 315°/17000 m	1	1.37	2.29	1.02	4.13
	2	1.98	2.34	1.51	6.31
	3	1.89	2.08	1.26	5.51
	4	3.31	3.01	2.02	9.16
	5	2.89	3.35	2.08	7.96
Mean		2.29	2.61	1.58	6.61
± SD		0.791	0.542	0.465	1.99

Vertical sectioning

Site 7 Location P 225°/2350 m

0-1 cm	2.89	2.75	1.50	4.77
1-3 cm	1.73	1.90	0.794	4.28
3-6 cm	1.24	1.93	0.686	2.56

Table 4.9 cont: *Concentration of 3-6 ring aromatics in sediments from Heidrun 1992 given as µg/kg dry weight.*

Site/ Location		Benzo(b/j/k) fluoranthene m/z 252	Benzo(a) pyrene m/z 252	Benso(ghi) perylene m/z 276	Indeno(1,2,3-cd) pyrene m/z 276	Dibenso(a,h) antrhasen m/z 278
7 P	1	35.5	4.63	22.6	9.07	3.21
225°/2350 m	2	27.7	4.19	20.3	7.18	2.83
	3	42.8	6.10	22.4	7.18	3.53
Mean		35.3	4.97	21.8	7.81	3.19
± SD		7.55	1.00	1.27	1.09	0.350
23 P	1	55.2	12.2	29.8	12.7	4.57
45°/5000 m	2	41.3	7.02	37.6	14.2	5.35
	3	52.6	9.86	36.3	12.1	4.49
Mean		49.7	9.69	34.6	13.0	4.80
± SD		7.39	2.59	4.18	1.08	0.475
24 P	1	17.0	2.76	-	-	-
315°/17000 m	2	30.4	5.73	19.9	7.97	2.87
	3	26.0	5.12	13.9	6.17	1.86
	4	37.7	6.39	23.4	10.1	3.07
	5	45.8	7.29	38.5	15.5	5.54
Mean		31.4	5.46	23.9	9.94	3.34
± SD		11.0	1.71	10.5	4.09	1.56

Vertical sectioning

Site 7 Location P 225°/2350 m

0-1 cm	27.7	4.19	20.3	7.18	2.83
1-3 cm	18.5	2.91	10.2	3.53	1.29
3-6 cm	16.2	3.20	9.49	4.95	1.39

Table 4.10 Mean concentration of TOC, THC, NPD, Decalines and 2-6 ring aromatics in sediments from the Heidrun field 1992. Limit of significant contamination (LSC) calculated by Students T-test at significance levels (p>0.95) and (p>0.99).

Parameter	Mean ± SD	LSC (p>0.95)	LSC (p>0.99)
TOC[1]	0.50 ± 0.046	0.58	0.63
THC[2]	1.16 ± 0.360	1.78	2.19
NPD[3]	77.8 ± 20.6	115	143
C_5 decaline	8.83 ± 2.54	13.5	17.1
C_6 decaline	12.9 ± 3.20	18.8	23.3
C_7 decaline	8.05 ± 4.63	16.5	23.1
C_8 decaline	8.83 ± 3.45	15.4	20.9
C_5-C_8 decalines[3]	36.9 ± 14.3	63.1	83.4
2-ring aromatics	6.35 ± 3.45	12.6	17.3
3-ring aromatics	7.48 ± 3.46	13.7	18.4
4-ring aromatics	16.7 ± 10.0	34.8	48.4
5-ring aromatics	47.3 ± 15.5	75.4	96.4
6-ring aromatics	36.0 ± 12.3	58.3	75.0
Sum PAH	111 ± 41.0	185	241
Acenaphthylene[3]	0.194 ± 0.0979	0.371	0.504
Acenaphthene[3]	0.441 ± 0.566	1.47	3.24
Fluorene[3]	0.979 ± 0.569	2.1	2.78
Anthracene[3]	0.275 ± 0.104	0.463	0.605
Fluoranthene[3]	3.71 ± 2.99	9.11	13.2
Pyrene[3]	3.50 ± 2.00	7.12	9.84
Benzo(a)anthracene[3]	2.12 ± 1.64	5.08	7.31
Chrysene[3]	7.39 ± 3.56	13.8	18.7
Benzo(b/j/k)fluoranthene[3]	37.5 ± 11.2	58.5	74.2
Benzo(a)pyrene[3]	6.48 ± 2.65	11.3	14.9
Benzo(ghi)perylene[3]	26.5 ± 8.54	42.1	54.2
Indeno (1,2,3-cd)pyrene[3]	10.2 ± 3.24	16.2	20.8
Dibenzo(a,h)anthracene[3]	3.73 ± 1.20	5.93	7.63

1) % dry weight
2) mg/kg dry weight
3) µg/kg dry weight

The total decaline concentration decreases with increasing depth in the sediment, but the values are within the same range as for the replicates analysed at the other sites.

The same trend is observed for the sum of 2-6 ring aromatics as for the NPDs. The concentration of 2-6 ring aromatics in the 0-1 cm sediment layer is higher than the 1-3 cm and 3-6 cm layers. There are no significant difference between the concentration in the 1-3 cm and 3-6 cm layers.

4.2.5 Heavy metals in sediments

A total of 7 elements were analysed: cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), iron (Fe), barium (Ba) and mercury (Hg). There were analysed three replicates of each sample while five replicates were analysed at the reference site. Table 4.11 shows the results in detail.

The mean content of each element is presented in Table 4.12 together with the limit of significant contamination. Results both from this years analyses and the 1988 baseline survey are presented. As could be seen from the results the content of each element except barium is quite similar to the 1988 baseline survey, and the concentrations of the elements are representative of an undisturbed sediment. Mercury was not detected at any site. The new LSC's ($p>0.99$) calculated were all very close to the 1988 values except for barium which decreased from 370 to 258 µg/kg.

Barium is used to increase the mud weight during drilling, and is thus useful in monitoring the distribution of drilling fluids in the platform environment. The content of barium ranged from 45.9 mg/kg (site 7) to 296 mg/kg (site 17) dry weight with an average of 90.3 ± 58.7 mg/kg. The highest content of barium (191.3 ± 99.1 mg/kg) was seen at site 17, while the lowest content (51.7 ± 1.6 mg/kg) was observed at the reference site (site 24). This result was in agreement with the result from the 1988 baseline survey.

Barium was the element which showed greatest change from the 1988 baseline survey, and the mean barium content decreased significant from 164 ± 80 mg/kg to 90.3 ± 58.7 mg/kg (see Table 4.13). The greatest change in the barium content was seen at site 7 decreasing from 130 ± 36 to 56.7 ± 11.9 mg/kg and at site 21 which showed a corresponding decrease.

The results from the heavy metal analyses indicate an uncontaminated area.

Table 4.11 Concentration of heavy metals in Heidrun sediments 1992 given as mg/kg dry sediment.

Site	Location	rep	Cd	Cu	Pb	Zn	Fe	Ba	Hg
7 P	225°/2350 m	1	0.067	6.57	11.6	33.1	11900	57.5	<0.1
		2	0.077	7.02	11.9	37.0	13000	45.9	<0.1
		3	0.067	7.14	15.8	39.0	13200	69.7	<0.1
Mean			0.070	6.91	10.1	36.3	12700	57.7	
SD			0.006	0.30	2.81	3.01	696	11.9	
14 P	315°/2500 m	1	0.083	8.73	19.6	45.2	15400	91.3	<0.1
		2	0.076	8.23	18.6	44.7	14700	133	<0.1
		3	0.071	8.08	15.4	42.7	14700	85.1	<0.1
Mean			0.077	8.35	17.9	44.2	14900	103	
SD			0.006	0.34	2.21	1.33	440	25.9	
17 P	135°/2500 m	1	0.107	8.91	22.5	46.0	15000	296	<0.1
		2	0.073	6.90	14.2	36.2	12000	179	<0.1
		3	0.064	7.25	16.8	38.4	13000	98.7	<0.1
Mean			0.081	7.69	17.8	40.2	13400	191	
SD			0.022	1.07	4.25	5.16	1513	99.1	
21 P	45°/1000 m	1	0.057	8.16	16.2	43.2	14500	66.3	<0.1
		2	0.066	7.11	14.1	38.9	13300	53.7	<0.1
		3	0.070	7.68	16.6	40.2	13500	73.5	<0.1
Mean			0.064	7.65	15.6	40.7	13800	64.5	
SD			0.007	0.53	1.34	2.20	660	10.0	
23 P	45°/5000 m	1	0.077	8.43	17.8	44.2	15200	97.6	<0.1
		2	0.070	8.50	17.3	44.7	15600	91.1	<0.1
		3	0.081	8.82	20.5	45.9	15600	109	<0.1
Mean			0.076	8.58	18.5	44.9	15500	99.2	
SD			0.006	0.21	1.69	0.85	236	9.00	
24 P	315°/17000 m	1	0.100	8.35	12.0	43.0	15100	52.7	<0.1
		2	0.060	8.32	14.0	42.3	14800	51.3	<0.1
		3	0.089	7.92	12.4	41.0	14600	49.9	<0.1
		4	0.069	8.00	15.1	41.7	14400	53.9	<0.1
		5	0.085	8.59	15.7	42.6	14800	50.9	<0.1
Mean			0.081	8.24	13.9	42.1	14700	51.7	
SD			0.016	0.27	1.64	0.79	255	1.60	
Detection limit (mg/kg)			0.01	0.6	0.2	1	1	0.5	0.1

Table 4.12 Comparison of heavy metals in Heidrun sediments from 1988 and 1992 given as mg/kg dry sediment. Limits of significant contamination (LSC) are given at significance level (p>0.95) and (p>0.99).

Element	1988			1992		
	Mean ± SD	LSC		Mean ± SD	LSC	
		p>0.95	p>0.99		p>0.95	p>0.99
Cd	0.081 ± 0.011	0.098	0.11	0.075 ± 0.013	0.097	0.11
Cu	8.8 ± 0.17	10.4	11.5	7.94 ± 0.71	9.17	9.97
Pb	17 ± 2.6	21	24	15.9 ± 2.95	21.0	24.3
Zn	43 ± 48	51	56	41.5 ± 3.50	47.6	51.5
Fe	16800 ± 187	20000	22000	14200 ± 1136	16200	17500
Ba	160 ± 80	290	370	90.3 ± 58.7	192	258
Hg	-	-	-	-	-	-

\- below detection limit

Table 4.13 Comparison of the barium content in Heidrun sediments from baseline surveys in 1988 and 1992 given as mg/kg dry sediment.

Site	Location	1988 Mean ± SD	1992 Mean ± SD
1	EPS 230°/5000 m	83 ± 13	-
2	234°/2500 m	91 ± 28	-
3	234°/1300 m	110 ± 42	-
4	234°/ 500 m	543 ± 570	-
5	EPS 315°/2500 m	100 ± 81	-
6	315°/1000 m	120 ± 38	-
7	EPS 150°/1000 m	130 ± 36	57.7 ± 11.9
	(P 225°/2350 m)		
8	150°/2500 m	320 ± 20	-
9	150°/5000 m	130 ± 58	-
10	EPS 73°/ 250 m	160 ± 51	-
11	73°/ 500 m	160 ± 15	-
12	73°/1000 m	210 ± 47	-
13	73°/1750 m	120 ± 21	-
14	P 315°/2500 m	140 ± 10	103 ± 25.9
15	315°/1000 m	170 ± 62	-
16	P 135°/1000 m	210 ± 32	-
17	135°/2500 m	333 ± 124	191 ± 99.1
18	135°/5000 m	200 ± 40	-
19	P 45°/ 250 m	300 ± 36	-
20	45°/ 500 m	200 ± 97	-
21	45°/1000 m	152 ± 58	64.5 ± 10.0
22	45°/2500 m	160 ± 50	-
23	45°/5000 m	82 ± 3.6	99.2 ± 9.00
24	P 315°/17000m	65 ± 5.1	51.7 ± 1.60
25	EPS 150°/ 500 m	149 ± 57	-
- not measured			
Field	Mean ± SD	164 ± 80	90.3 ± 58.7
Limit of significant contamination:		370	258

4.3 Biological characterization of the sediments.

4.3.1 Number of species

The number of species were low. Altogether 73 taxa were identified, with the number of taxa for each station varying from 11 (st. 14) to 30 (st. 17) (Table 4.14). At the reference station (st. 24) a total of 45 species were found. The bristles worms (Annelida: Polychaeta) constituted the most important group with the bivalves (Mollusca: Bivalvia) the second most important. Other important groups were the sipunculids and sponges (Porifera). Densities for the most important species are shown in Table 4.15. Complete results are given in Appendix 5.

Curves of species numbers versus area for the stations are shown in Fig. 4.3. All curves show an increasing trend indicating that further sampling (more replicates) would have produced more species. The trend is particularly strong on stations 17 and 21 which had the highest species numbers. At the reference station (st. 24) the catch in a number of the replicates was extremely small leading to flat sections of the curve. The general trend, however, suggest that more species would have been collected by further sampling.

4.3.2 Total fauna densities

The number of individuals was low, in many samples extremely low (Table 4.14). Total densities for the five near platform stations ranged from 31 (st. 23) to 93 (st. 7) specimens/0.5 m^2. The highest individual count was 12 specimens of the isopod crustacean *Cirolana borealis* in one of the replicates from station 7.

The reference station had particularly low densities with a total catch of 45 individuals for the 10 replicates (1.0 m^2). In five of the replicates there were not more than two specimens and in only one the number of specimens exceeded 10. The highest species count in a sample was three (of the polychaete *Lumbrineris* sp.).

The sediment catch in the grab samples was good (Table 2.1, Appendix 1). It does not seem that the low numbers could have been caused by insufficient gear operation.

Table 4.14 Community parameters for the benthic macrofauna H' = Shannon-Wiener diversity. J = Pielou evenness.

Station no	Area sampled, m^2	Number of taxa	Total number of individuals	H' (ln)	H' (log_2).	J
7	0,5	27	93	2,73	3,93	0,83
14	0,5	11	23	1,93	2,78	0,80
17	0,5	30	72	2,95	4,25	0,87
21	0,5	29	51	3,17	4,57	0,94
23	0,5	16	31	2,47	3,56	0,89
24	1,0	24	45	2,87	4,13	0,90

Table 4.15 The most frequently occurring taxa in the Heidrun field 1992: number of individuals for stations and total abundances.

Station no.	7	14	17	21	23	24	Sum
Sampled area , m2	0.5	0.5	0.5	0.5	0.5	1.0	3.5
PORIFERA							
Porifera indet	3	1	1	-	4	-	9
POLYCHAETA							
Clymenura sp	3	-	-	2	-	-	5
Harmothoe sp	-	-	1	1	-	1	3
Lumbrineris sp	4	3	3	2	8	8	28
Maldanidae indet	-	-	1	3	-	-	4
Onuphis fiordica	21	10	14	1	-	5	51
Onuphis quadricuspis	10	2	7	3	-	5	27
Ophelina sp	-	-	2	1	-	3	6
Orbinia norvegica	-	-	1	2	1	-	4
Paramphinome jeffreysii	5	1	4	6	1	1	18
Spiochaetopterus typicus	-	-	2	1	1	2	6
BIVALVIA							
Abra longicallus	6	1	2	5	2	1	17
Bathyarca pectunculoides	-	-	1	2	1	-	4
Kelliella miliaris	1	-	1	-	-	1	3
Limopsis minuta	7	-	8	2	-	-	17
Nucula tumidula	2	1	5	3	3	1	15
Yoldiella cf. acuminata	-	-	1	-	2	-	3
ISOPODA							
Cirolana borealis	12	-	1	2	-	-	15
AMPHIPODA							
Eriopisa elongata	-	-	-	-	2	2	4
SIPUNCULIDA							
Golfingia sp	-	-	-	1	1	1	3
Onchnesoma steenstrupi	3	1	3	2	4	3	16
ASCIDIACEA							
Molgulidae indet	-	-	3	-	-	1	4

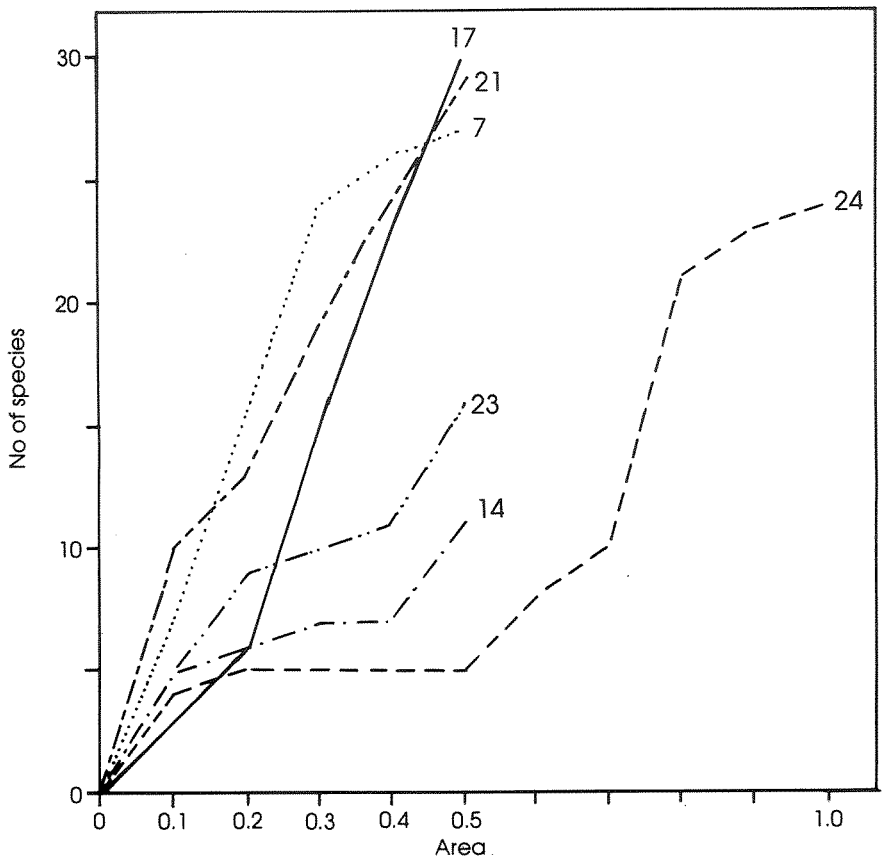


Fig. 4.3. Cumulative numbers of species versus sampled area for the stations in the Heidrun field in 1992.

4.3.3 Diversity and dominance

Most methods used routinely for description of diversities and other community parameters (e.g. distribution of individuals among species) assume that the samples are of some size with regard to total abundances. With small samples the indices may give unreliable and even misleading results. In the present investigation values have been calculated for the most common indices of diversity and evenness (Shannon-Wiener information index (H'), Pielou evenness index (J)). Other indices were omitted because it was considered unrealistic to discuss variations in values among the indices. Also the index based on Hurlbert rarefaction curves (ES_{100}) was omitted because the total abundances were below 100 individuals at all stations.

The indices are shown in Table 4.14. The values of H' ranged from moderate to low. However, for small samples this index is generally dependent on the number of species (i.e. correlated with species richness) and therefore partly reflects the species numbers. The index took the lowest values for the stations with the lowest species numbers.

The evenness (J) was high and stable among the stations. Conversely the dominance, defined as 1-J, was low. The result expresses that there were no strongly dominating species in the area and that the stations were similar.

Table 4.16 The 10 numerically dominant species for the stations in the Heidrun field 1992. Rank numbers for the baseline study in 1988 are shown in far right column. Asterisks indicate species which were among the top ten ranked on other stations in 1988.

Station 7

	N	%	cum %	rank -88
Onuphis fiordica Fauchald 1974	21	22,58	22,58	7
Cirolana borealis Lilljeborg	12	12,90	35,48	
Onuphis quadricuspis M.Sars 1872	10	10,75	46,24	*
Limopsis minuta (Philippi)	7	7,53	53,76	*
Abra longicallus (Scacchi 1836)	6	6,45	60,22	10
Paramphinome jeffreysii (McIntosh 1868)	5	5,38	65,59	6
Lumbrineris sp	4	4,30	69,89	1
Clymenura sp	3	3,23	73,12	
Onchnesoma steenstrupi Koren & Danielssen 1876	3	3,23	76,34	*
Cirratulidae indet	2	2,15	78,49	

Station 14

	N	%	cum %	rank -88
Onuphis fiordica Fauchald 1974	10	43,48	43,48	4
Lumbrineris sp	3	13,04	56,52	2
Onuphis quadricuspis M.Sars 1872	2	8,70	65,22	*
Onuphis sp	1	4,35	69,57	*
Paramphinome jeffreysii (McIntosh 1868)	1	4,35	73,91	*
Scolelepis tridentata Southern 1914	1	4,35	78,26	
Typosyllis cornuta (Rathke 1843)	1	4,35	82,61	
Abra longicallus (Scacchi 1836)	1	4,35	86,96	*
Nucula tumidula (Malm)	1	4,35	91,30	7
Nebalia bipes Fabricius	1	4,35	95,65	

Station 17

	N	%	cum %	rank -88
Onuphis fiordica Fauchald 1974	14	19,44	19,44	2
Limopsis minuta (Philippi)	8	11,11	30,56	5
Onuphis quadricuspis M.Sars 1872	7	9,72	40,28	*
Nucula tumidula (Malm)	5	6,94	47,22	7
Paramphinome jeffreysii (McIntosh 1868)	4	5,56	52,78	*
Lumbrineris sp	3	4,17	56,94	8
Onchnesoma steenstrupi Koren & Danielssen 1876	3	4,17	61,11	*
Molgulidae indet	3	4,17	65,28	1
Ophelina sp	2	2,78	68,06	*
Spiochaetopterus typicus M.Sars 1856	2	2,78	70,83	3

Station 21

	N	%	cum %	rank -88
Paramphinome jeffreysii (McIntosh 1868)	6	11,76	11,76	1
Abra longicallus (Scacchi 1836)	5	9,80	21,57	6
Maldanidae indet	3	5,88	27,45	
Onuphis quadricuspis M.Sars 1872	3	5,88	33,33	*
Nucula tumidula (Malm)	3	5,88	39,22	9
Clymenura sp	2	3,92	43,14	*
Lumbrineris sp	2	3,92	47,06	4
Orbinia norvegica (M.Sars 1872)	2	3,92	50,98	
Bathyarca pectunculoides (Scacchi 1836)	2	3,92	54,90	*
Limopsis minuta (Philippi)	2	3,92	58,82	*

Table 4.16 cont. *The 10 numerically dominant species for the stations in the Heidrun field 1992. Rank numbers for the baseline study in 1988 are shown in far right column. Asterisks indicate species which were among the top ten ranked on other stations in 1988.*

Station 23

	N	%	cum %	rank -88
Lumbrineris sp	8	25,81	25,81	5
Onchnesoma steenstrupi Koren & Danielssen 1876	4	12,90	38,71	*
Nucula tumidula (Malm)	3	9,68	48,39	7
Abra longicallus (Scacchi 1836)	2	6,45	54,84	*
Yoldiella cf. acuminata (Jeffreys)	2	6,45	61,29	
Eriopisa elongata Bruzelius	2	6,45	67,74	*
Kophobelemnon stelliferum (O.F.Mueller)	1	3,23	70,97	
Marphysa belli (Audouin&Milne Edwards 1834)	1	3,23	74,19	
Notomastus latericeus Sars 1851	1	3,23	77,42	*
Orbinia norvegica (M.Sars 1872)	1	3,23	80,65	

Station 24

	N	%	cum %	rank -88
Lumbrineris sp	8	17,78	17,78	3
Onuphis fiordica Fauchald 1974	5	11,11	28,89	2
Onuphis quadricuspis M.Sars 1872	5	11,11	40,00	*
Ophelina sp	3	6,67	46,67	*
Onchnesoma steenstrupi Koren & Danielssen 1876	3	6,67	53,33	5
Spiochaetopterus typicus M.Sars 1856	2	4,44	57,78	1
Eriopisa elongata Bruzelius	2	4,44	62,22	9
Amage auricula Malmgren 1865	1	2,22	64,44	
Ampharetidae indet	1	2,22	66,67	
Amythasides macroglossus Eliason 1955	1	2,22	68,89	

4.3.4 Rank abundance of most common species

The most abundant species were the polychaetes *Lumbrineris* sp., *Onuphis fiordica* (= *Sarsonuphis fiordica*), *Onuphis quadricuspis* (= *Sarsonuphis quadricuspis*) and *Paramphinome jeffreysi*, the bivalves *Abra longicallus*, *Limopsis minuta* and *Nucula tumidula*, the isopod crustacean *Cirolana borealis* and the sipunculan *Onchnesoma steenstrupi* (Table 4.15). The two species of *Onuphis* make fairly strong membraneous tubes encrusted with mud and sandgrains to protect themselves. The other species, except for *Cirolana borealis*, are sediment dwellers with limited ability to move around. *Lumbrineris* and *Abra* may dig deep into the sediment and contribute substantially to the reworking of the sediment because of their activity. *Cirolana* is a vagile scavenger with good swimming ability. It searches for dead fish on the bottom where it may congregate in large numbers.

The ten most abundant species for each station are shown in Table 4.16. *Onuphis fiordica* is top ranked on three stations (7, 14, 17) and second ranked on the reference station (24). *Lumbrineris* sp. is top ranked on the reference station and one of the other stations (23) and second ranked on one station (14). The fauna was generally similar over the stations. The three to four top ranked on one station were also among the ten ranked on some other station, except for *Cirolana* (st. 7) and maldanid polychetes (st. 21).

4.3.5 Faunal similarity among stations

Fig. 4.4 shows the dendrogram for the cluster analysis of the fauna of the stations. The three stations 7, 17 and 21 in the SE part of the field form a group, while the reference station (st. 24) is grouped with st. 14. All stations, however, are connected on a fairly high similarity level without marked gaps in the diagram, illustrating the generally similar fauna of the stations. Stations 17 and 21 are the two stations showing the highest pairwise similarity. This obviously reflects the species composition, as these stations have many species in common (Table 4.15).

Fig. 4.5 shows the MDS ordination plot. The location of the station points correspond well with the groups in the cluster analysis. The plot, however, indicates that the reference station (st. 24) is about equally different from st. 23 and the group formed by stationsh 7, 17 and 21.

The analysis should be interpreted with caution because of the low species numbers and abundances on which it is based.

4.3.6 Comparison with previous investigations

In the Heidrun baseline survey in 1988 high numbers of species and individuals were recorded at all stations. The mean number of species retained on the 1 mm sieve was 65 and the number of individuals 270. The diversity was generally very high. The polychaetes were the most prominent group, but other common forms were *Golfingia* cf. *minuta*, tunicates and bivalves (e.g. *Limopsis minuta*). The number of taxa retained on the 1 mm screen was 56-89 % of the total number retained on both 1 and 0.5 mm screens. There were no convincing trends in numbers, diversity or species occurrences across the field, but a slight SW to NE gradient in community composition could possibly be linked to grain size.

The difference in species and individual numbers between the 1988 baseline survey and the present investigation was dramatic (Table 4.17). The number of species in 1992 was about a third (15-53 %) of the number recorded in 1988 and the number of individuals was about a fifth (7-32 %). However, there were no major changes in species composition. The most abundant species were also common in 1988 (Table 4.18). The polychaetes *Lumbrineris* sp. and *Onuphis fiordica* were very common all over the Heidrun field in 1988. Also *Paramphinome jeffreysii* was common, and was, may be accidentally, first ranked on the same station (st. 21) in both years. The same bivalves were found in both investigations.

A number of species which were abundant in 1988, however, were uncommon or lacking in the present survey (Table 4.19). The list is dominated by polychetes, but includes sipunculans, bivalves and crustaceans as well. The change was particularly strong for the sipunculan *Golfingia* cf. *minuta* and the polychaetes *Spiochaetopterus typicus, Spiophanes kroyeri, Chaetozone setosa* and *Augeneria tentaculata.*

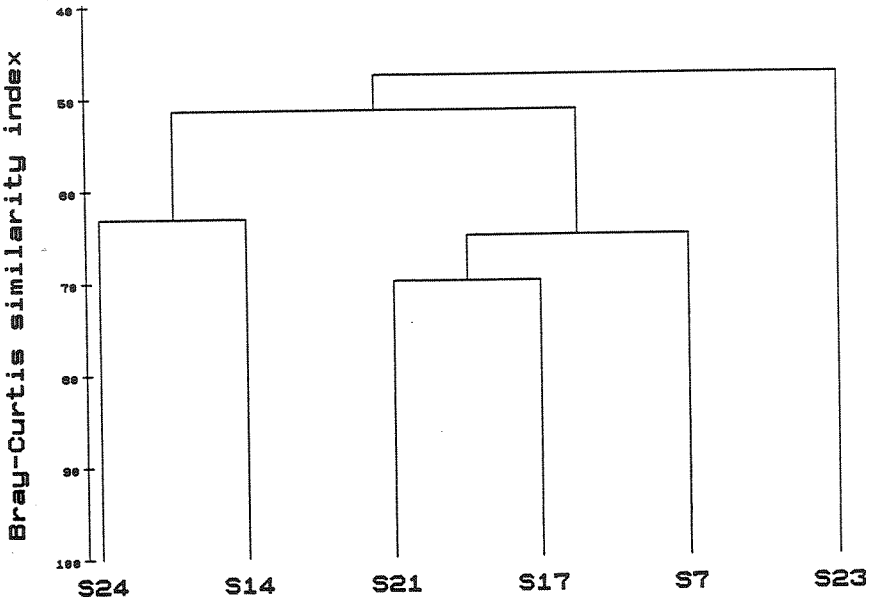


Fig. 4.4 *Cluster analysis of stations: Bray-Curtis similarity index and group average sorting. The analysis is based on 21 taxa, Porifera and species with total counts < 3 individuals were deleted (cf. Table 4.15).*

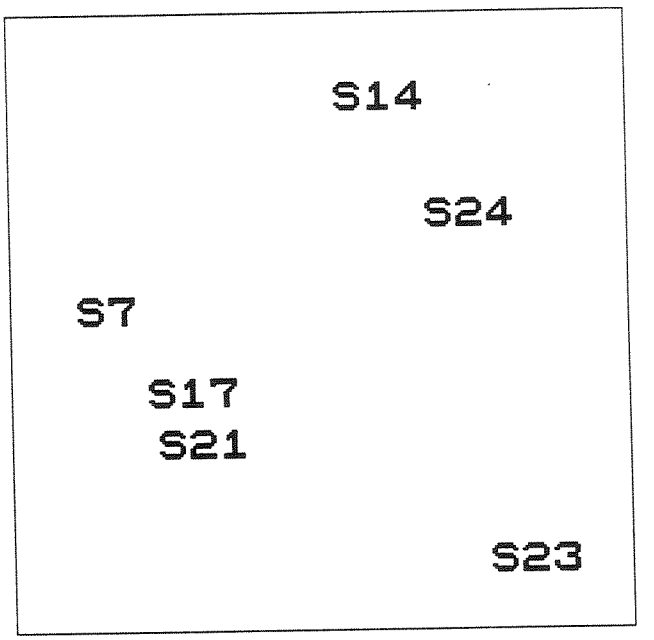


Fig. 4.5 *Multidimensional scaling analysis (MDS) of stations. The analysis is performed on the same data as the cluster analysis in Fig. 4.4. The plot shows a two-dimensional ordination, stress value 0.0026.*

Table 4.17. Comparative data for number of species and individuals of the stations. The total area sampled at station 24 (reference) was 1,0 m^2 in 1992 and 0,8 m^2 in 1988, other values are for 0,5 m^2. The data for the 1988-survey refer to the 1 mm fraction. S = number of species, N = total number of individuals.*

	1992		1988 (Bakke et al.)		1985 (Bowler et al.)	
Station	S	N	S	N	S	N
3	-	-	72	333	35	86
7	27	93	65	286	-	-
14	11	23	72	327	-	-
17	30	72	74	370	-	-
21	29	51	54	158	-	-
23	16	31	67	262	-	-
24*	24	45	63	207	39	77

During the Haltenbanken survey in 1985 most stations were characterized by a total population of 100-500 individuals representing 40-80 taxa (Bowler et al. 1986). However, very low numbers of individuals and taxa very recorded at stations 1-6, including the Heidrun area, in the northern and deepest part of the survey area. At station 3 (corresponding to station 24 in the present survey) 39 taxa and 77 individuals were found for 0.5 m^2 (Table 4.17). The most common species at these stations were *Onuphis quadricuspis*, *Nothria opalina?* (presumably *O. fiordica*), *Lumbrineris* spp., *Spiophanes kroyeri*, *Clymenura borealis*, *Golfingia* sp. and tunicates. These results are rather similar to the present survey, both regarding species composition and numbers of individuals. The most abundant species over all stations in the survey area was *Spiophanes kroyeri*, accounting for 32 % of the total population. It had a very variable occurrence in the samples, however.

The species which decreased strongly in occurrence in 1992 (Table 4.19) are suspension or deposit feeders. *Spiochaetopterus typicus* and *Chaetozone setosa* are generally considered tolerant to pollution, while *Spiophanes kroyeri* and *Terebellides stroemi* are considered moderately tolerant (Rygg 1986). It is not likely that the reduced species numbers and abundances should have been caused by some sort of pollution.

The stations groups formed in the cluster and MDS analyses did not correspond to patterns identified in the 1988 samples. This is not unexpected regarding the reduction in species numbers and abundances. But it should be noted that in both surveys the fauna was found to be homogeneous over the whole field with only weak gradients. In 1988 the gradients could at least partly be related to minor changes in grain size distributions and depths among the stations, which is a quite normal result when the fauna is abundant and species-rich.

Table 4.18 List of most abundant species in the Heidrun field in 1992 (density > 3 ind./0.5 m2). Species are ranked according to number of registrations on top ten lists for the stations (Table 4.16). Number of registrations in 1988 (1 mm fraction) are shown for comparison.

	Number of registrations on top-ten lists	
	1992 (6 stations)	1988 (25 stations)
Lumbrineris sp.	5	24
Onuphis fiordica	4	25
Onuphis quadricuspis	4	6
Paramphinome jeffreysii	4	11
Onchnesoma steenstrupi	4	7
Nucula tumidula	3	13
Limopsis minuta	2	13
Abra longicallus	2	14
Clymenura borealis	1	7
Ophelina sp.	1	-
Maldanidae ind.	1	-
Cirolana borealis	1	-
Molgulidae ind.	1	14

Table 4.19 List of species which were abundant in 1988, but sparsely occurring or not found in 1992. Species are ranked according to number of registrations on top ten lists for the stations in 1988 (1 mm fraction). + = present in small numbers.

	Number of registrations on top ten lists 1988 (25 stations)	1992
Golfingia cf. minuta	18	+
Spiochaetopterus typicus	15	+
Spiophanes kroyeri	14	-
Chaetozone setosa	14	-
Augeneria tentaculata	11	-
Bathyarca pectunculoides	8	+
Yoldiella cf. acuminata	5	+
Terebellides stroemi	4	-
Paradoneis lyra	4	-
Eclysippe vanelli	3	-
Notomastus latericeus	2	+
Parvicardium minimum	2	-
Cuspidaria lamellosa	2	+
Tharyx sp.	1	+
Chlamys sulcata	1	-
Thyasira obsoleta	1	-
Apseudes spinosus	1	+
Harpinia pectinata	1	-
Eriopisa elongata	1	+

5. DISCUSSION AND CONCLUSIONS

The chemical and biological analyses of the present survey gave rather different results compared to the 1988 Heidrun baseline survey. While the chemical results indicated stable and environmentally good conditions, the biological results would suggest that some changes might have occurred. The results are, however, far from conclusive. The fauna may react to changes in the environment which do not affect chemical parameters, but generally it is to be expected that major environmental disturbances will lead to changes in both sediment chemistry and biology.

Chemical and sedimentological parameters (e.g. grain size distribution) are generally conservative parameters, i.e. they are expected to vary little during stable conditions. In this respect they differ from the biological parameters, which vary, as the populations of the species vary, both seasonally and from year to year. However, it is considered that some faunal parameters such as species numbers and diversity indices vary less than total abundances and populations of individual species. Further, it is recommended to perform sampling at certain periods of the year to control the variation. Nevertheless, the number of species and densities recorded in the present survey are far below what would be considered normal.

External factors which may cause reductions in species and individual numbers include:

- pollution (chemical compounds or overload of organic matter)
- mechanical disturbance of the sediments, e.g. fishing activities such as bottom trawling.
- changes in water characteristics and/or water quality, especially reduced oxygen content

The chemical analyses showed that the sediments in the Heidrun field were uncontaminated with values for hydrocarbons (THC) and heavy metals at background level. Compared to the 1988 baseline survey there was a reduction in the values for THC and barium. Barium is a constituent of drilling fluids and is therefore commonly used as a tracer for dispersal of drilling fluids in the environment. The results are in accordance with the cease of drilling activity in the field. Judged from the chemical data there have been no changes in the area and no detectable chemical pollution which could influence the fauna.

The grain size distribution analyses, which showed a more coarse sediment than in 1988, could indicate some physical/mechanical disturbance of the bottom. However, the character of the difference and particle distributions was such that it is difficult to explain the changes from natural causes (Chapter 4.1). The largest difference was registered at the reference station (st. 24). Presumably the differences reflect local variations in sediment characteristics, may be combined with measurement deviations (even using standardized techniques). It is perhaps notable that the reference station in 1985 had a very fine-grained sediment (φ-median = 7.60, st. 3: Bowler at al. 1986). However, the possibility that the sediments have been disturbed from fishing activities cannot be ruled out.

The chemical and sedimentological parameters thus do not indicate any anthropogenic factors which could be the reason for the sparse fauna. Changes in water quality are not likely considering the location and depths of the Haltenbanken area. Further, there is nothing to indicate gear malfunction or incorrect routines during the biological sampling. As far as can be ascertained the van Veen grab worked properly. Actually this is supported by the consistent and similar results of the samples. If the grab performance or processing of samples had been subject to errors, great variation among samples would have been expected.

The possibility therefore exists that the results represent a large and unexpected, though natural, variation in the bottom fauna of the area. In fact the general knowledge about seasonal and year-to-year fluctuations in comparable areas is sparse. Most of what is known about seasonality or long term

variability in offshore benthic communities is from more shallow and sandy bottom areas in the North Sea. During the Haltenbanken survey in 1985 low species numbers and abundances were found in the Heidrun area (cf. Table 4.17) (Bowler et al. 1986). In the 1988 baseline study no reasonable explanation was found for the marked increases at the corresponding stations. In the report causes related to the gear, sampling design or working procedures were suggested (Bakke et al. 1989).

It should also be notet that the 1988 samples were taken ultimo June, i.e. about two weeks after the recommended final time limit for offshore monitoring. It is possible that the sampling took place during the period of recruitment of most species, which may account for the high species numbers in 1988. However, the abundances were not particularly high, indicating that recruitment is not the only cause of the differences.

In conclusion the 1992 survey showed that:

- the *physical* and *chemical* conditions in the Heidrun field bottom sediments had changed somewhat since the main baseline survey four years earlier, but not to a degree beyond what may be natural fluctuations. The changes did not indicate any man-made or other disturbances.

- the sea-bed *fauna* was extremely sparse and had changed dramatically since 1988. There are good reasons to believe that the changes were natural, although the information necessary to identify the causes were lacking.

The results of the two surveys in the Heidrun field, the main baseline in 1988 and the present supplementary baseline in 1992, should form a good basis for future monitoring. The *chemical analyses* have documented consistently low and generally stable levels of contaminants in the bottom sediments. It is also assumed that the *biological analyses* constitute a good basis for monitoring despite the large and unexplained changes in the fauna. It should be emphasized that the fauna both in 1988 and in 1992 was homogeneous and showed neither haphazard variation nor marked trends across the field. Any effects due to oil production activities after the installation of a platform in the field are expected to lead to directional gradients in the fauna.

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APPENDICES

1. Cruise log

Station No.: 7

Location adjusted to 1000 m at 150° from EPS.
Position UTM easting: 419916, northing: 7244468.
Latitude: 65° 18' 42.16", longitude: 07° 16' 53.18".

Water depth: 339 m.

Station occupied from 920505 15:04 to 920505 16:35. Depature for station no. 14 at 16:35.

Time	Haul No.	Sampler type	Waterdepth m	Catchment volum liter	Sed. type	Colour	Analysis	Comments
15:20	A	Box corer	341	Full -16	Clay	5Y 4/3 olive	Chem.	Sample A
15:30	B	Box corer	341	Full -16	Clay	5Y 4/3 olive	Chem.	Sample B
15:40	C	Box corer	341	Full -16	Clay	5Y 4/3 olive	Chem.	Sample C
15:45	D	Box corer	341	Empty	-	-	-	No release
15:55	E	Van Veen	341	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 7-1
16:05	F	Van Veen	341	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 7-2
16:12	G	Van Veen	341	3/4 - 12	Clay	5Y 4/3 olive	Bio.	Sample 7-3
16:18	H	Van Veen	341	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 7-4
16:27	I	Van Veen	341	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 7-5

Standard station with standard menu of subsamples taken. Grainsize and core from haul A.
Total 9 hauls, one Van Veen grab did not release. Weather conditions fairly good, some wind.

Station No.: 14

Location adjusted to 2500 m at 315° from platform.
Position UTM easting: 419936, northing: 7247804.
Latitude: 65° 20' 29.87", longitude: 07° 16' 48.30".

Water depth: 335 m.

Station occupied from 920505 17:00 to 920505 20:15.
Depature for station no. 24 at 20:15.

Time	Haul No.	Sampler type	Waterdepth m	Catchment volum liter	Sed. type	Colour	Analysis	Comments
17:00	A	Van Veen	352	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 14-1
17:10	B	Van Veen	352	-	-	-	-	Lost grab
17:25	C	Box corer	352	Full -16	Clay	5Y 4/3 olive	Chem.	Sample A
17:35	D	Box corer	352	Full -16	Clay	5Y 4/3 olive	Chem.	Sample B
17:45	E	Box corer	352	Full -16	Clay	5Y 4/3 olive	Chem.	Sample C
18:50	F	Van Veen	352	Empty	-	-	-	No release
19:00	G	Van Veen	352	Empty	-	-	-	No release
19:10	H	Van Veen	352	Empty	-	-	-	No release
19:15	I	Van Veen	352	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 14-2
19:25	J	Van Veen	352	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 14-3
19:35	K	Van Veen	352	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 14-4
19:45	L	Van Veen	352	Empty	-	-	-	No release
1950	M	Van Veen	352	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 14-5

Standard station with standard menu of subsamples taken. Grainsize from haul C.
Total 13 hauls, lost equipment on 2nd haul. The total of 4 Van Veen grabs did not release. Weather conditions fairly good, with increasing winds.

Station No.: 17

Location adjusted to 2500 m at 135° from platform.
Position UTM easting: 423374, northing: 7244176.
Latitude: 65° 18' 35.72", longitude: 07° 21' 21.42".

Water depth: 335 m.

Station occupied from 920505 05:30 to 920505 09:10.
Depature for station no.23 at 09:10.

Time	Haul No.	Sampler type	Waterdepth m	Catchment volum liter	Sed. type	Colour	Analysis	Comments
06:49	A	Box corer	341	Empty	-	-	-	No release
07:10	B	Box corer	340	Full -16	Clay	5Y 4/3 olive	Chem.	Sample A
07:15	C	Box corer	336	Empty	-	-	-	No release
07:17	D	Box corer	338	Empty	-	-	-	No release
07:23	E	Box corer	338	Full -16	Clay	5Y 4/3 olive	Chem.	Sample B
07:35	F	Box corer	340	Full -16	Clay	5Y 4/3 olive	Chem.	Sample C
07:45	G	Van Veen	339	Empty	-	-	-	No release
08:05	H	Van Veen	337	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 17-1
08:15	I	Van Veen	335	Empty	-	-	-	No release
08:20	J	Van Veen	337	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 17-2
08:35	K	Van Veen	340	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 17-3
08:55	L	Van Veen	340	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 17-4
09:05	M	Van Veen	340	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 17-5

Standard station with standard menu of subsamples taken. Grainsize from haul B.
Total 13 hauls, light Van Veen did not give catchment. The total of 2 Van Veen grabs and 3 box cores did not release. Weather conditions fairly good, some wind.

Station No.: 21

Location adjusted to 1000 m at 045° from platform.
Position UTM easting: 422381, northing: 7246678.
Latitude: 65° 19' 55.64", longitude: 07° 19' 59.58".

Water depth: 348 m.

Station occupied from 920505 12:50 to 920505 14:37.
Depature for station no. 7 at 14:37.

Time	Haul No.	Sampler type	Waterdepth m	Catchment volum liter	Sed. type	Colour	Analysis	Comments
12:55	A	Box corer	346.5	Empty	-	-	-	No release
13:10	B	Box corer	346.5	Empty	-	-	-	No release
13:20	C	Box corer	346.5	Empty	-	-	-	No release
13:30	D	Van Veen	346.5	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 21-1
13:40	E	Van Veen	346.5	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 21-2
13:50	F	Van Veen	346.5	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 21-3
14:00	G	Van Veen	346.5	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 21-4
14:10	H	Van Veen	346.5	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 21-5
14:15	I	Box corer	346.5	Full -16	Clay	5Y 4/3 olive	Chem.	Sample A
14:25	J	Box corer	346.5	Full -16	Clay	5Y 4/3 olive	Chem.	Sample B
14:35	K	Box corer	346.5	Empty	-	-	-	No release
14:40	L	Box corer	346.5	Full -16	Clay	5Y 4/3 olive	Chem.	Sample C

Standard station with standard menu of subsamples taken. Grainsize from haul H.
Total 12 hauls, the total of 4 box cores did not release. Weather conditions fairly good, some wind.

Station No.: 23

Location adjusted to 5000 m at 045° from platform.
Position UTM easting: 425282, northing: 7249429.
Latitude: 65° 21' 26.89", longitude: 07° 23' 38.39".

Water depth: 340 m.

Station occupied from 920505 10:03 to 920505 12:00.
Depature for station no.21 at 12:00.

Time	Haul No.	Sampler type	Waterdepth m	Catchment volum liter	Sed. type	Colour	Analysis	Comments
10:10	A	Van Veen	352	Full - 15	Clay	5Y 5/3 olive	Bio.	Sample 23-1
10:25	B	Van Veen	352	Full - 15	Clay	5Y 5/3 olive	Bio.	Sample 23-2
10:35	C	Van Veen	352	Full - 15	Clay	5Y 5/3 olive	Bio.	Sample 23-3
10:45	D	Van Veen	352	Empty	-	-	-	No release
10:50	E	Van Veen	352	Full - 15	Clay	5Y 5/3 olive	Bio.	Sample 23-4
11:00	F	Van Veen	352	Full - 15	Clay	5Y 5/3 olive	Bio.	Sample 23-5
11:10	G	Box corer	352	Full -16	Clay	5Y 5/3 olive	Chem.	Sample A
11:20	H	Box corer	352	Empty	-	-	-	No release
11:25	I	Box corer	352	Empty	-	-	-	No release
11:30	J	Box corer	352	Empty	-	-	-.	No release
11:40	K	Box corer	352	Full -16	Clay	5Y 5/3 olive	Chem.	Sample B
11:55	L	Box corer	352	Full -16	Clay	5Y 5/3 olive	Chem.	Sample C

Standard station with standard menu of subsamples taken. Grainsize from haul G.
Total 12 hauls, the total of 1 Van Veen grabs and 3 box cores did not release. Weather conditions fairly good, some wind.

Station No.: 24

Reference station. Location corresponds to 1985 Haltenbanken survey site no.3.
Position UTM easting: 411146, northing: 7260142.
Latitude: 65° 27' 00.00", longitude: 07° 4' 59.99".

Water depth: 380 m.

Station occupied from 920505 22:17 to 920506 03:05. Sampling survey terminated at 03:05.

Time	Haul No.	Sampler type	Waterdepth m	Catchment volum liter	Sed. type	Colour	Analysis	Comments
22:20	A	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-1
22:30	B	Van Veen	389	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-2
22:40	C	Van Veen	386	Empty	-	-	-	No release
22:50	D	Van Veen	386	Empty	-	-	-	No release
23:10	E	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-3
23:20	F	Box corer	383	Full -16	Clay	5Y 4/3 olive	Chem.	Sample A
23:30	G	Box corer	383	Empty	-	-	-	No release
23:40	H	Box corer	383	Empty	-	-	-	No release
23:50	I	Box corer	383	Empty	-	-	-.	No release
24:00	J	Box corer	383	Empty	-	-	-	No release
00:15	K	Box corer	383	Empty	-	-	-	No release
00:30	L	Box corer	383	Empty	-	-	-.	No release
00:55	M	Box corer	383	Full -16	Clay	5Y 4/3 olive	Chem.	Sample B
01:05	N	Box corer	383	Full -16	Clay	5Y 4/3 olive	Chem.	Sample C
01:40	O	Box corer	383	Full -16	Clay	5Y 4/3 olive	Chem.	Sample D
01:45	P	Box corer	383	Empty	-	-	-	No release
01:50	Q	Box corer	383	Empty	-	-	-	No release
01:55	R	Box corer	383	Empty	-	-	-.	No release
02:00	S	Box corer	383	Full -16	Clay	5Y 4/3 olive	Chem.	Sample E
02:10	T	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-4
02:15	U	Van Veen	386	Empty	-	-	-	No release
02:20	V	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-5
02:27	W	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-6
02:43	X	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-7
02:50	Y	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-8
03:00	Z	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-9
03:10	Æ	Van Veen	383	Full - 15	Clay	5Y 4/3 olive	Bio.	Sample 24-10

Standard station with standard menu of subsamples taken. Grainsize from haul F.
Total 27 hauls, the total of 3 Van Veen grabs and 9 box cores did not release. Weather conditions poor, strong winds.

2. Grain size distribution tables and histograms

Data set nr. 1: HEIDRUN ST.7

GRAIN SIZE DISTRIBUTION

Grain size interval (mm) min	max	Weight fraction (g)	Percentages of distribution fraction	cumulative min - ∞	cumulative 0 - max
1.0000 to	∞	.125	.203	.203	100.000
.5000 to	1.0000	.714	1.163	1.366	99.797
.3550 to	.5000	2.952	4.809	6.176	98.634
.2500 to	.3550	3.569	5.814	11.990	93.824
.1800 to	.2500	7.352	11.978	23.968	88.010
.1250 to	.1800	9.942	16.199	40.167	76.032
.0900 to	.1250	9.192	14.976	55.143	59.833
.0630 to	.0900	10.411	16.963	72.106	44.857
.0440 to	.0630	2.820	4.595	76.701	27.894
.0310 to	.0440	5.090	8.293	84.994	23.299
.0220 to	.0310	3.670	5.980	90.974	15.006
.0150 to	.0220	2.530	4.122	95.096	9.026
.0080 to	.0150	1.860	3.031	98.126	4.904
.0040 to	.0080	.870	1.418	99.544	1.874
.0000 to	.0040	.280	.456	100.000	.456

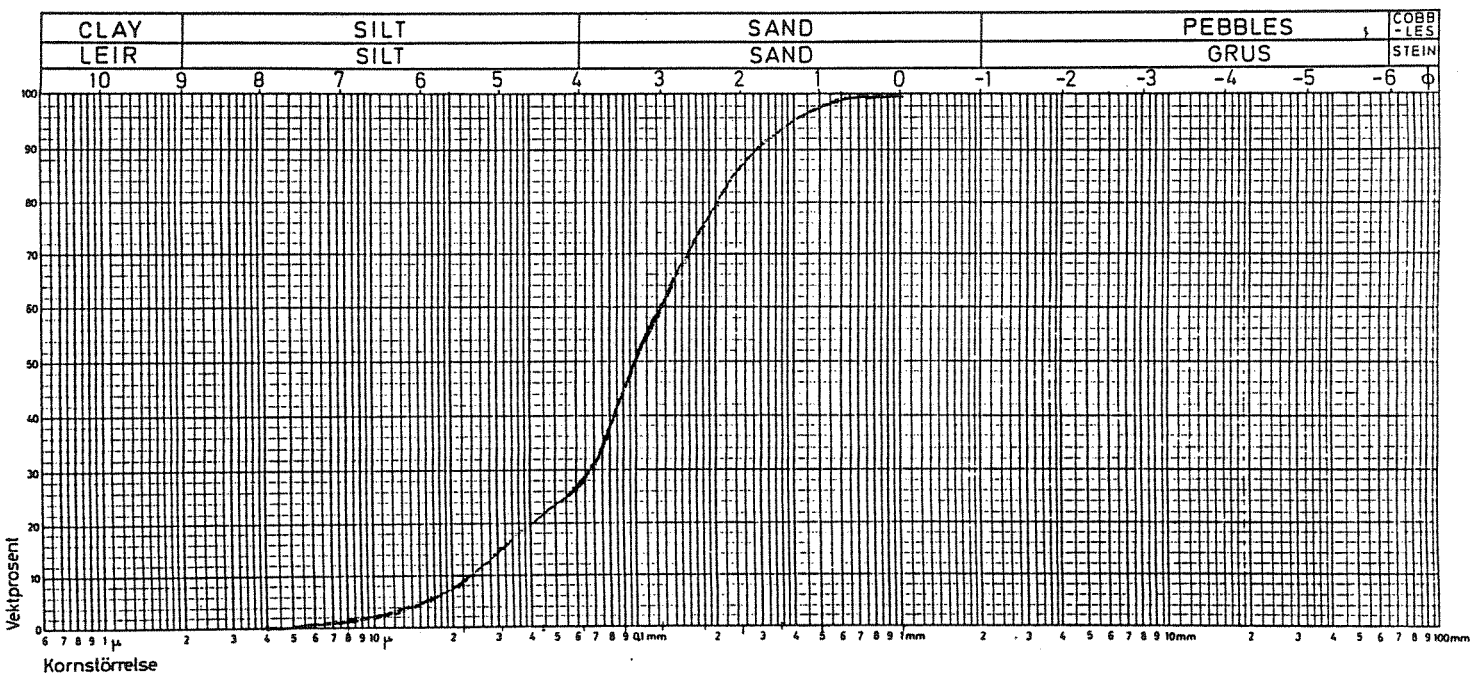
Total weight : 61.375 g

PHI fractiles:

Percentage (>PHI)	(<PHI)	PHI value
95.0	5.0	1.379
84.0	16.0	2.201
75.0	25.0	2.506
50.0	50.0	3.349
25.0	75.0	4.323
16.0	84.0	4.946
5.0	95.0	6.041

Statistical measures:

PHI Median :	3.349
Deviation:	1.393
Skewness :	.159
Kurtosis :	1.051



PRØVE NR.	STED
	St. 7 Heidrun 5.5.92

Data set nr. 2: HEIDRUN ST.14

GRAIN SIZE DISTRIBUTION

Grain size interval (mm) min	max	Weight fraction (g)	Percentages of distribution fraction	cumulative min - ∞	cumulative 0 - max
1.0000 to	∞	.099	.208	.208	100.000
.5000 to	1.0000	2.274	4.796	5.004	99.792
.3550 to	.5000	4.510	9.510	14.515	94.996
.2500 to	.3550	4.241	8.944	23.458	85.485
.1800 to	.2500	5.578	11.764	35.222	76.542
.1250 to	.1800	5.718	12.058	47.280	64.778
.0900 to	.1250	5.282	11.138	58.418	52.720
.0630 to	.0900	6.319	13.325	71.743	41.582
.0440 to	.0630	1.710	3.606	75.349	28.257
.0310 to	.0440	3.520	7.423	82.772	24.651
.0220 to	.0310	3.190	6.727	89.498	17.228
.0150 to	.0220	2.200	4.639	94.138	10.502
.0080 to	.0150	1.740	3.669	97.807	5.862
.0040 to	.0080	.800	1.687	99.494	2.193
.0000 to	.0040	.240	.506	100.000	.506

Total weight : 47.422 g

PHI fractiles:

Percentage (>PHI)	Percentage (<PHI)	PHI value
95.0	5.0	1.000
84.0	16.0	1.583
75.0	25.0	2.070
50.0	50.0	3.134
25.0	75.0	4.458
16.0	84.0	5.071
5.0	95.0	6.209

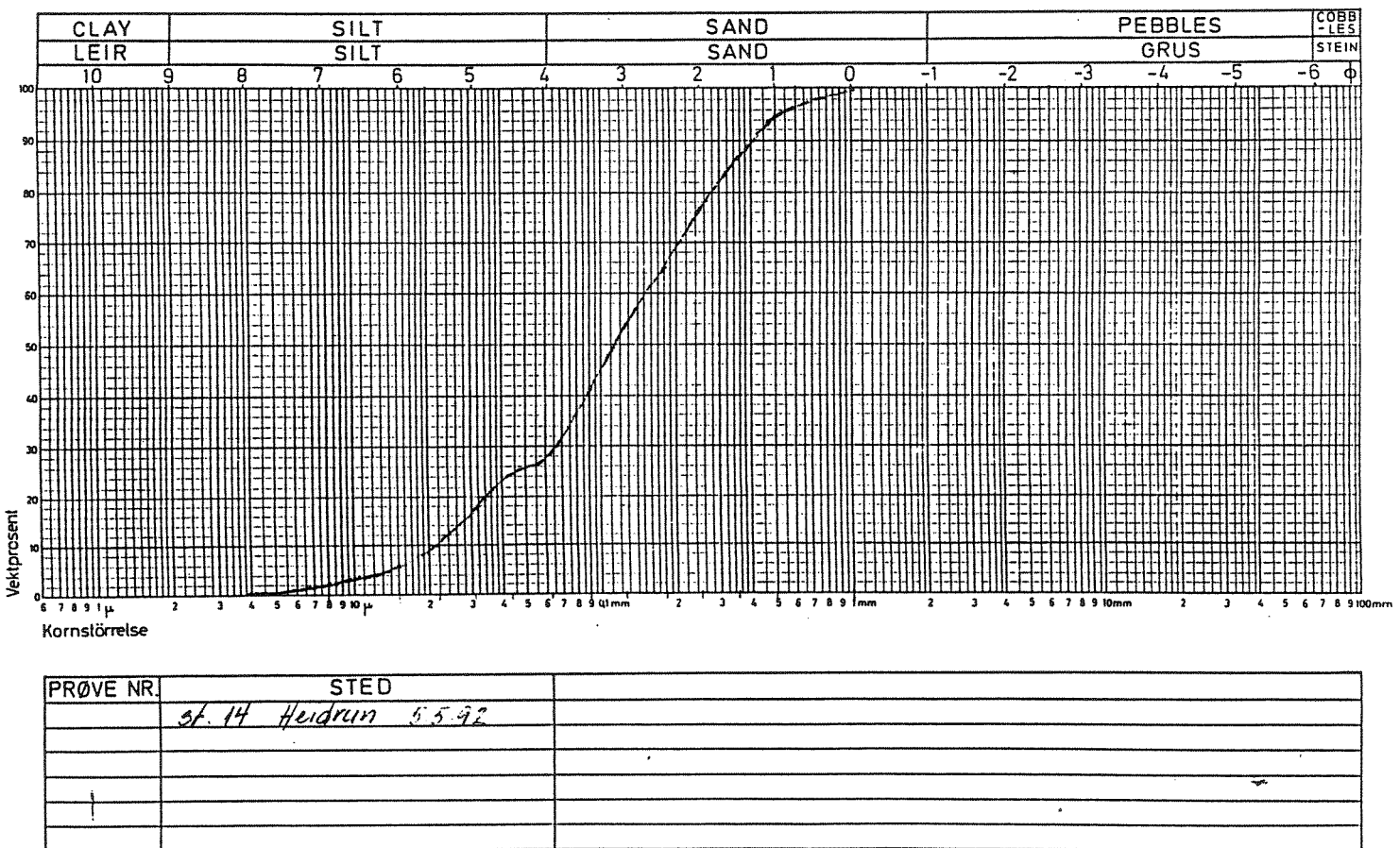
Statistical measures:

PHI Median : 3.134

Deviation: 1.661

Skewness : .145

Kurtosis : .894



PRØVE NR.	STED
	St. 14 Heidrun 5.5.92

Data set nr. 3: HEIDRUN ST.17

GRAIN SIZE DISTRIBUTION

Grain size interval (mm) min	max	Weight fraction (g)	Percentages of distribution fraction	cumulative min - ∞	0 - max
1.0000 to	∞	.106	.185	.185	100.000
.5000 to	1.0000	.439	.768	.953	99.815
.3550 to	.5000	3.010	5.260	6.213	99.047
.2500 to	.3550	4.600	8.039	14.252	93.787
.1800 to	.2500	6.753	11.802	26.054	85.748
.1250 to	.1800	6.687	11.686	37.740	73.946
.0900 to	.1250	6.765	11.823	49.563	62.260
.0630 to	.0900	8.060	14.086	63.649	50.437
.0440 to	.0630	3.060	5.348	68.997	36.351
.0310 to	.0440	5.780	10.101	79.098	31.003
.0220 to	.0310	4.370	7.637	86.736	20.902
.0150 to	.0220	3.410	5.959	92.695	13.264
.0080 to	.0150	2.720	4.754	97.448	7.305
.0040 to	.0080	1.160	2.027	99.476	2.552
.0000 to	.0040	.300	.524	100.000	.524

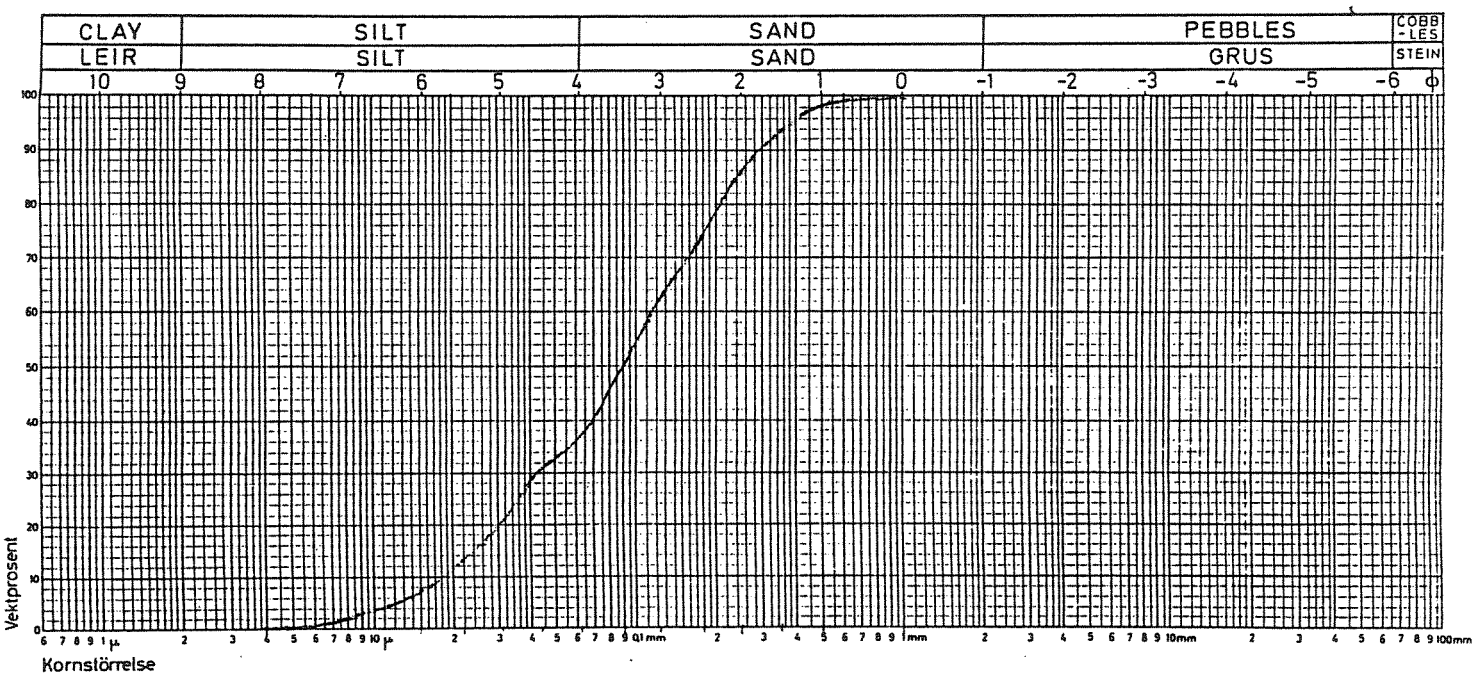
Total weight : 57.221 g

PHI fractiles:

Percentage (>PHI)	(<PHI)	PHI value
95.0	5.0	1.406
84.0	16.0	2.079
75.0	25.0	2.431
50.0	50.0	3.485
25.0	75.0	4.801
16.0	84.0	5.308
5.0	95.0	6.392

Statistical measures:

PHI Median :	3.485
Deviation:	1.563
Skewness :	.148
Kurtosis :	.862



PRØVE NR.	STED
	St. 17 Heidrun 5.5.92.

Data set nr. 4: HEIDRUN ST.21

GRAIN SIZE DISTRIBUTION

Grain size interval (mm) min		max	Weight fraction (g)	Percentages of distribution fraction	cumulative min - ∞	cumulative 0 - max
1.0000	to	∞	.135	.204	.204	100.000
.5000	to	1.0000	2.461	3.719	3.923	99.796
.3550	to	.5000	6.054	9.149	13.072	96.077
.2500	to	.3550	6.139	9.276	22.348	86.928
.1800	to	.2500	7.007	10.588	32.936	77.652
.1250	to	.1800	10.052	15.190	48.126	67.064
.0900	to	.1250	8.527	12.885	61.010	51.874
.0630	to	.0900	9.402	14.208	75.218	38.990
.0440	to	.0630	2.240	3.385	78.603	24.782
.0310	to	.0440	5.220	7.888	86.491	21.397
.0220	to	.0310	3.760	5.682	92.173	13.509
.0150	to	.0220	2.440	3.687	95.860	7.827
.0080	to	.0150	1.830	2.765	98.625	4.140
.0040	to	.0080	.710	1.073	99.698	1.375
.0000	to	.0040	.200	.302	100.000	.302

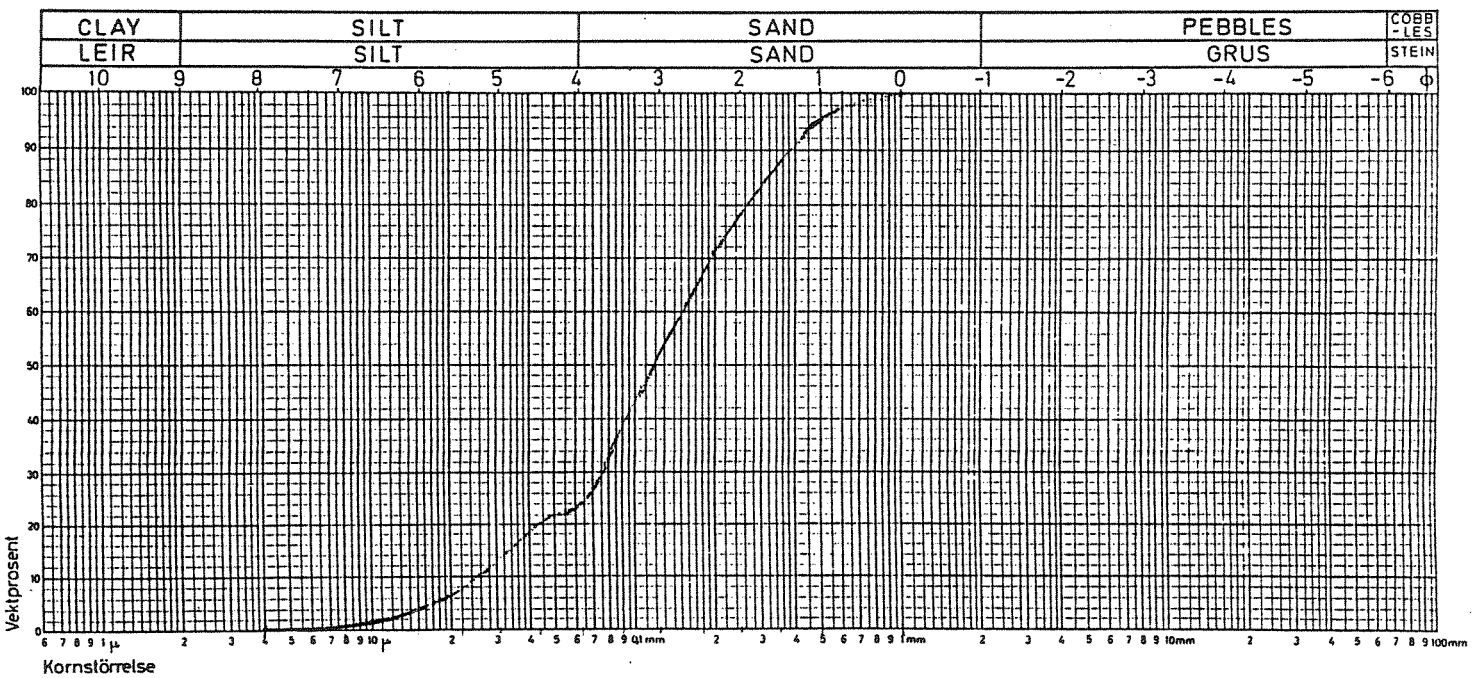
Total weight : 66.177 g

PHI fractiles:

Percentage (>PHI)	Percentage (<PHI)	PHI value
95.0	5.0	1.085
84.0	16.0	1.646
75.0	25.0	2.130
50.0	50.0	3.065
25.0	75.0	3.978
16.0	84.0	4.843
5.0	95.0	5.897

Statistical measures:

PHI Median :	3.065
Deviation:	1.528
Skewness :	.145
Kurtosis :	1.067



PRØVE NR.	STED	
	St. 21 Heidrun 5.5.92.	

Data set nr. 5: HEIDRUN ST.23

GRAIN SIZE DISTRIBUTION

Grain size interval (mm) min	max	Weight fraction (g)	Percentages of distribution fraction	cumulative min - ∞	cumulative 0 - max
1.0000 to	∞	.238	.437	.437	100.000
.5000 to	1.0000	.644	1.179	1.616	99.563
.3550 to	.5000	3.031	5.554	7.170	98.384
.2500 to	.3550	5.507	10.089	17.259	92.830
.1800 to	.2500	7.196	13.184	30.443	82.741
.1250 to	.1800	8.106	14.852	45.296	69.557
.0900 to	.1250	6.192	11.345	56.641	54.704
.0630 to	.0900	7.675	14.062	70.703	43.359
.0440 to	.0630	1.960	3.591	74.294	29.297
.0310 to	.0440	3.740	6.852	81.147	25.706
.0220 to	.0310	3.580	6.559	87.706	18.853
.0150 to	.0220	2.950	5.405	93.111	12.294
.0080 to	.0150	2.330	4.269	97.380	6.889
.0040 to	.0080	1.080	1.979	99.359	2.620
.0000 to	.0040	.350	.641	100.000	.641

Total weight : 54.579 g

PHI fractiles:

Percentage (>PHI)	(<PHI)	PHI value
95.0	5.0	1.349
84.0	16.0	1.948
75.0	25.0	2.288
50.0	50.0	3.190
25.0	75.0	4.561
16.0	84.0	5.212
5.0	95.0	6.363

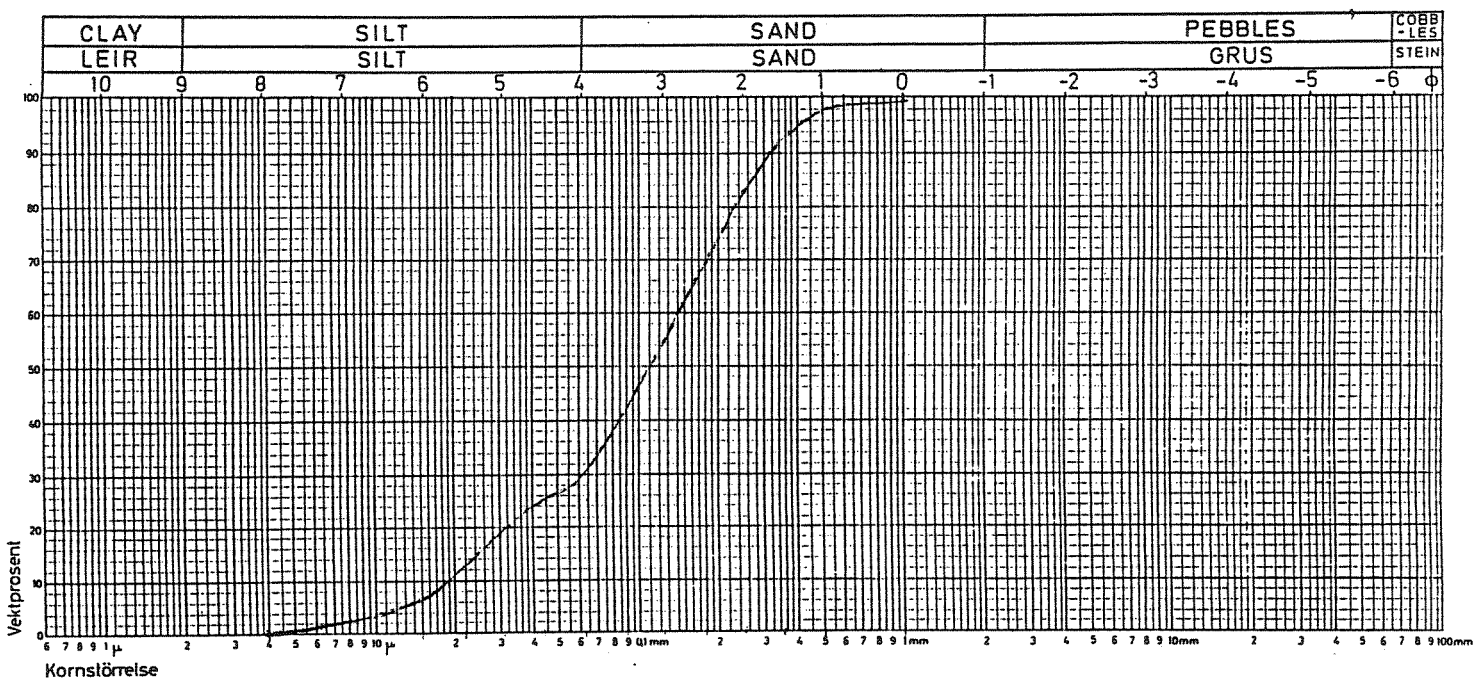
Statistical measures:

PHI Median : 3.190

Deviation: 1.576

Skewness : .253

Kurtosis : .904



PRØVE NR.	STED	
	St 23 Heidrun 5.5.92	

Data set nr. 6: HEIDRUN ST.24 REF.

GRAIN SIZE DISTRIBUTION

Grain size interval (mm) min	max	Weight fraction (g)	Percentages of distribution fraction	cumulative min - ∞	0 - max
1.0000 to	∞	.086	.134	.134	100.000
.5000 to	1.0000	4.148	6.434	6.568	99.866
.3550 to	.5000	7.679	11.910	18.478	93.432
.2500 to	.3550	7.749	12.019	30.497	81.522
.1800 to	.2500	7.466	11.580	42.076	69.503
.1250 to	.1800	7.188	11.149	53.225	57.924
.0900 to	.1250	5.698	8.838	62.063	46.775
.0630 to	.0900	7.749	12.020	74.083	37.937
.0440 to	.0630	1.420	2.202	76.285	25.917
.0310 to	.0440	4.620	7.166	83.451	23.715
.0220 to	.0310	3.550	5.506	88.957	16.549
.0150 to	.0220	2.960	4.591	93.548	11.043
.0080 to	.0150	2.480	3.846	97.394	6.452
.0040 to	.0080	1.250	1.939	99.333	2.606
.0000 to	.0040	.430	.667	100.000	.667

Total weight : 64.474 g

PHI fractiles:

Percentage (>PHI)	(<PHI)	PHI value
95.0	5.0	.911
84.0	16.0	1.397
75.0	25.0	1.768
50.0	50.0	2.843
25.0	75.0	4.186
16.0	84.0	5.055
5.0	95.0	6.317

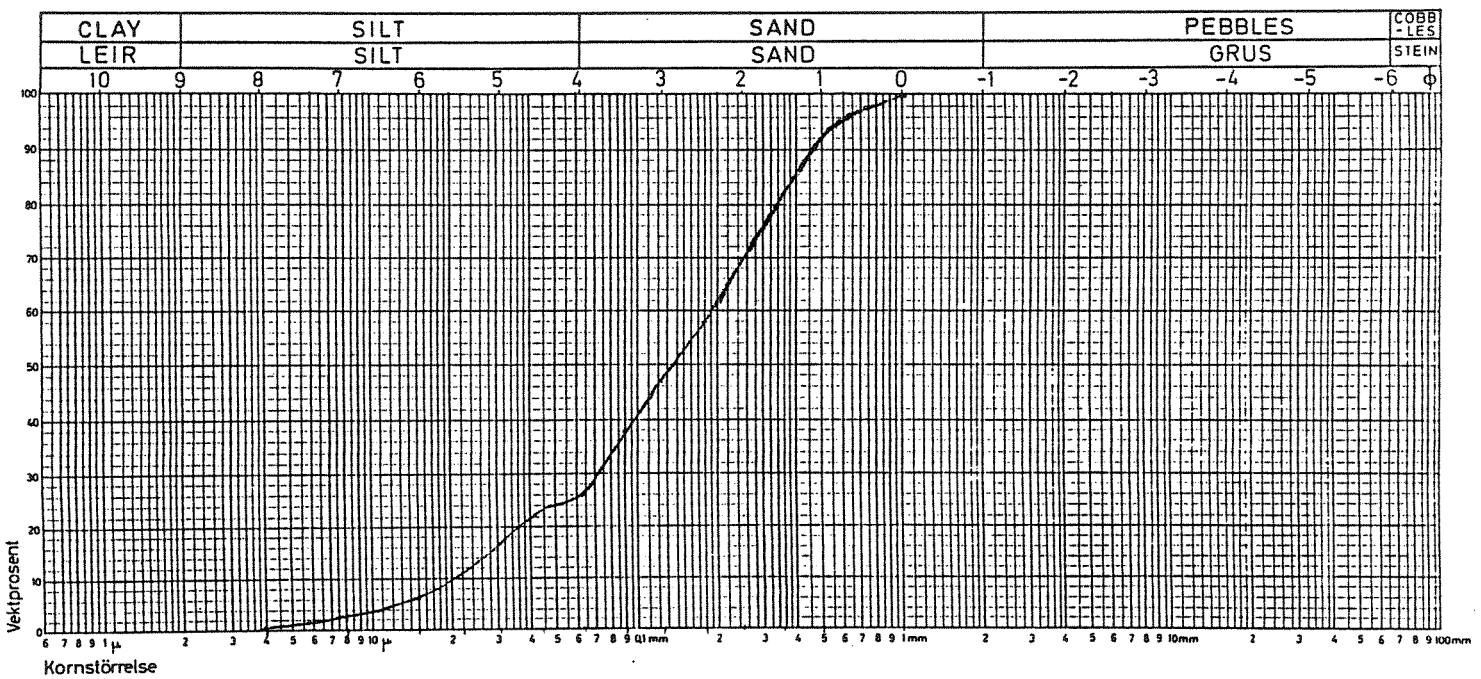
Statistical measures:

PHI Median : 2.843

Deviation: 1.733

Skewness : .247

Kurtosis : .916



PRØVE NR.	STED
	st. 24 ref. Heidrun 6.5 97

3. Gas-chromatograms of total hydrocarbons (THC)

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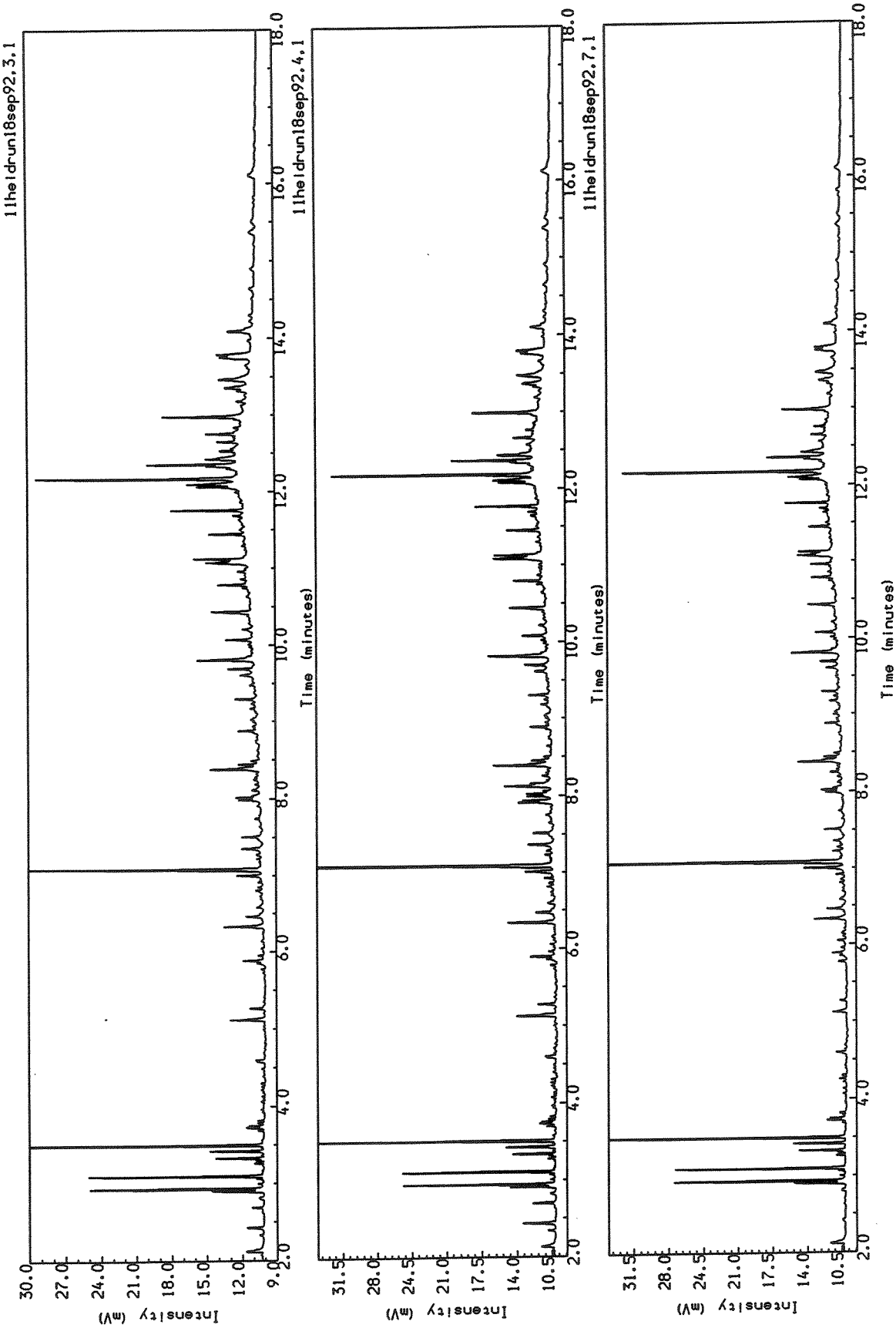

Figure 1 *Chromatograms from site 7 location P 225°/2350 m.*

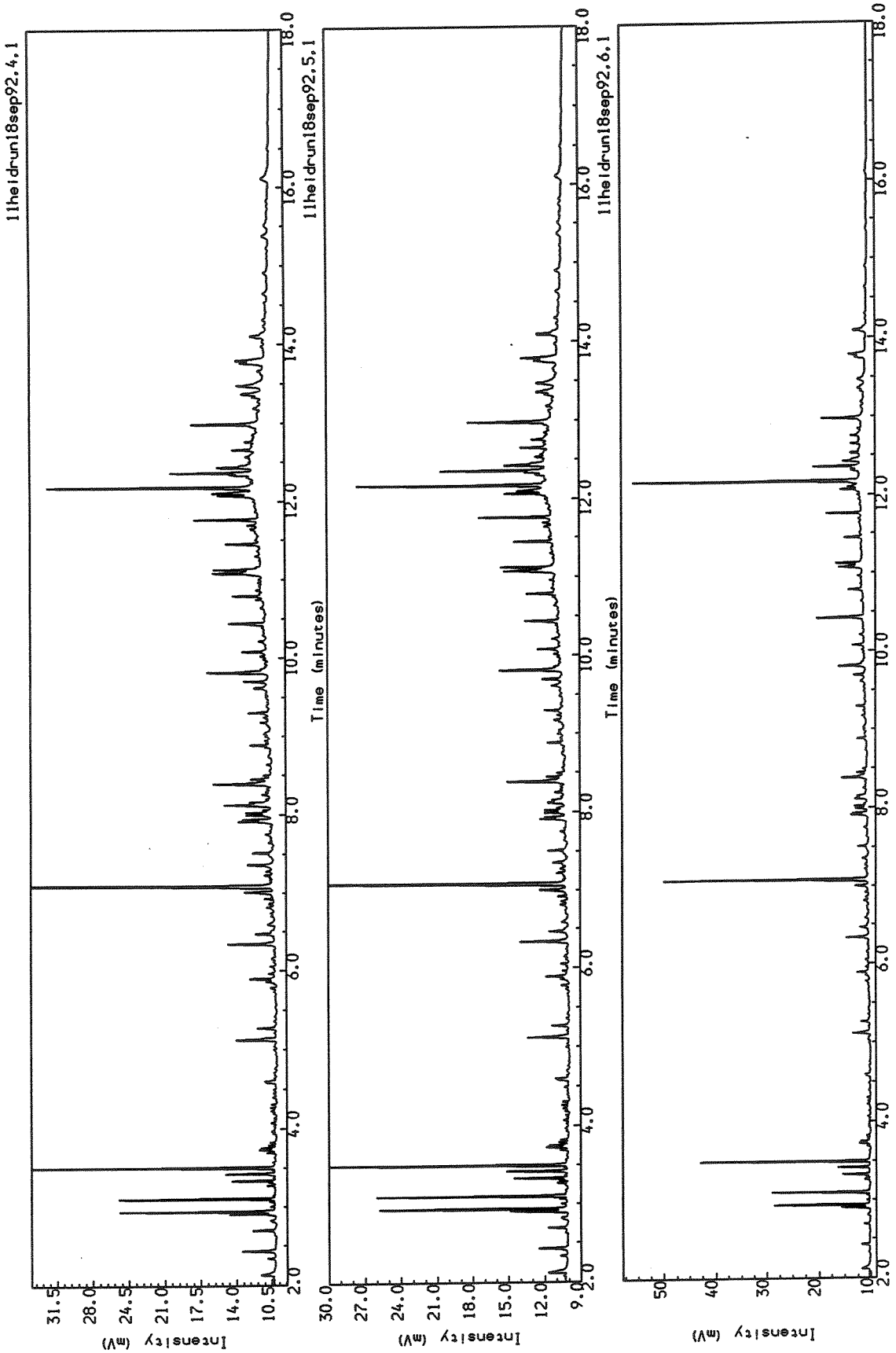

Figure 2 *Chromatograms from site 7 location P 225°/2350 m, vertical sectioning (0-1 cm, 1-3 cm, 3-6 cm).*

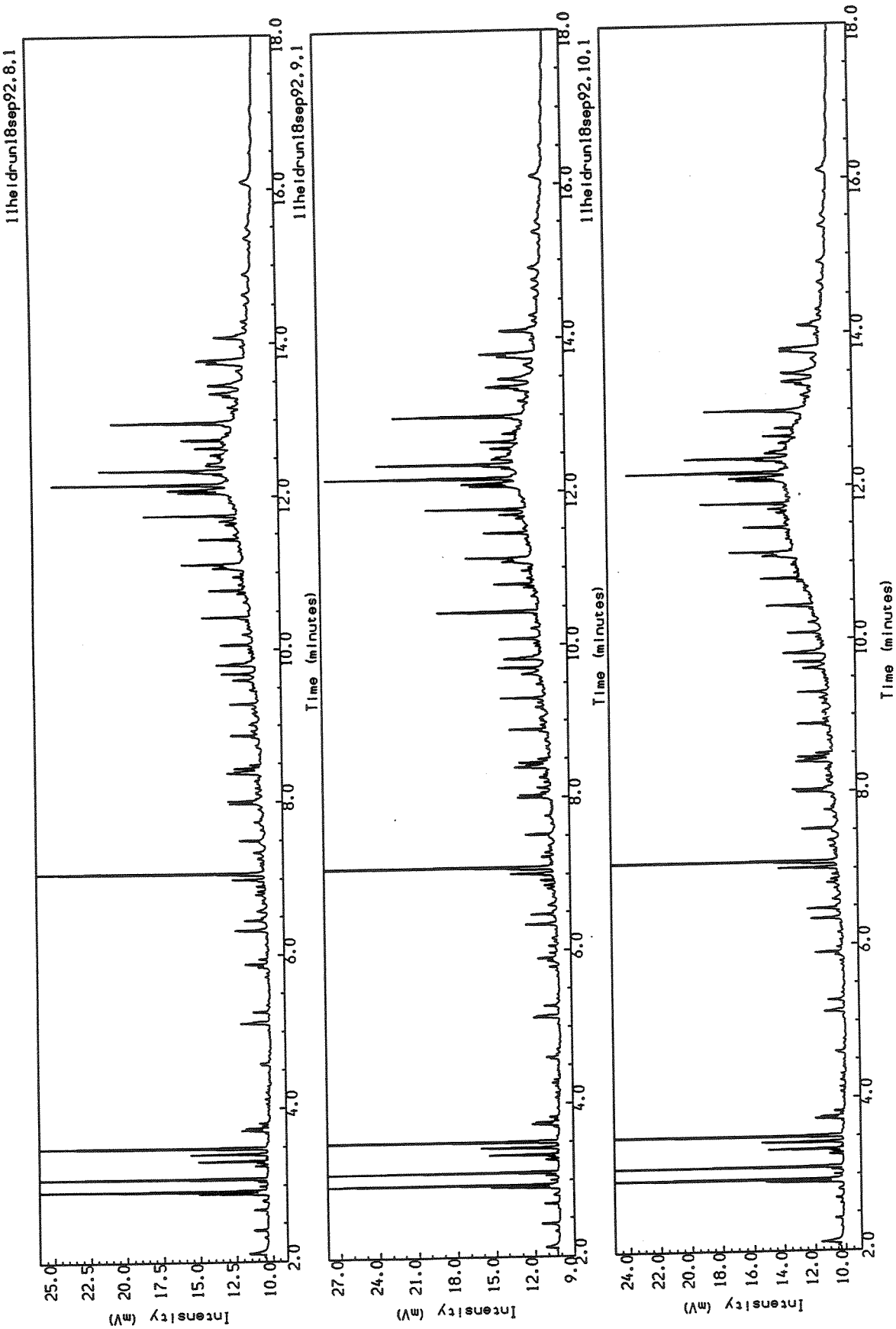

Figure 3 *Chromatograms from site 14 location P 315°/2500 m*

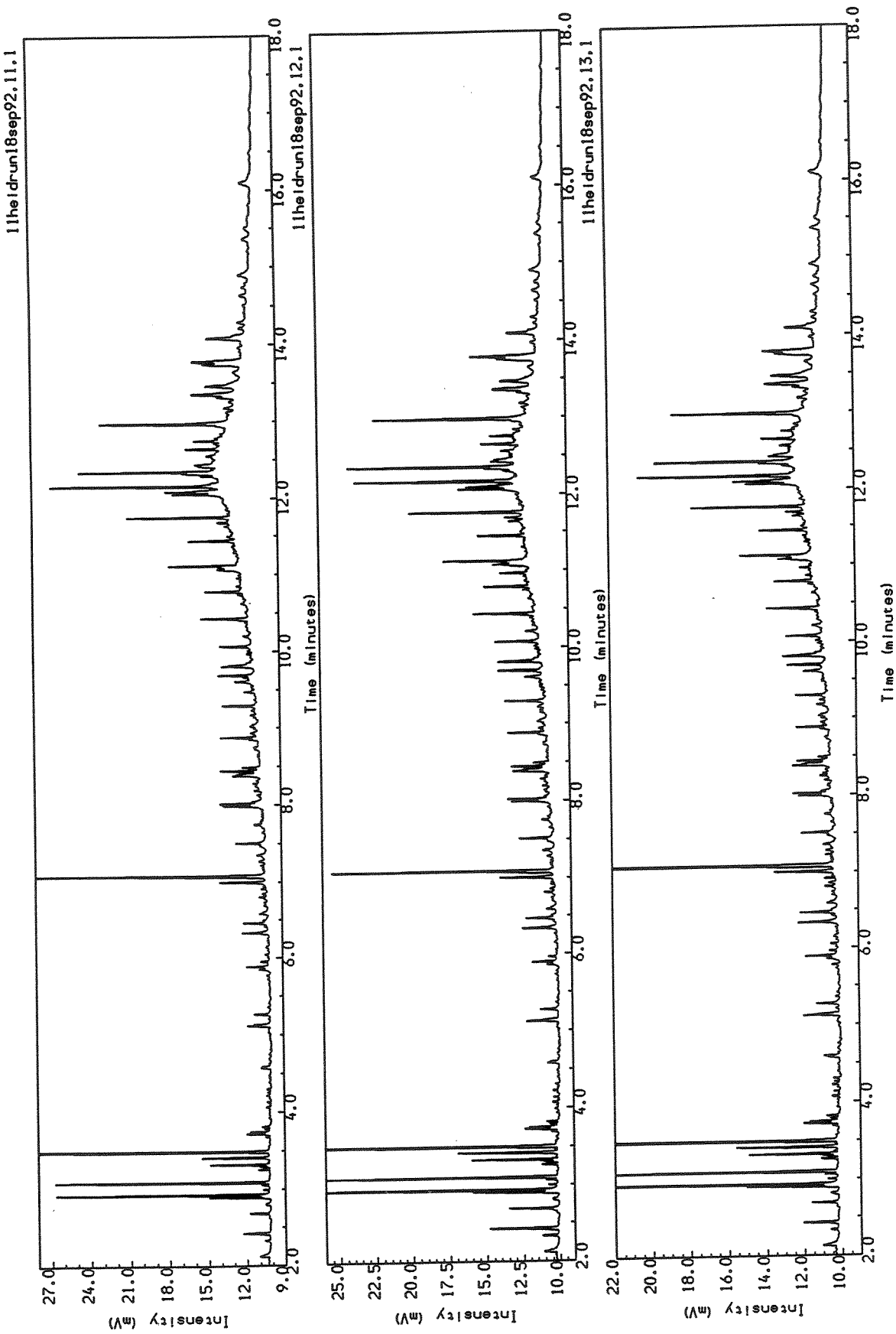

Figure 4 *Chromatograms from site 17 location P 135°/2500 m*

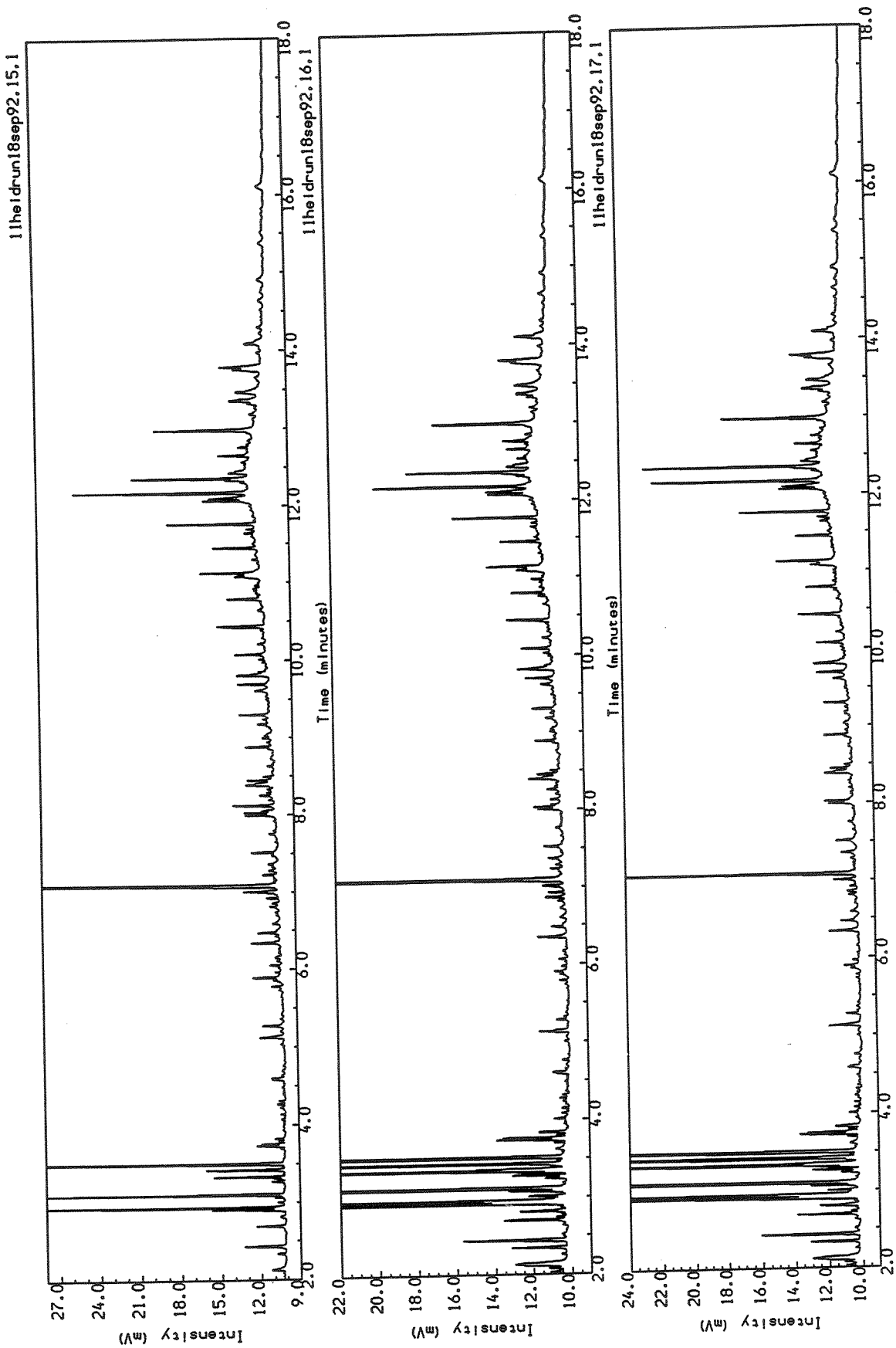

Figure 5 *Chromatograms from site 21 location P 45°/1000 m*

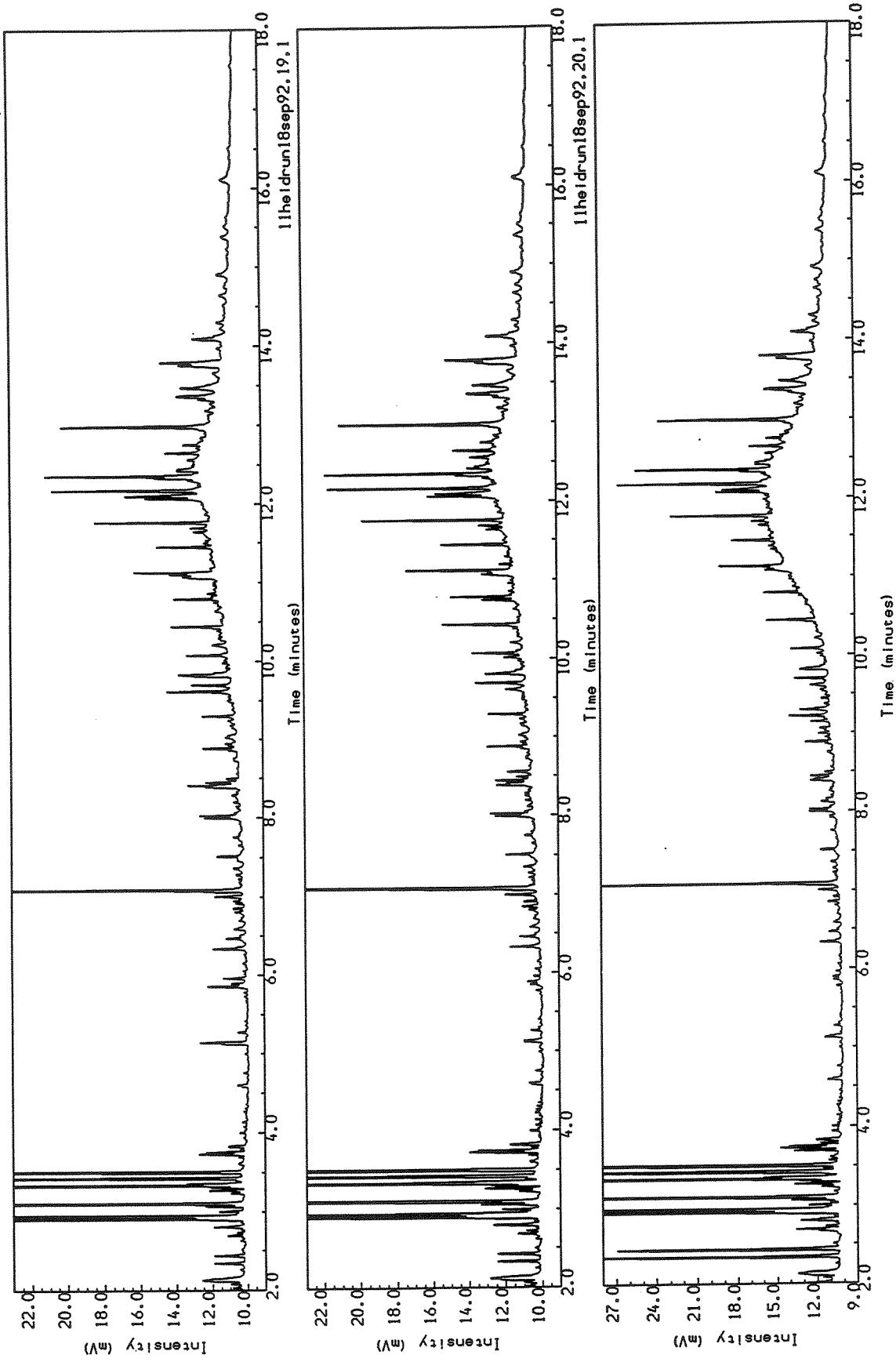

Figure 6 *Chromatograms from site 23 location P 45°/5000 m*

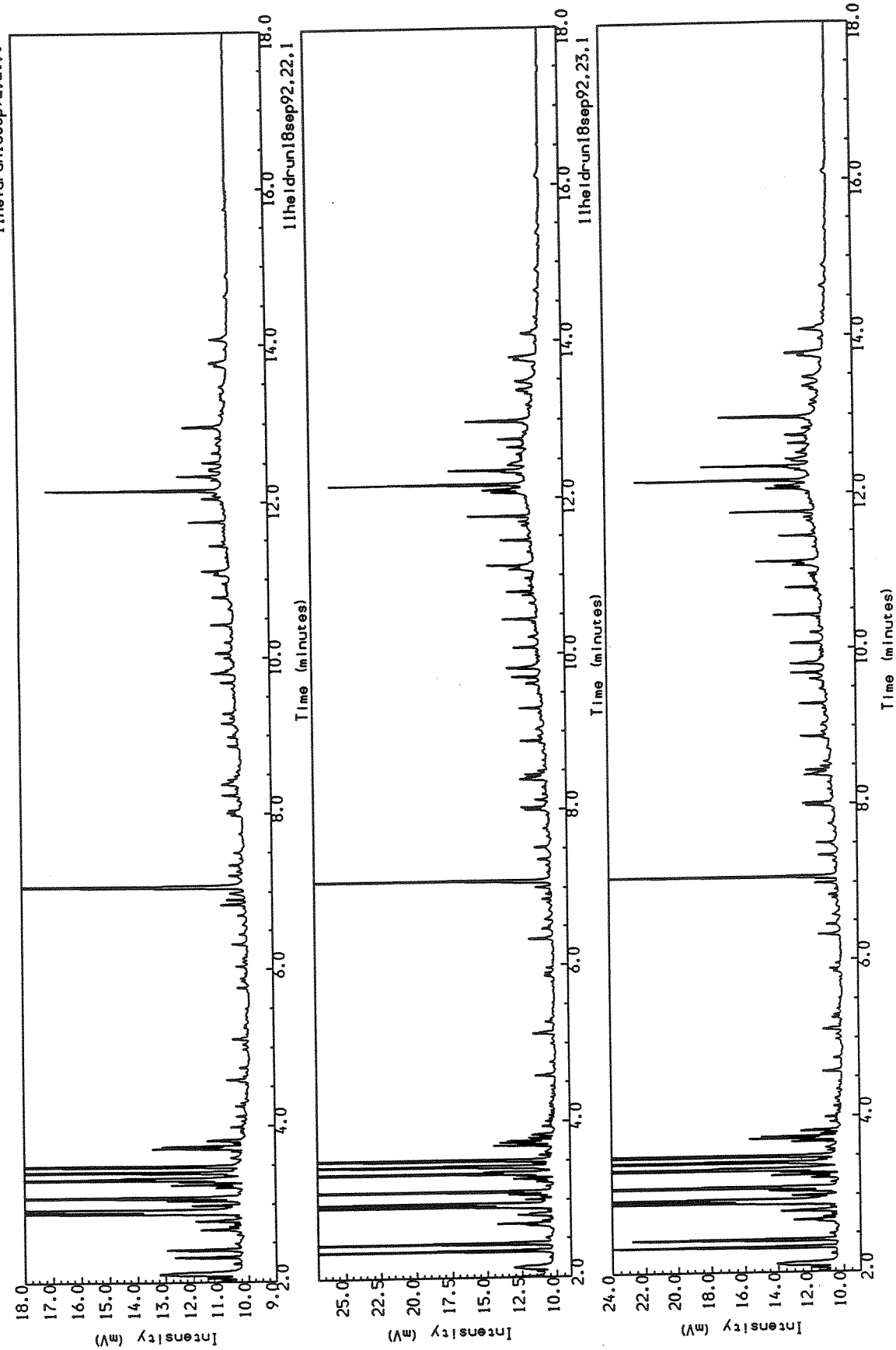

Figure 7 *Chromatograms from site 24 location P 315°/17000 m*

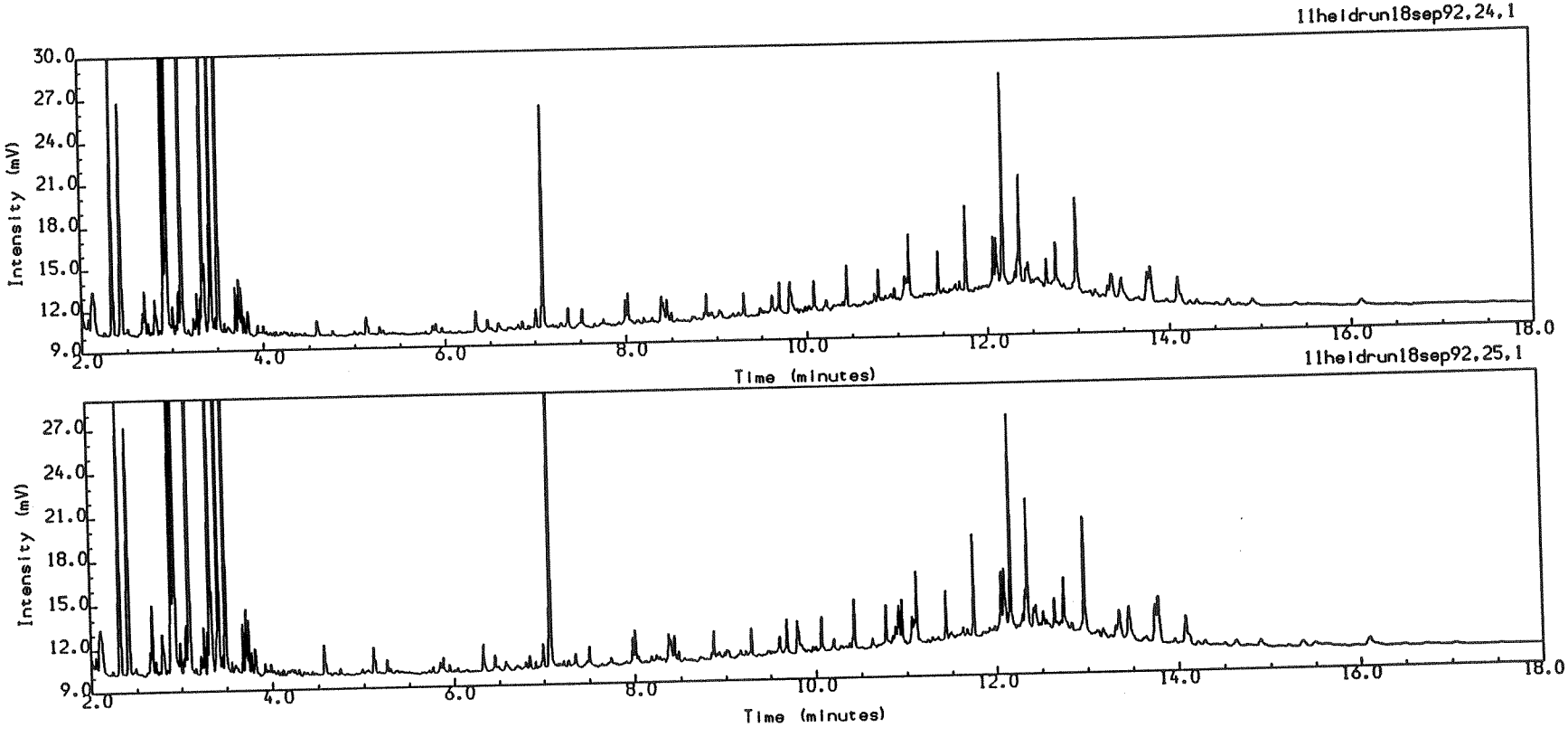

Figure 8 *Chromatograms from site 24 location P 315°/17000 m*

4. Quality assurance of chemical analyses

QUALITY ASSURANCE OF CHEMICAL ANALYSES

Hydrocarbons

The quality assurance program of the chemical analyses was divided in two parts. One part is the control of the analytical equipment, and the other part is the control of the analytical procedures.

The linearity of the flame ionization detector was examined before the start of THC-analysis. Standards ranging in concentrations from 0.1 mg/ml to 10.0 mg/ml were analyzed. A linear regression analysis was done. The correlation coefficient was 0.9999. Quantification was done using a stepped calibration curve. This is shown in Figure A2.1.

To control the precision of the analytical equipment, a standard with concentration 1.0 mg/ml was analysed several times during the analyses of the Heidrun samples. The results of these analyses are given in Table A2.1.

Table A2.1 Results from the analyses of the 1.0 mg/ml standard during analyses of the Heidrun samples.

Sample	Mean Area	% SD	Number of analyses
STD 1.0 mg/ml	$120*10^5$	0.96	4

The precision of the GC/MS system was controlled in the same manner. The standard which was used in calculating the relative response ratio was analysed after every second station (every 7th hour). The analysis of the Heidrun samples lasted for 28 hours. During this time the relative response ratios differed with 3.1% - 14.9%.

The analytical procedure was controlled by analysing blanks and by adding a base oil (100 mg) to the sediment (100g), (spiking). The % recovery was determined for THC, naphthalenes, phenanthrenes, dibenzothiophenes and C_5-C_8 decalines. The results from these analyses are given in Table A2.2.

Table A2.2 Results from the analyses of the spiked samples given in % recovery.

Parameter	% Recovery	Mean ± SD	
THC	89.6	90.1 ± 0.68	mg THC/mg oil
Naphthalenes	115	0.576 ± 0.0449	µg N/mg oil
Phenanthrenes	129	0.0374 ± 0.00566	µg P/mg oil
Dibenzothiophenes	85.1	0.0372 ± 0.00195	µg D/mg oil
C_5-C_8 Decalines	80.6	29.7 ± 0.777	µg/mg oil

The recovery of NP(D)'s is high. This can be explained by the difference in the composition of the spiked sample and the 100% standard. The 100% standard is prepared by diluting the base-oil with hexane to give a final concentration similar to the concentration of the spiked sample. It is possible that not all NPDs will be in solution, while the 100% standard will contain compounds that are removed from the spiked sample during the work-up procedure. This could mean that the 100% standard will show low concentrations of NP(D)'s and thus too high recoveries.

The analysis of the blank samples were used in calculating limits of detection (LOD) and quantification (LOQ). LOD was defined as mean concentration in the blank samples + 3x standard deviation. LOQ was defined as mean concentration in the blank sample + 10x standard deviation. The results are given in Table A2.3

Table A2.3 Results from the analyses of blank samples.

Parameter	Concentration			Mean ± SD	LOD	LOQ
THC[1]	0.041	0.041	0.039	0.040 ± 0.0015	0.0445	0.055
Naphtalenes[2]	0.427	0.322	0.288	0.346 ± 0.0725	0.563	1.07
Phenanthrenes[2]	0.346	0.295	0.345	0.329 ± 0.0292	0.416	0.620
Dibenzothiophenes[2]	0.113	0.103	0.143	0.120 ± 0.0208	0.182	0.328
C_5-C_8 decalines[2]				2.38 ± 0.557	4.05	7.95
Naphthalene (2-ring)[2]				0.129 ± 0.0637	0.320	0.766
Acenaphtylene[2]				0.00145 ± 0.0000636	0.00164	0.00209
Acenaphthene[2]				0.00917 ± 0.00188	0.0148	0.0280
Fluorene[2]				0.00763 ± 0.000669	0.00964	0.0143
Phenanthrene[2]				0.00636 ± 0.000750	0.00861	0.0139
Anthracene[2]				- -	-	-
Sum 3-ring aromatics				0.0241 ± 0.00291	0.0328	0.0532
Fluoranthene[2]				0.00343 ± 0.000165	0.00393	0.00508
Pyrene[2]				0.00274 ± 0.000503	0.00425	0.00777
Benzo(a)anthracene[2]				-	-	-
Chrysene[2]				-	-	-
Sum 4-ring aromatics[2]				0.00618 ± 0.000611	0.00801	0.0123
Benzo(b/j/k)fluoranthene[2]				-	-	-
Benzo(a)pyrene[2]				-	-	-
Dibenzo(a,h)anthracene[2]				-	-	-
Sum 5-ring aromatics[2]				-	-	-
Benzo(ghi)perylene[2]				-	-	-
Indeno(1,2,3-cd)pyrene[2]				-	-	-
Sum 6-ring aromatics[2]				-	-	-

[1] concentration given in mg
[2] concentrations given in µg

Heavy metals

To test the accuracy of the method used for heavy metal analysis, the following standard reference sample material were used:

NBS 1646, Estuarine Sediment (National Bureau of Standards)
BCR 320, River Sediment (Community Bureau of Reference)

The analyses were carried out according to the Norwegian standard method 4770. The results are summarised in Table A2.4. Analysis of a blank sample is also reported.

Table A2.4: Values from analysis of reference material in mg/kg.

Sample	Hg	Cd	Pb	Fe	Zn	Cu	Ba
BCR 320	1.02	0.45	28.7	27420	116	41.1	102
Reference	1.03	0.533	42.3	44800[1]	142	44.1	530[1]
Reference NS[2]	1.0	0.48	29.0	29100	115	40.9	104
NBS 1646	<0.1	0.35	22.1	25862	120	14.4	40
Reference	0.063	0.36	28.2	33500	138	18	399[3]
Reference NS[2]	<0.1	0.34	20	26000	113	14.7	44
Blind	<0.1	<0.01	<0.2	<1	<1	<0.6	<0.5
Detection limit	0.1	0.01	0.2	1	1	0.6	0.5

[2]) not certified value
[2]) determined from previous Norsk Standard
[3]) not certified value - determined from previous analysis

To control the precision, 3 parallel samples were taken out from site 24 (Ref. A). The results are given in Table A2.5.

Table A2.5: Values from precision analyses of samples from reference site 24 (Ref. A) given in mg/kg.

	Hg	Cd	Pb	Fe	Zn	Cu	Ba
Mean	<0.1	0.100	11.99	15076	43.00	8.35	52.7
± SD	-	0.004	0.17	306	1.00	0.19	2.0

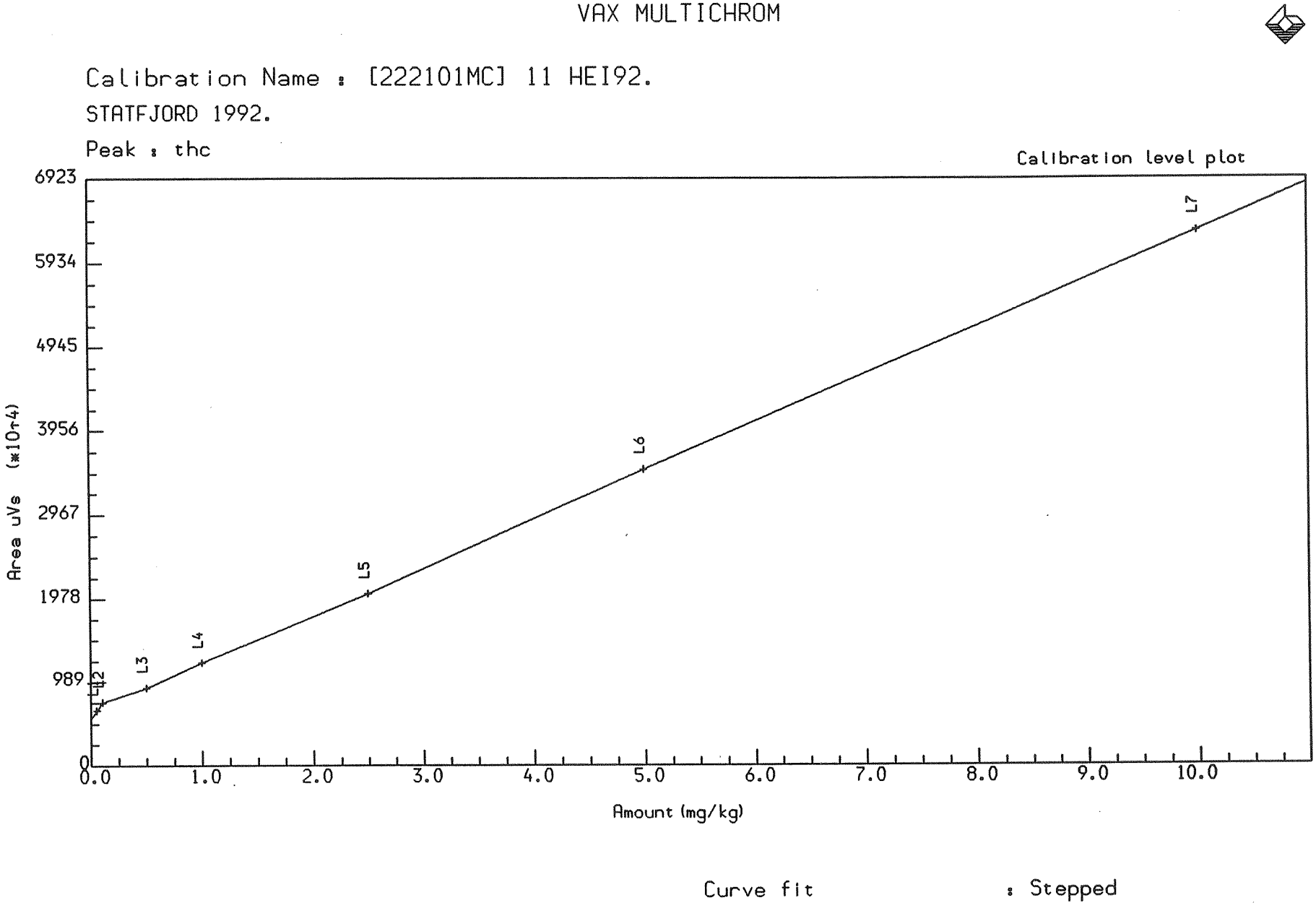

Figure A2.1 Stepped calibration curve used during calibration of THC from Heidrun 1992.

5. Macrofauna species abundances

Heidrun 1992	Stasjon	7					7 Sum
	Replikatnr.	G4	G5	G6	G7	G8	
PORIFERA							
Porifera indet		-	-	-	3	-	3
POLYCHAETA							
Cirratulidae indet		-	1	-	1	-	2
Clymenura sp		-	1	1	1	-	3
Lumbrineris sp		2	1	-	1	-	4
Marphysa belli (Audouin&Milne Edwards 1834)		-	1	-	-	-	1
Nephtys sp		1	-	-	-	-	1
Onuphis fiordica Fauchald 1974		3	4	9	3	2	21
Onuphis quadricuspis M.Sars 1872		1	5	2	-	2	10
Ophelina cf. norvegica Stoep-Bowitz 1945		-	1	-	-	-	1
Paramphinome jeffreysii (McIntosh 1868)		-	4	-	-	1	5
Phyllodocidae indet		-	-	1	-	-	1
Pista cristata (O.F.Mueller 1776)		-	-	1	-	-	1
Prionospio sp		-	1	1	-	-	2
Samythella neglecta Wollebaek 1912		-	-	1	-	-	1
Tharyx sp		-	1	1	-	-	2
Typosyllis cornuta (Rathke 1843)		-	-	-	1	-	1
GASTROPODA							
Alvania subsoluta (Aradas)		1	-	-	-	-	1
BIVALVIA							
Abra longicallus (Scacchi 1836)		-	1	3	1	1	6
Cuspidaria lamellosa (G.O.Sars)		-	-	1	-	-	1
Kelliella miliaris (Philippi 1844)		-	-	1	-	-	1
Limatula gwyni (Sykes)		-	-	1	-	-	1
Limopsis minuta (Philippi)		1	-	4	1	1	7
Nucula tumidula (Malm)		1	1	-	-	-	2
ISOPODA							
Cirolana borealis Lilljeborg		-	12	-	-	-	12
DECAPODA							
Munida sarsi Brinkmann		-	-	1	-	-	1
SIPUNCULIDA							
Onchnesoma sp		-	-	-	1	-	1
Onchnesoma steenstrupi Koren & Danielssen 1876		-	-	1	-	2	3
Sipunculida indet		-	-	-	-	1	1
		10	34	29	13	10	96

Heidrun 1992	Stasjon	14					14 Sum
	Replikatnr.	G4	G5	G6	G7	G8	
PORIFERA							
Porifera indet		-	-	-	-	1	1
POLYCHAETA							
Lumbrineris sp		-	1	-	1	1	3
Onuphis fiordica Fauchald 1974		-	-	4	2	4	10
Onuphis quadricuspis M.Sars 1872		1	-	-	1	-	2
Onuphis sp		-	1	-	-	-	1
Paramphinome jeffreysii (McIntosh 1868)		1	-	-	-	-	1
Scolelepis tridentata Southern 1914		1	-	-	-	-	1
Typosyllis cornuta (Rathke 1843)		-	-	-	-	1	1
BIVALVIA							
Abra longicallus (Scacchi 1836)		-	-	-	-	1	1
Nucula tumidula (Malm)		-	1	-	-	-	1
LEPTOSTRACA							
Nebalia bipes Fabricius		-	-	-	-	1	1
SIPUNCULIDA							
Onchnesoma steenstrupi Koren & Danielssen 1876		-	-	-	-	1	1
		3	3	4	4	10	24

Heidrun 1992	Stasjon	17					17 Sum
	Replikatnr.	G4	G5	G6	G7	G8	
PORIFERA							
Porifera indet		-	-	1	-	-	1
POLYCHAETA							
Harmothoe sp		-	-	-	-	1	1
Lumbrineris sp		2	-	1	-	-	3
Maldanidae indet		-	-	1	-	-	1
Myriochele sp		-	-	-	-	1	1
Nephtys incisa Malmgren 1865		1	-	-	-	-	1
Onuphis fiordica Fauchald 1974		2	3	2	4	3	14
Onuphis quadricuspis M.Sars 1872		-	-	1	2	4	7
Ophelina sp		-	-	-	1	1	2
Orbinia norvegica (M.Sars 1872)		-	-	-	1	-	1
Paramphinome jeffreysii (McIntosh 1868)		-	-	1	1	2	4
Scolelepis sp		-	-	-	-	1	1
Sigalioninae indet		-	-	1	-	-	1
Spiochaetopterus typicus M.Sars 1856		-	-	-	1	1	2
BIVALVIA							
Abra longicallus (Scacchi 1836)		-	-	-	-	2	2
Bathyarca pectunculoides (Scacchi 1836)		-	-	-	-	1	1
Delectopecten vitreus (Gmelin 1789)		-	-	-	1	-	1
Kelliella miliaris (Philippi 1844)		-	-	-	1	-	1
Limopsis minuta (Philippi)		-	-	2	5	1	8
Nucula tumidula (Malm)		1	-	-	2	2	5
Parvicardium scabrum (Philippi)		1	-	-	-	-	1
Yoldiella cf. acuminata (Jeffreys)		-	-	1	-	-	1
Yoldiella fraterna Verrill & Bush		-	-	-	-	1	1
ISOPODA							
Cirolana borealis Lilljeborg		-	-	-	-	1	1
AMPHIPODA							
Lysianassidae indet		-	-	1	-	-	1
Orchomenella sp		-	-	1	-	-	1
Tryphosa hoeringii Boeck		-	-	1	-	-	1
SIPUNCULIDA							
Onchnesoma steenstrupi Koren & Danielssen 1876		-	-	-	2	1	3
ECHINODERMATA							
Amphilepis norvegica Ljungman		-	-	-	1	-	1
Amphiura chiajei Forbes		-	1	-	-	-	1
ASCIDIACEA							
Molgulidae indet		-	-	-	1	2	3
		7	4	14	23	25	73

Heidrun 1992	Stasjon	21					21 Sum
	Replikatnr.	G4	G5	G6	G7	G8	
CNIDARIA							
Isidella lofotensis		-	-	-	1	-	1
POLYCHAETA							
Clymenura sp		-	-	2	-	-	2
Ditrupa arietina (O.F.Mueller 1776)		-	-	-	1	-	1
Eunicidae indet		-	-	1	-	-	1
Glyceridae indet		-	-	-	1	-	1
Harmothoe sp		-	-	-	-	1	1
Lumbrineris sp		1	-	-	1	-	2
Maldanidae indet		2	-	-	-	1	3
Nephtys sp		-	-	1	-	-	1
Onuphis fiordica Fauchald 1974		1	-	-	-	-	1
Onuphis quadricuspis M.Sars 1872		-	1	-	1	1	3
Ophelina sp		-	1	-	-	-	1
Orbinia norvegica (M.Sars 1872)		2	-	-	-	-	2
Paramphinome jeffreysii (McIntosh 1868)		-	1	-	1	4	6
Spiochaetopterus typicus M.Sars 1856		-	-	-	1	-	1
BIVALVIA							
Abra longicallus (Scacchi 1836)		2	-	1	1	1	5
Astarte cf. acuticostata Friele		-	-	1	-	-	1
Bathyarca pectunculoides (Scacchi 1836)		-	-	-	2	-	2
Limopsis minuta (Philippi)		2	-	-	-	-	2
Nucula tumidula (Malm)		2	-	-	-	1	3
Thyasira ferruginea (Forbes)		-	-	1	-	-	1
SCAPHOPODA							
Entalina quinquangularis (Forbes)		-	-	-	-	1	1
TANAIDACEA							
Apseudes spinosus (M.Sars)		1	-	-	-	-	1
ISOPODA							
Cirolana borealis Lilljeborg		-	-	1	1	-	2
AMPHIPODA							
Neohela monstrosa (Boeck)		1	-	-	-	-	1
SIPUNCULIDA							
Golfingia cf. minuta (Keferstein)		-	-	-	-	1	1
Golfingia sp		-	-	-	-	1	1
Onchnesoma squamatum (Koren & Danielssen)		-	-	-	-	1	1
Onchnesoma steenstrupi Koren & Danielssen 1876		1	-	-	-	1	2
		15	3	8	11	14	51

Heidrun 1992	Stasjon	23					23 Sum
	Replikatnr.	G4	G5	G6	G7	G8	
PORIFERA							
Porifera indet		-	-	1	1	2	4
CNIDARIA							
Kophobelemnon stelliferum (O.F.Mueller)		-	-	-	-	1	1
POLYCHAETA							
Lumbrineris sp		1	3	-	2	2	8
Marphysa belli (Audouin&Milne Edwards 1834)		-	-	-	-	1	1
Notomastus latericeus Sars 1851		-	-	-	-	1	1
Orbinia norvegica (M.Sars 1872)		-	-	1	-	-	1
Paramphinome jeffreysii (McIntosh 1868)		-	1	-	-	-	1
Spiochaetopterus typicus M.Sars 1856		-	-	-	-	1	1
GASTROPODA							
Lunatia montagui (Forbes)		1	-	-	-	-	1
BIVALVIA							
Abra longicallus (Scacchi 1836)		-	-	-	1	1	2
Bathyarca pectunculoides (Scacchi 1836)		-	1	-	-	-	1
Nucula tumidula (Malm)		1	1	-	-	1	3
Yoldiella cf. acuminata (Jeffreys)		-	1	-	-	1	2
AMPHIPODA							
Eriopisa elongata Bruzelius		1	1	-	-	-	2
SIPUNCULIDA							
Golfingia sp		-	1	-	-	-	1
Onchnesoma steenstrupi Koren & Danielssen 1876		2	-	-	-	2	4
ECHINODERMATA							
Ophiuroidea indet		-	-	-	-	1	1
		6	9	2	4	14	35

Heidrun 1992	Stasjon	24										24 Sum
	Replikatnr.	G10	G11	G12	G13	G14	G15	G6	G7	G8	G9	
POLYCHAETA												
Amage auricula Malmgren 1865		-	-	-	-	-	1	-	-	-	-	1
Ampharetidae indet		-	-	-	-	-	-	1	-	-	-	1
Amythasides macroglossus Eliason 1955		-	-	-	-	-	-	-	1	-	-	1
Goniada maculata Oersted 1843		-	-	-	-	-	-	-	-	1	-	1
Harmothoe sp		-	-	-	-	-	1	-	-	-	-	1
Lumbrineris sp		-	1	-	-	1	2	-	3	-	1	8
Onuphis fiordica Fauchald 1974		1	-	1	-	1	-	-	-	2	-	5
Onuphis quadricuspis M.Sars 1872		1	1	1	1	-	-	-	-	1	-	5
Ophelina sp		-	-	-	-	-	-	-	2	1	-	3
Paramphinome jeffreysii (McIntosh 1868)		-	-	-	-	-	-	-	1	-	-	1
Spiochaetopterus typicus M.Sars 1856		-	-	-	-	-	-	-	2	-	-	2
BIVALVIA												
Abra longicallus (Scacchi 1836)		-	-	-	-	-	1	-	-	-	-	1
Astarte cf. acuticostata Friele		-	-	-	-	-	-	-	-	-	1	1
Kelliella miliaris (Philippi 1844)		-	-	-	-	-	-	-	1	-	-	1
Nucula tumidula (Malm)		-	-	-	-	-	-	-	1	-	-	1
Yoldiella fraterna Verrill & Bush		-	-	-	-	-	-	-	1	-	-	1
Yoldiella lucida (Loven 1846)		-	-	-	-	-	-	-	1	-	-	1
TANAIDACEA												
Apseudes spinosus (M.Sars)		-	-	-	-	-	-	-	-	1	-	1
AMPHIPODA												
Eriopisa elongata Bruzelius		-	-	-	-	-	-	1	-	1	-	2
SIPUNCULIDA												
Golfingia cf. minuta (Keferstein)		-	-	-	-	-	-	-	1	-	-	1
Golfingia sp		1	-	-	-	-	-	-	-	-	-	1
Onchnesoma squamatum (Koren & Danielssen)		-	-	-	-	-	-	-	1	-	-	1
Onchnesoma steenstrupi Koren & Danielssen 1876		1	-	-	-	-	2	-	-	-	-	3
ASCIDIACEA												
Molgulidae indet		-	-	-	-	-	-	-	1	-	-	1
		4	2	2	1	2	7	2	16	7	2	45