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Monitoring environmental impacts of washed OBM drill cuttings discharged on the Dutch continental shelf, 1989:

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Sediment analysis and bioaccumulation

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CONTENTS

SAMENVATTING EN CONCLUSIES

Dit rapport beschrijft het onderzoek naar sedimentverontreinigingen en naar de bioaccumulatie van contaminanten in het kader van het "environmental impact monitoring" programma ten aanzien van "offshore" booractiviteiten op het Nederlandse Continentale plat in 1989. Het programma was in 1989 toegespits op vaststelling van de efficientie van de nieuwe behandelingstechniek (n.l. het "wassen" van boorgruis), opgezet om de milieuschade door boorgruislozingen te reduceren.

Sedimentmonsters werden verzameld op een transect bij de verlaten boorlokaties L-5-5 en L-9-4, die respectievelijk gelegen zijn in en nabij een ecologisch belangrijk sedimentatiegebied, het zgn. "Friesche Front". Op beide lokaties hadden in 1988 lozingen van gewassen boorgruis plaatsgevonden. Sedimenten van nabij de lokatie L-5-5 werden ook in een "boxcosm-bioassay" gebruikt.
Nabij de lokatie L-13-Fd-103 werd voorts een "Actieve Biologische Monitoring" (ABM)-programma uitgevoerd in een periode dat daar gewassen boorgruis werd geloosd.

De textuur van het sediment bij lokatie L-5-5 is zeer fijn, speciaal in vergelijking met het relatief grove sediment bij lokatie L-9-4. Op de lokatie L-9-4 was dichtbij het lozingspunt (afstand 25-100 m) het aandeel van de grove fractie (>500 µm) iets verhoogd ten opzichte van verder verwijderde monsterpunten. Op de lokatie L-5-5 werden geen verschillen in de korrelgrootte samenstelling waargenomen.

Het bariumgehalte van het sediment weerspiegelt op beide lokaties duidelijk de verspreiding van het geloosde boorgruis. Tot op 1000 m in de richting van de reststroom ter plekke werden verhoogde bariumgehalten op basis van de korrelgrootte fractie <63 µm gemeten. In andere richtingen werden lagere gehalten van barium gemeten. Op beide lokaties werden op de monsterpunten 100 m van het lozingspunt verhoogde bariumgehalten tot 30 cm diepte in het sediment aangetroffen.

Het oliegehalte van de sedimentmonsters is zeer goed lineair gecorreleerd met het bariumgehalte. Het relatieve olieverontreinigingsniveau nabij L-5-5 en L-9-4 is van overeenkomstige aard en laag te noemen in vergelijking met voorheen bestudeerde lokaties waar niet-gewassen boorgruis werd geloosd. Alle olie-analyses toonden duidelijke dat de "UCM"-fractie de beste indicator is voor aan de lozingen van OBM-gruis gerelateerde

olieverontreiniging. Dit is te danken aan de lage achtergrondniveaus. Een verhoging boven achtergrondniveaus is herkenbaar op duidelijk grotere afstanden dan andere oliebestanddelen.
Verondersteld wordt dat binnen tijdreeksen de "olie"/"barium"-verhouding een index kan zijn voor de afbraak van olie, gezien het inerte karakter van barium. De verhouding kan ook gebruikt worden om de relatieve olieverontreinigingsniveaus als gevolg van boorgruislozingen te verifiëren.

Verschillen in de chemisch-analytische uitkomsten met betrekking tot sediment monsters die respectievelijk met een "Van Veen"-happer en met een boxcorer werden verzameld worden besproken in relatie tot de heterogene distributie van "oil based" boorgruis in mariene sedimenten en methodologische problemen.

De sedimenten in de "boxcosms" vertoonden duidelijk een trend van afnemende olieconcentraties met toenemende afstand tot het lozingspunt. De concentraties van olie die accumuleerde in de toetssoorten *Amphiura filiformis* (brokkelster) en *Echinocardium cordatum* (zeeklit) blootgesteld aan sedimenten verzameld op 25 m en 250 m afstand van het lozingspunt overtroffen die in het weefsel van dezelfde soorten die aan referentie sedimenten waren blootgesteld, maar toonden onderling geen consistente verschillen. De referentiesedimenten werden op 5000 m van het lozingspunt verzameld.
De stekelhuidigen *A. filiformis* en *E. cordatum* worden niet beschouwd als goede indicatorsoorten voor het kwantificeren van de blootstelling van biota aan olie in sedimenten aan de hand van bioaccumulatie metingen. Er wordt beargumenteerd dat Actieve Biologische Monitoring (ABM) met de mossel *Mytilus edulis* daartoe meer geschikt is.
Op de lokatie L-13-Fd-103 overschrijdt de olieconcentratie in ABM-mosselen uit de oppervlaktelaag die in ABM-mosselen van dieper water nabij de zeebodem tot op een afstand van 500 m. Op 1000 m afstand is dit patroon omgedraaid. Dit indiceert een tendens van olie, die uit het geloosde boorgruis vrijkomt, om nabij het lozingspunt naar de oppervlakte te drijven. Ook in mosselweefsel is de "UCM" fractie de beste indicator voor lozingen van "OBM"-gruis. Verhoogde gehalten werden aangetroffen tot op 1000 m van het lozingspunt in de richting van de reststroom. Deze afstand is minder dan gevonden bij L-4-a, alwaar niet-gewassen gruis werd geloosd en verhoogde gehalten tot op 5000 m voorkwamem (1988). De lozing van gewassen boorgruis leidde niet tot effecten op de groei.
Daar de meeste effecten zijn waargenomen tot op 1000 m van het lozingspunt en de 5000 m monsterpunten geen enkel effect vertonen, wordt ten zeerste aanbevolen in

toekomstige meetprogramma's één of meer meetpunten tussen 1000 en 5000 m van het lozingspunt te situeren.

De informatie die door middel van deze studie werd verkregen, leidt tot de volgende conclusies:

1. In vergelijking met lozingen van niet-"gewassen" boorgruis leidt het "wassen" van gruis tot een verminderde blootstelling van mariene organismen aan olie.

2. Op de lokaties L-5-5 en L-9-4 werden verhoogde concentraties van barium en "totaal"-olie aangetroffen in sedimenten tot op 1000 m in de richting van de reststroom ter plekke. Verhoogde UCM-concentraties zijn wellicht tot op grotere afstanden te ontdekken, maar niet op 5000 m van het lozingspunt.

3. Op de lokatie L-13-Fd-103 werden verhoogde, door ABM-mosselen geaccumuleerde, olieconcentraties aangetroffen.

4. Geloosd boorgruis wordt vooral in de richting van de reststroom verspreid en kan op 100 m van het lozingspunt tot op 30 cm diepte in het sediment worden aangetroffen.

5. De concentratie van de "UCM"-oliefractie in het sediment en de bariumconcentratie uitgedrukt op basis van de sedimentfractie < 63 μm lijken de beste chemische indicatoren te zijn om de verspreiding van boorgruis en mud in ruimte en tijd te bestuderen.

6. De verhouding "olie"/"barium" is een bruikbare parameter om het relatieve niveau van olieverontreiniging door geloosd boorgruis te schatten. De verhouding is tevens een potentiële index voor de meting van olie-afbraak aan de hand van monsters in tijdreeksen als gevolg van het inerte karakter van barium.

7. Er is geen indicatie verkregen dat de mobiliteit van olie uit geloosd boorgruis door "wassen" veranderd, of dat de mobiliteit van in sedimenten van het "Friese Front" geaccumuleerde olie van geloosd boorgruis (L-5-5) verschilt van die geaccumuleerd in "Oestergronden"-sediment (F-18-9).

8. De stekelhuidigen, *Amphiura filiformis* en *Echinocardium cordatum*, zijn geen goede indicatoren voor kwantitatieve bioaccumulatie studies die erop gericht zijn om de

werkelijke blootstelling van biota aan olieverontreiniging in het sediment vast te stellen.

9. De mossel, *Mytilus edulis* is een goede indicator voor gebruik in "Actieve Biologische Monitoring" (ABM) programma's waarmee de blootstelling aan olie in de veldsituatie wordt gemeten.

10. De analyse van sedimentmonsters die met een "Van Veen"-happer zijn verzameld geeft resultaten die verschillen van analyseresultaten van sedimentmonsters die met een boxcorer zijn verkregen. Dit is te wijten aan een heterogene verspreiding van boorgruis, en problemen met de bemonstering van de meest verontreinigde toplaag met de "Van Veen"-happer methode.

11. Het wordt sterk aanbevolen om in toekomstige monitoringsprogramma's monsterpunten tussen 1000 en 3000 m van het lozingspunt op te nemen.

SUMMARY AND CONCLUSIONS

This report describes the sediment contaminant and bioaccumulation studies within the environmental impact monitoring of offshore drilling activities at the Dutch Continental Shelf in 1989. The 1989 program was focused on the efficiency of a new technique for treatment of cuttings (viz. washing of the cuttings) in reducing the environmental impacts of cuttings discharges.

Sediments were sampled along a transect around the abandoned drilling locations L-5-5 and L-9-4, located in respectively near an ecologically important sedimentation region called "Frisian Front" area. At both locations washed drill cuttings had been discharged in 1988.
Sediments collected near the location L-5-5 were also used in a boxcosm-bioassay.
An Active Biological Monitoring (ABM) program with mussels has been performed around the drilling location L-13-Fd-103, during the discharges of washed drill cuttings.

The texture of the sediment around location L-5-5 is indeed very fine, especially compared to the relatively coarse sediment around location L-9-4. At location L-9-4 the sediment near the discharge point (25-100 m) had a slightly elevated coarse fraction (>500 μm). At location L-5-5 no changes in sediment texture was observed.

The barium content of the sediment clearly reflects the distribution of discharged drill cuttings at both stations. Elevated barium levels, expressed on basis of the sediment fraction < 63 μm, have been measured up to 1000 m in the direction of the residual currents. Lower barium levels were found in other directions. At both locations elevated barium levels were found down to a depth of 30 cm in the sediment at the stations at 100 m distance from the discharge point.

The oil content of sediments shows a very good linear correlation with the barium content. The relative oil pollution level around L-5-5 and L-9-4 is similar and low compared to previously monitored locations where unwashed cuttings were discharged. All oil analyses clearly showed that the "UCM" fraction is the best indicator for oil pollution related to discharges of OBM-cuttings, due to low background levels. An elevation above background levels is recognizable at distinctly larger distances than other oil compounds or barium.

It is hypothesized that for time series the "oil"/"barium" ratio could be an index for oil breakdown, due to the inertia of barium. The ratio can also be used to verify the relative oil pollution level of discharged cuttings.

Differences in the results of chemical analysis of samples collected with a van Veen grab and those collected with a boxcorer, are discussed in relation to the heterogenous distribution of oil based cuttings in marine sediments and methodological problems.

The sediments in the boxcosms clearly showed a trend of decreasing oil concentrations at increasing distance from the discharge point. The oil concentration accumulated in the test species *Amphiura filiformis* (brittlestar) and *Echinocardium cordatum* (sea-potato) exposed to sediments collected at 25 and 250 m from the drilling point exceeded that of the same species exposed to reference sediments (collected 5000 m from the drilling point), but are among themselves not consistently clearly different.
The echinoderms *Amphiura filiformis* and *Echinocardium cordatum* are judged to be no good indicator species for bioaccumulation studies, directed to the assessment of the exposure of biota to oil in sediments. It is argued that with Active Biological Monitoring (ABM) the mussel *(Mytilus edulis)* should be a better indicator.

Up to 500 m from the discharge point at location L-13-Fd-103, the oil concentration of ABM-mussels in surface waters exceeds that of ABM-mussels from deeper water layers near the seabed. At 1000 m this is reversed, indicating a tendency of oil, that is released from the discharged cuttings, to float towards the surface water near the discharge point. Also in the mussel tissues the "UCM" fraction is the best indicator for discharges of OBM-cuttings. Elevated levels were found up to 1000 m from the drilling point in the residual current direction, which is less compared to location L-4-a where unwashed cuttings were discharged and elevated levels have been found up to 5000 m .The growth of mussels is not affected by the discharges of washed drill cuttings.
Since most effects have been observed up to 1000 m from the discharge point, and the 5000 m stations do not show any effect, it is strongly recommended to include one or more stations between 1000 and 5000 m from the discharge point in future monitoring programs.

From all the information obtained in this study we can conclude that:

1. Washing of cuttings results in a reduced exposure of marine biota to oil from discharged cuttings, in comparison to discharges of unwashed cuttings.

2. At locations L-5-5 and L-9-4 elevated barium and total oil levels were found in sediments up to 1000 m along the residual current direction. Enhanced UCM-concentrations might be detectable at larger distances, but not at 5000 m.

3. At location L-13-Fd-103 elevated bioaccumulation levels of oil were found in the ABM-mussels.

4. Discharged cuttings are mainly distributed along the residual current direction, and can be found down to a depth of 30 cm into the sediment at 100 m from the discharge point.

5. The concentration of the "UCM" oil-fraction in sediment, and the barium concentration expressed on basis of the sediment fraction < 63µm seem to be the best indicators for monitoring the distribution of (oil based) drill cuttings.

6. The "oil"/"barium" ratio is a useful parameter to estimate the relative level of oil pollution of discharged cuttings, and a potential index for the assessment of oil breakdown from time series, due to the inertia of barium.

7. There is no indication that the mobility of oil from discharged cuttings is affected by washing, or that the mobility of oil from discharged cuttings accumulated in "Frisian Front" sediments (L-5-5) is different from that of "Oysterground" sediments (F-18-9).

8. The echinoderms *Echinocardium cordatum* and *Amphiura filiformis* are no good indicators for quantitative bioaccumulation studies directed to assess the actual exposure of biota to oil pollution from sediments.

9. The mussel *Mytilus edulis* is a good indicator for Active Biological Monitoring of oil exposure in the field situation.

10. Analysis of sediment samples collected with a van Veen grab gives results that differs from those collected with a boxcorer, due to heterogeneity in the distribution of cuttings and methodological problems with the "Van Veen" grab sampling.

11. It is strongly recommended to include sampling stations between 1000 and 5000 m from the discharge point in future monitoring programs.

1. INTRODUCTION

The North Sea countries have committed themselves to assess and monitor the environmental effects of offshore oil- and gas exploration and exploitation activities (Paris Commission). Most attention is paid to the discharges of drill cuttings. These drill cuttings are contaminated with residuals of drilling muds, which are used in the drilling process. Some of the muds are based on oil, that is proved to be toxic for marine life. Due to fast technological development more sophisticated and less toxic muds came into use. Moreover, the cuttings became less contaminated with muds due to the application of newly developed, more efficient separation techniques.
These developments are promoted by tightening up of regulations with respect to the type of mud that is allowed for use, and to the maximum allowable oil content of the discharged cuttings. Since 1988, drill cuttings are discharged after a washing procedure reducing the oil content.

Numerous monitoring studies have been performed around drilling locations in the North Sea to assess the accumulation of cuttings, and adherent oil, in the sea-bed and the biological consequences (reviews by Bedborough *et al.*, 1987; Kingston, 1987; Davies *et al.*, 1989; Reiersen *et al.*, 1989 and Scholten *et al.*, 1989).
Since 1985 drilling activities at the Dutch Continental Shelf have been monitored for environmental impacts by the TNO Laboratory for Applied Marine Research (sediments, bioaccumulation in mussels) and the Netherlands Institute for Sea Research (biological effects), on behalf of the Dutch Ministeries of Economical Affairs (State Supervision of Mines); of Transport and Public Works (North Sea Directorate) and of Public Health, Planning and Environment (Water Directorate).

The objectives of the Dutch monitoring program have been defined as follows:

1. To develop and optimize suitable monitoring techniques for assessment of the distribution of drill cuttings and their biological effects.
2. The assessment of the scale and trends (both spatial and temporal) of chemical and biological effects around offshore installations.
3. To study the effects of secondary contamination (i.e. redistribution of contaminated sediments and the release of oil from the sediment to the water).

4. To study the difference in effects of water based muds (WBM) versus oil based muds (OBM).
5. To compare the effects in areas with a different type of sedimentation (net-sedimentation, -transition and -erosion areas).
6. To establish field dose-effect relations in experimental setups using undisturbed contaminated sediments derived from the drilling location at various distances.

The data obtained in the period 1985-1988 have been reported as follows:

	Sediment, Mussels (TNO)	**Biological effects (NIOZ)**
1985	Kuiper *et al.*, 1986	Mulder *et al.*, 1987
1986	v/h Groenewoud *et al.*, 1988	Mulder *et al.*, 1988
1987/88	v/h Groenewoud, 1991	Daan *et al.*, 1990

Zevenboom *et al.* (1989) have reviewed the Dutch studies for the period 1985-1987. De Jong *et al.* (1991) reviewed the results for 1988-1990.
This report describes the 1989 studies on sediment contamination and bioaccumulation of oil. The associated biological effects are reported by Daan *et al.* (1991).

In the 1989 program, work of former years was continued, aimed at the development, evaluation and selection of appropriate monitoring techniques for environmental impact assessment. More specifically, the 1989 program was focused on the efficiency of a new technique for treatment of oil contaminated cuttings (viz. washing of the cuttings) in reducing the environmental impacts of cuttings discharges. This treatment had become obligatory from 1988 on the Dutch part of the Continental Shelf.

Sediments were sampled along transects around two drilling locations where washed drill cuttings had been discharged. The drilling locations L-5-5 and L-9-4 are located in the middle respectively somewhat south of an ecologically important region of the North Sea called the "Frisian Front" area. The "Frisian Front" region is a transition zone between sand an silty sediments which is biologically enriched due to high sedimentation rates of organic materials (de Gee *et al.*, 1991), and is part of the Dutch "environmental zone". The locations were drilled in the autumn of 1988 and abandoned afterwards, without a platform left. The sediments of both locations have been used for physical monitoring (grain size)and chemical monitoring (barium and oil concentrations). Biological monitoring (species diversity and fauna abundance) was restricted to location L-5-5. The latter is reported in Daan *et al.* (1991). Similar sediment monitoring surveys have been performed at locations where unwashed cuttings were discharged (table 1).

Grainsize composition characteristics of the sediment around the drilling sites are particularly important for the determination of the heterogeinity of sediments at a certain location on which variation in biological survey data might depend. Moreover, it might be useful to determine the distribution of coarse cutting particles. The small mud fraction is hardly detectable as fraction < 63 µm. However, the barium content is a better tracer for the distribution of muds. It is not degradable and barite ($BaSO_4$) is used in large amounts in many mud compositions.
The oil concentration is measured because this component of drill cuttings is assumed to be responsible for toxic effects on biota.

Intact sediment cores collected at location L-5-5 were used for a controlled bioassay with the natural infauna and with added *Echinocardium cordatum, Amphiura filiformis*, *Corystes cassivelaunus* and *Nucula turgida* in boxcosms under laboratory conditions. The aim was to quantify dose-effect relations and to select appropriate testspecies for bioaccumulation studies in order to monitor sediment pollution. The chemical analyses, meant to quantify the oil concentration in sediment and the oil accumulation in the testspecies *Echinocardium cordatum* and *Amphiura filiformis* are reported here. The corresponding biological effects (behaviour and mortality) are reported by Daan *et al.* (1991).

During the drilling at location L-13-Fd-103, an Active Biological Monitoring (ABM) program with mussels (*Mytilus edulis*) was performed, in order to assess the bioaccumulation of oil originating from discharged washed cuttings. Such ABM's have been performed before, at locations where unwashed cuttings were discharged (table 1).

Mussels are very useful indicator organisms. Each adult mussel is filtering about 50 litres of seawater per day; they show no significant (active) breakdown of oil compounds; they allow reliable chemical analysis and there are good references available. Furthermore, they are easy to handle, immobile and can be exposed under various conditions or at several sites.

The "fingerprint" of oil compounds demonstrated in the mussel tissue reflects the original oil exposure, so that a particular source can be distinguished from background exposures (Kuiper, 1986; van het Groenewoud *et al.*, 1988, van het Groenewoud, 1990).

Table 1. *An overview of sediment and mussel monitoring studies at drilling locations in the Dutch Continental Shelf.*

Year	Sediment	Mussels
1985	K-12a, P-6b, P-15a	K-12b, K-12d
1986	K-12a, L-4a, F-18-8	L-4a
1987	K-12a, L-4a	K-12a
1988	K-12a, F-14-6, F-18-9	
1989	L-5-5, L-9-4	L-13-Fd-103

2. METHODS

2.1 Field survey

The abandoned locations L-5-5 and L-9-4 (Fig. 1) have been monitored in the period May 15-25, 1989. With the help of "side scan" sonar, navigation by means of "dynamic positioning" and underwater video-cameras, the research vessel "RV Mitra" was positioned accurately (± 10 m) at the discharge point and the desired monitoring stations along a cross-shaped transect. One axis of the transect runs parallel with the residual current direction, the other axis perpendicular to the first one (Fig. 2). The outermost stations, at 5 km from the drilling locations, were assumed to represent a reference situation.

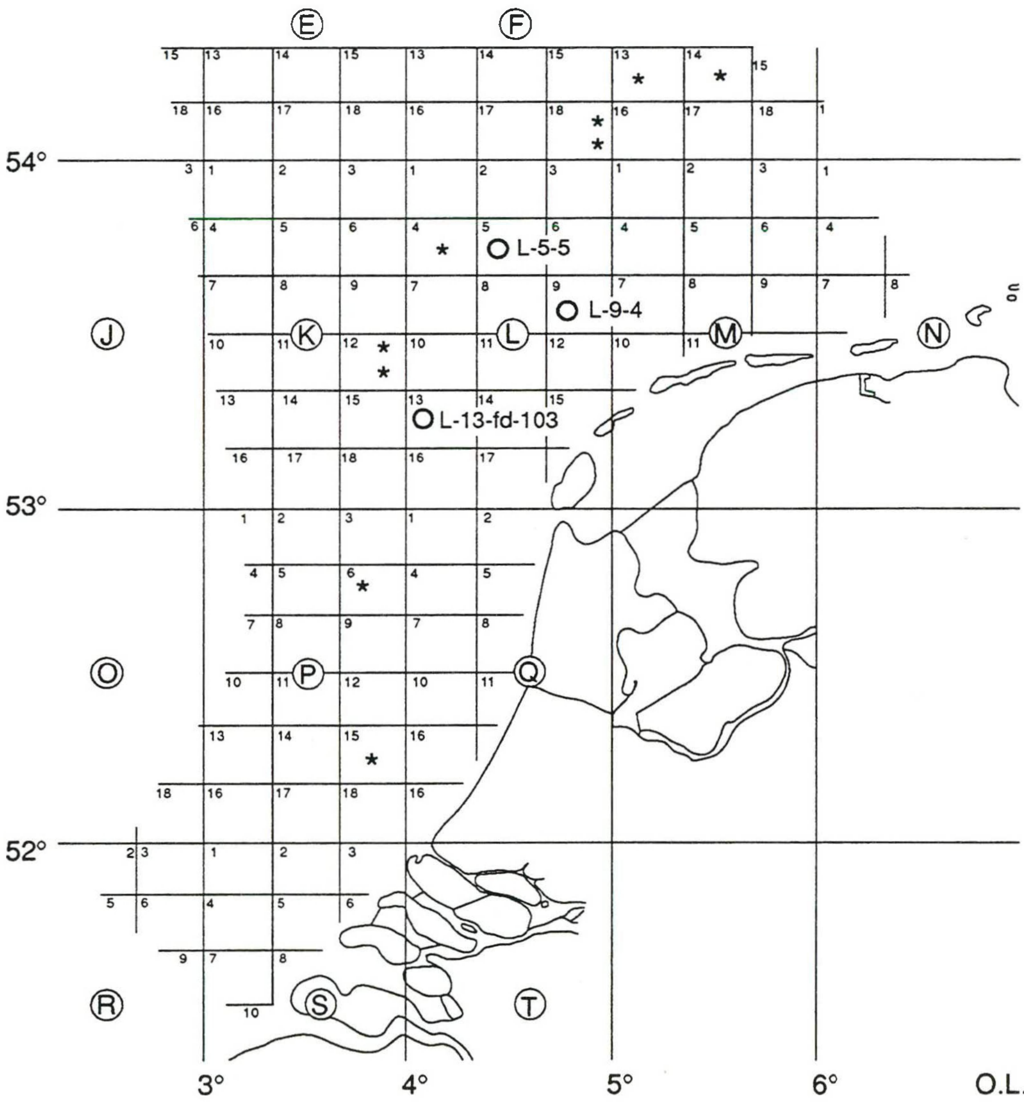


Figure 1: *Positions of the drilling locations that have been monitored in 1989 (o) and before (*).*

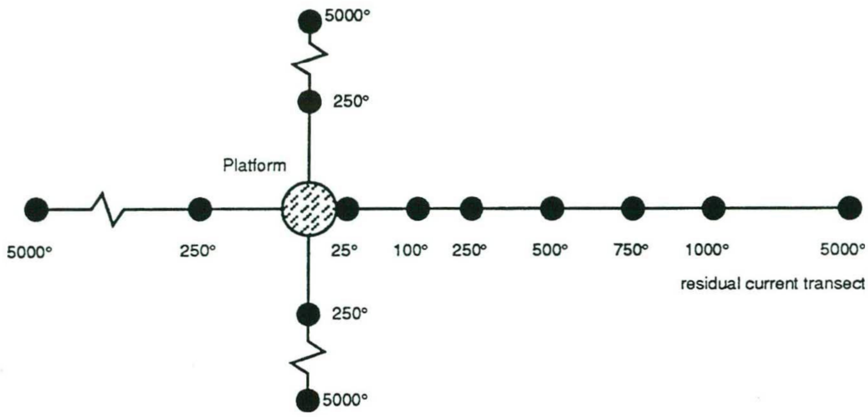


Figure 2: *Positions of the sampled stations (distance to drilling location in m).*

At all stations 10 sediment samples were collected with a 0.2 m^2 van Veen grab. From each grab sample 2 subsamples were obtained using a tube core sampler with an internal diameter of 25 mm and a length of ca. 10 cm. The subsamples were pooled and mixed thoroughly, packed in glass with teflon-lined caps and immediately frozen to -20 °C until analysis.
At one station (100 m, residual current) a sediment sample was taken with a 0.071 m^2 Reineck boxcorer. Subsamples were taken for the determination of a depth profile (0-2 cm, 2-10 cm and 25-30 cm).

During the collection of boxcosms (see section 2.2) in the period September 1-5, 1989, all stations at location L-5-5 have been similarly resampled for barium and oil analysis, in order to verify the data collected from the earlier monitoring session in May 1989.

All sediment samples were analyzed for grainsize composition (see appendix A1 for analytical procedures) and barium content (see appendix A2 for analytical procedures). On a selection of samples (depending on the outcome of the barium content) oil concentrations were measured (see appendix A3 for analytical procedures).

2.2 Boxcosm experiment

A bioassay was performed in boxcosms (50x50x60 cm) containing undisturbed natural sediments, collected with a Scripp's-corer at three stations along the residual current tran-

sect of location L-5-5 (discharges from discharge point: 25 m, n = 5; 250 m, n = 4; and 5000 m, n = 5).
The intact sediment cores were held in stainless steel boxes, furnished with a mica-teflon coating, placed in an indoor basin and incubated under dark conditions. During the test-period (September 1 - December 6, 1989) the incubation temperature was gradually lowered from 16 °C to 11 °C, according to *in situ* temperatures. The water on top of the cores was continuously replaced with filtered and O_2-saturated Wadden Sea water. The boxcosms were stocked with two echinoderms *(Echinocardium cordatum*, 4 cores per station; *Amphiura filiformes*, 2 cores per station), a mollusc *(Nucula turgida*, 4 cores per station) and a crustacean *(Corystes cassivelaunus*, separately in the 5th cores of the stations 25m and 5000m). A more detailed description of the boxcosm experiments is given by Daan *et al.* (1991).
At the end of the experiments the sediments were sampled for the determination of oil concentrations following identical procedures as used in the field surveys (section 2.1). From each boxcosm (except those stocked with *Corystes cassivelaunus*) 10 sediment subsamples were obtained using the 25 mm tube core sampler with a length of ca. 10 cm. The subsamples were pooled and mixed thoroughly, packed in glass with teflon-lined caps and immediately frozen to -20 °C until analysis.

The test species were recollected by sieving the sediments and the number of surviving animals was determined. Random selected living individuals of *Echinocardium* and *Amphiura* were used for determination of bioaccumulated oil. From the indiviuals of *Echinocardium* the tissues of the gonads were removed from the shells and analysed, while from *Amphiura* the whole individual was used for analyses. The tissues were homogenised using a titanium modified Ultra Turrax homogeniser. Subsamples of the homogenates were used for separate dry- and ashfree dry weight determinations (De Kock, 1983) and oil analyses (see appendix A4 for technical procedures).

2.3 Active Biological Monitoring

In an ABM program, mussels of a certain length class are selected from a relatively unpolluted standard stock. The organisms are divided at random in similar groups, and these samples are exposed at the selected monitoring locations. After a certain exposure period (4-8 weeks) the samples of organisms are recollected and the bioaccumulation levels of pre-selected chemicals are determined. Advantages of this ABM-technique are a great discrimination power, standardisation and a free choice of monitoring locations.

An ABM program was carried out in the periode June 1 - July 24, 1988 around the drilling platform L-13-Fd-103. On May 30, 1989 mussels *(Mytilus edulis)* were obtained with the assistance of the Fishery Inspection Service from a natural stock in the Eastern Scheldt basin. Adult individuals in the length class 4-5 cm were selected and randomly pooled in 18 samples of 100 specimens, packed in polythene baskets. One sample was kept behind to be analyzed as initial reference.

The baskets were fixed in stainless steel cages. Each cage contained 2 baskets with 50 specimens per basket. The cages, linked to buoys, were exposed at two depths: 3 meter below the watersurface and 0.5 - 1 meter above the seabed respectively. The M.V. "Breeveertien" of the Directorate Shipping and Maritime Affairs of the Ministry of Transport and Public Works placed special temporal buoys and anchorstones on pre-selected stations at 250 m, 500 m, 1000 m, 5000 m and 10000 m from the platform in the geographical direction of the residual currents (= 0°), and at 250 m from the platform in the perpendicular direction (=270°).
Moreover, cages were fixed to the platform (0 m) and to the permanent buoy Pen 9 (reference).
Due to pipelaying activities at June 15, 1989 the buoy at the 250 m station at 270° had to be towed to a new position, i.e. at 500 m, 90° from the platform.

Although it was planned to start the drilling activities on the first of june, these actually started on July 9, 1989. Directly after the termination of the drilling activities on July 24, 1989, the mussels were recovered and directly frozen at -20 °C. The cages fixed to the platform have been lost, due to unknown causes.

After thawing of the frozen material, tissues were removed from the shells by means of a titanium knife. Prior to the analyses the tissues were homogenised using a titanium modified Ultra Turrax homogeniser. Separate subsamples of the homogenates were taken for separate dry and ash weight determination and oil analyses, following procedures described by de Kock (1983). The procedure for oil analysis is given in appendix A4.

3. RESULTS

3.1 Field survey

Grain size composition

The texture of the sediment at location L-5-5 (Frisian Front area) is relatively fine compared to that of L-9-4 (Fig. 3).

At location L-5-5 there are no clear differences in grain size composition between stations up to 5000 meter from the discharge point in all directions (Fig. 4), except for the station at 5000 meter on the residual current. The fraction 160-250 µm is somewhat larger at this reference station, while the fraction 80-125 µm is smaller.

At location L-9-4 the grain size composition varies between stations. The sediments at the reference stations (at 5000m) strongly differ from the sediments in the vicinity (up to 1000m) of the discharge point. Moreover, the reference stations at the four directions are strongly different among themselves. This indicates heterogeneity of sediments at this spatial scale around the location L-9-4.

At a smaller scale (<1000m from the discharge point) the sediments are more homogeneous. However, the fraction < 63µm is slightly higher at the stations at 100 and 250 m from the discharge point in both directions of the residual current, compared to the stations at 500 and 1000 m, and the stations at 250 m in the directions perpendicular to the residual current. Close to the discharge point (at 25 m), the fraction < 63µm is lowest. Up to 100 m from the discharge point the fraction > 500µm is somewhat enhanced.

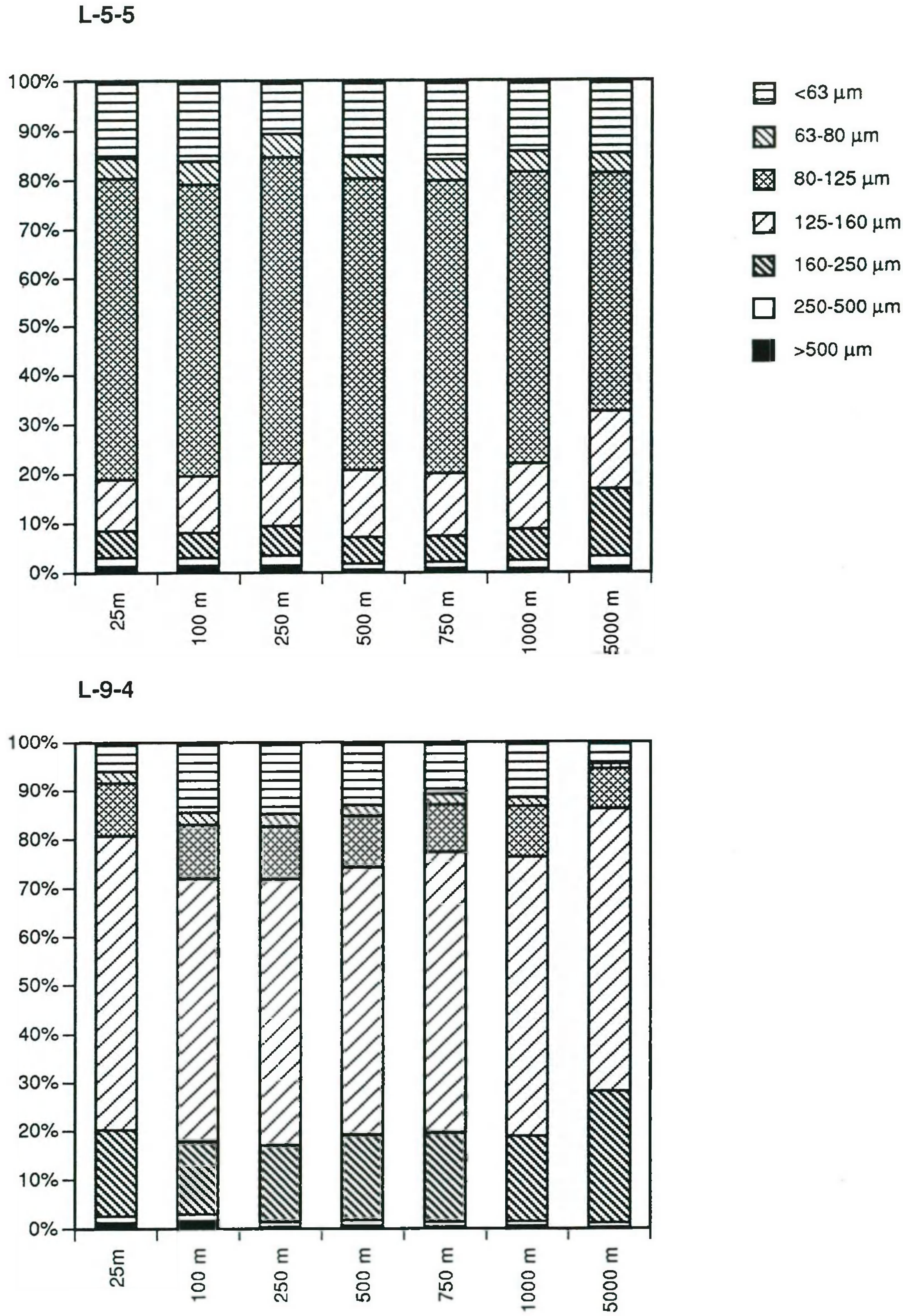


Figure 3: *Grain size frequency (percentage of distinguished fraction) of sediments along a transect following the residual current direction from the drilling locations L-5-5 (above) and L-9-4 (below), May 1989.*

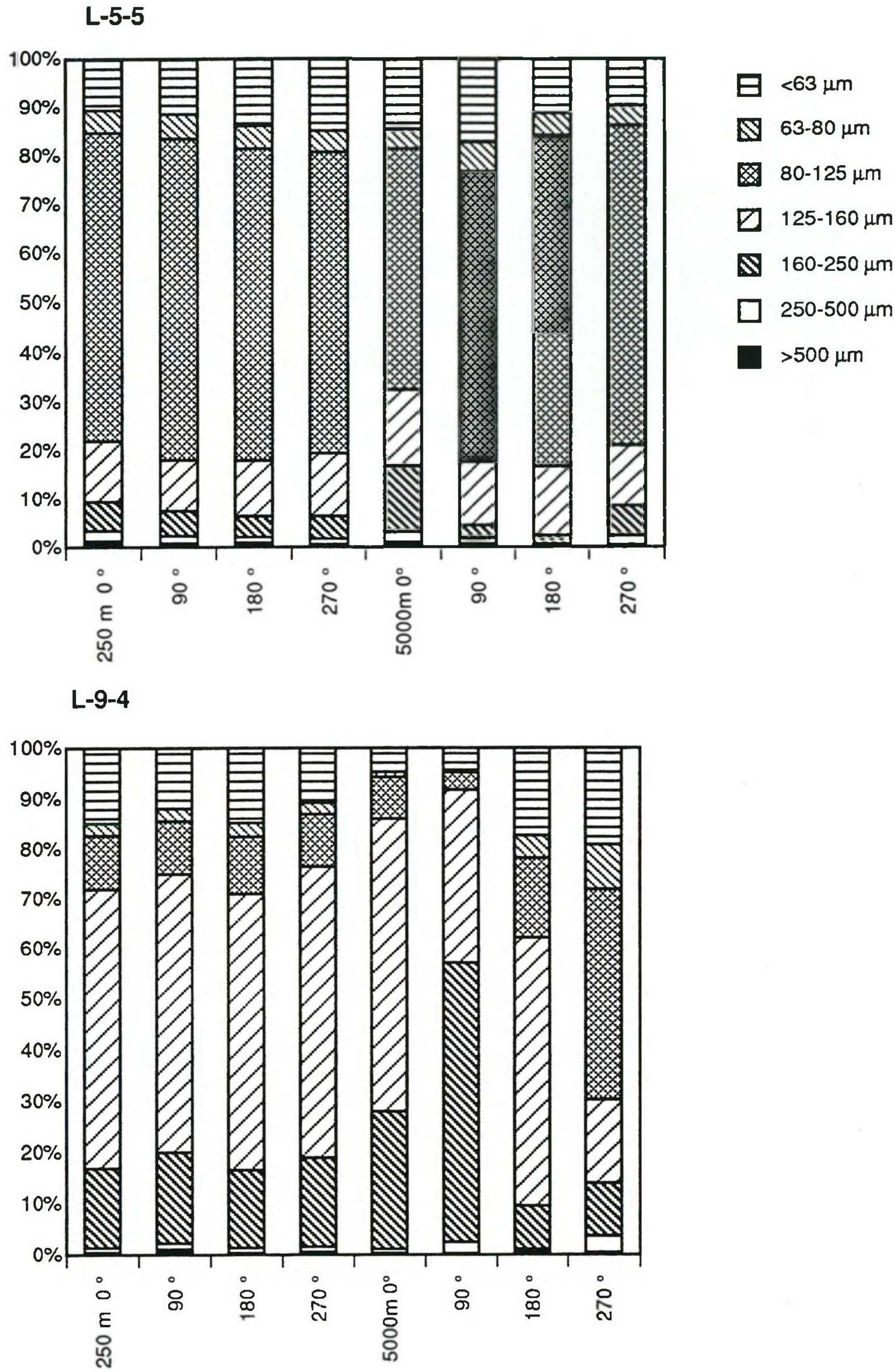


Figure 4: *Grain size frequency (percentage of distinguished fractions) of sediments at two distances from the drilling locations L-5-5 (above) and L-9-4 (below), in different directions (parallel and perpendicular to the residual current direction), May 1989. The direction of the residual current is set at 0° (77° in the field).*

Barium

The barium content of the sediment clearly reflects the distribution of discharged drill cuttings (Fig. 5), regardless whether water-based or (washed) oil-based muds were used. At station L-9-4 there is a gradual decrease in barium concentration from the drilling location outwards.

The results at location L-5-5 in May are less distinct, as the 250 m station shows the highest barium content. This may partly be explained by an incorrect positioning of the dischargepoint (0 m point), which was later confirmed by information (platform sketch) obtained from the drilling company.

Resampling of the location in September resulted in data that are more similar to those found at station L-9-4, but leaving some of the irregularity unsolved.

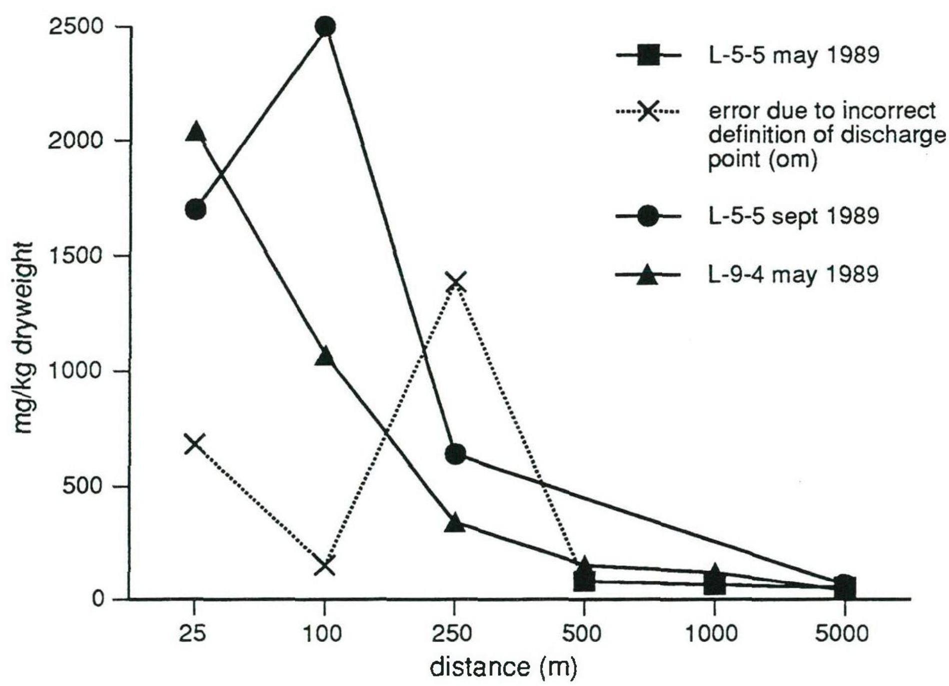


Figure 5: *Barium content of sediments (expressed on the basis of total dry weight) along a transect in the residual current direction at locations L-9-4 (May) and L-5-5 (May and September).*

In order to draw conclusions from the results one has to consider that in the reference situation (5000 m stations) the barium concentration is positively correlated to the percentage of the fine sediment fraction (< 63 μm). Compared to these background concentrations, the barium levels measured up to 1000 m in the direction of the residual currents are substantially elevated. This is clearly demonstrated in figure 6 for the stations at 500-1000 m from the discharge point. From this figure one can also conclude that the elevation of the barium content above background concentrations at a distance of 500-1000 m is larger at location L-9-4 compared to location L-5-5.

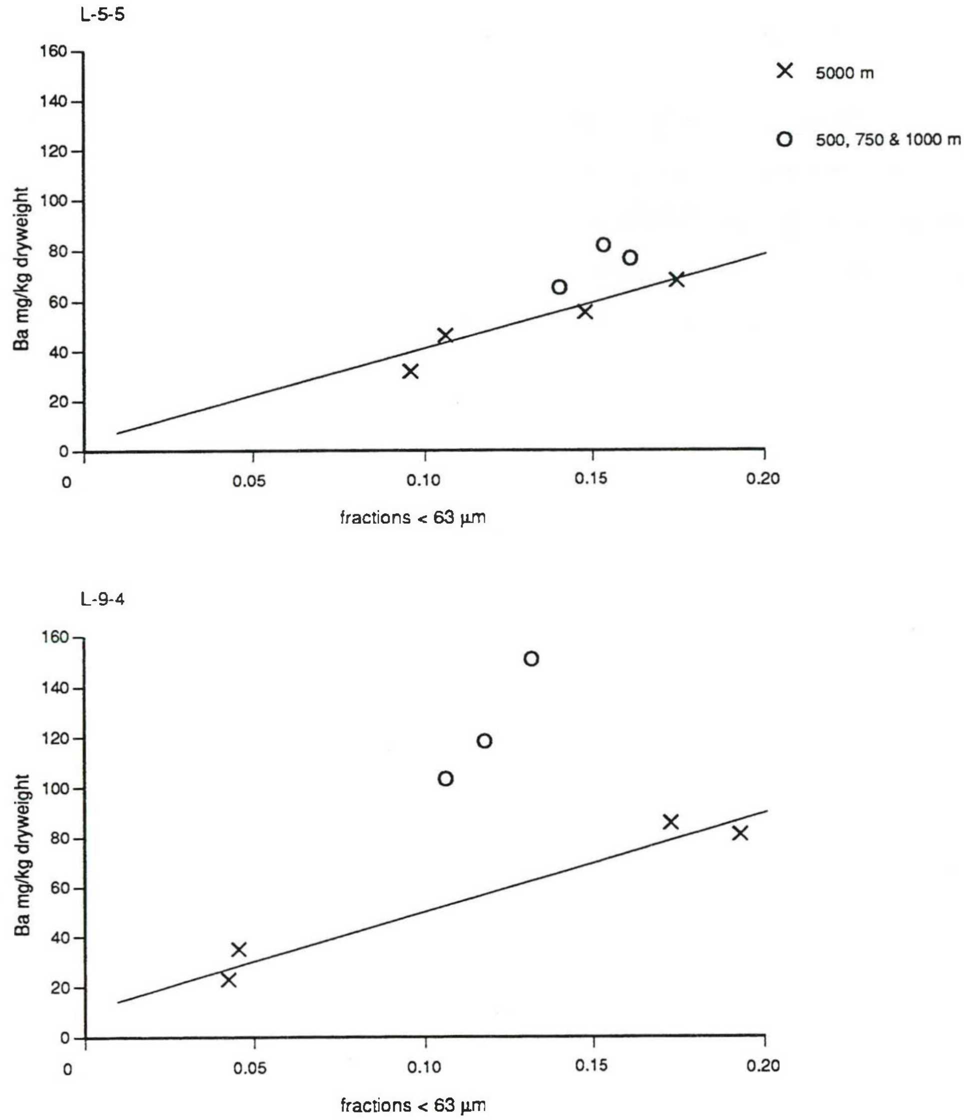


Fig. 6. *The correlation between the barium content and the fraction < 63µm of sediments at reference stations (5000m; background level = regression line), compared to those at stations 500-1000m from the drilling locations L-5-5 (above) and L-9-4 (below).*

Considering the correlation between the barium concentration of sediments and the dry weight of the fraction < 63µm, the barium data from figure 5 have been redrawn on this fractional basis in figure 7. In this way the reference background level becomes 370 (L-5-5) - 460 (L-9-4) $mg.kg^{-1}$

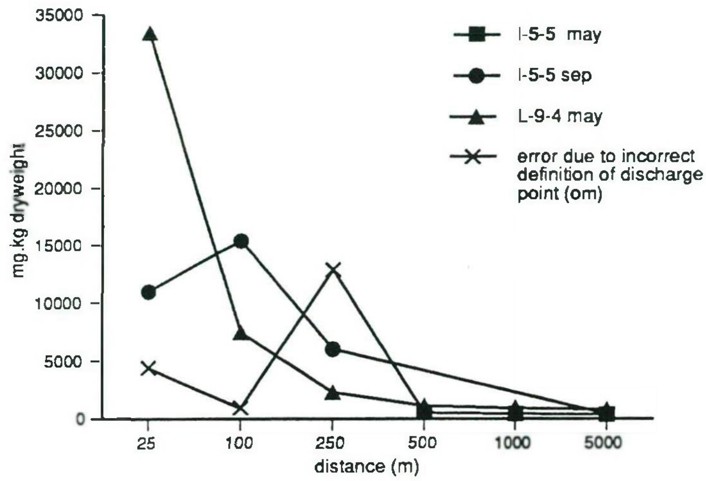


Fig. 7. *Barium content of sediments (expressed on the basis of dry weight of the fraction < 63µm) along a transect in the residual current direction at locations L-9-4 (May) and L-5-5 (May and September).*

The results of the radius of 250 m stations around the discharge point are given in table 2. The main distribution of the barium follows the axes 0° and 180° (residual current direction), which is analogous to the results of our earlier studies. Barium levels exceed the background level, except for the 90° and 270°stations at L-5-5.
In the boxcorer-sample at the 100 m station a distinct profile in barium content is found at the locations L-5-5 and L-9-4 (table 2). The Ba-profiles at both locations are quite similar and in both samples elevated barium concentrations are found down to a depth of 30 cm in the sediment, probably due to physical turbation of the sediments.

Table 2: *Barium content of sediment in mg/kg dry weight (total and fraction < 63µm).*

Stations	L-5-5 may		L-9-4 May	
	total	< 63µm	total	< 63µm
toplayer				
250 m 0° r.current	1385	12826	342	2288
250 m 90° "	61	529	129	1078
250 m 180° "	173	1234	890	5985
250 m 270° "	60	399	112	1033
profiles, 100 m 0° r. current				
0- 2 cm depth	5552	35115	5964	31117
2-10 cm depth	876	9306	1005	5231
25-30 cm depth	475	2816	574	2721

Oil

A selection of sediment samples was made, in which the oil content was measured. A distinction was made between the fractions: "sum C8/C32" (alkanes), "OTHER", and "UCM" (see appendix B1/B2). The summation of the three fractions is defined as "total".

The "total" oil content of the sediments (Fig. 8) follows the same patterns as found with barium. Slighty elevated oil levels were found up to 250 m from the discharge point in the residual current direction. At larger distances no substantial elevation above background-levels has been found. The relative high value at the station 5000 m from L-5-5 in May is likely to be the result of a local pollution from another source, as the UCM fraction is negligible.

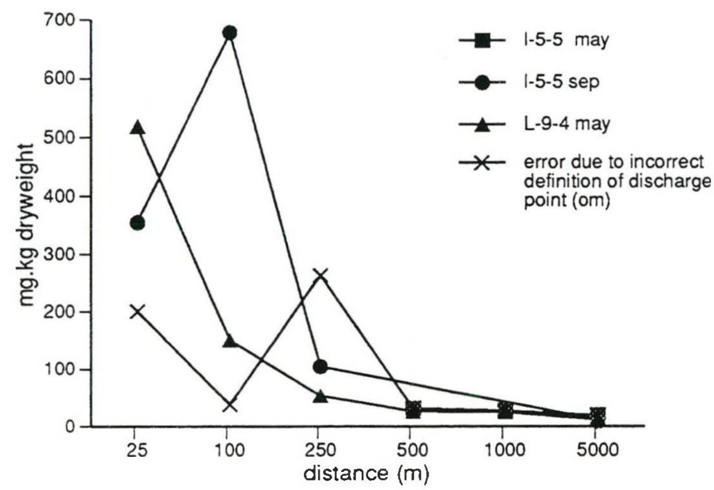


Figure 8: *"Total" oil content of sediments (expressed on the basis of total dry weight) along a transect in the residual current direction at locations L-9-4 (May) and L-5-5 (May and September).*

Indeed, there is a very good linear correlation between barium and "total" oil in the sediment, which is surprisingly similar for both locations L-9-4 and L-5-5: "Total" oil = 0.244 Ba - 11.83; R^2=0.95; n= 16 (Fig. 9).

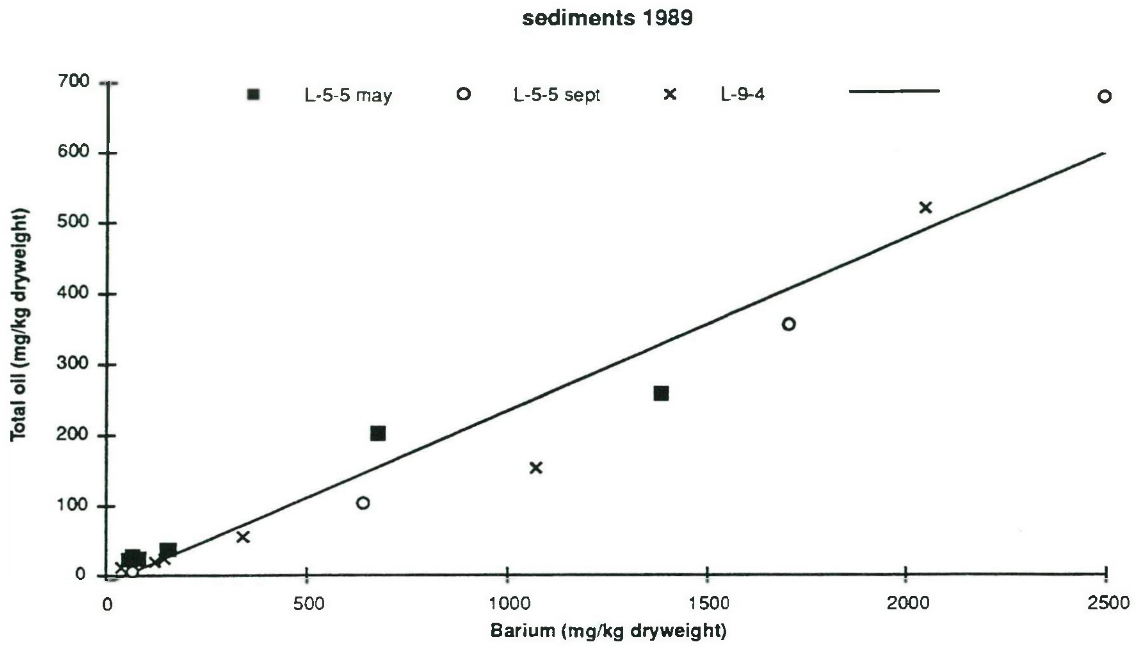


Figure 9: *The correlation between the "total" oil and barium content of the sediment around L-5-5 and L-9-4.*

Barium can be seen as an indicator for the distribution of cuttings. For time series a reduction of the "total" oil/"barium"-ratio could be an index for oil breakdown as barium is persistent. With this index, oil degradation could be distinguished from dispersion.

The results of L-5-5 give no indication of a substantial breakdown of oil between may and september 1991. The "total" oil/barium ratio at stations 50, 100 and 250 m from the drilling point ranged from 0.18 to 0.30 in May and from 0.16 to 0.27 in September.

The oil analyses clearly showed that the fraction "UCM" is the best indicator for oil pollution due to discharges of cuttings (fig. 10 and 11), being almost absent in the unpolluted reference situations.

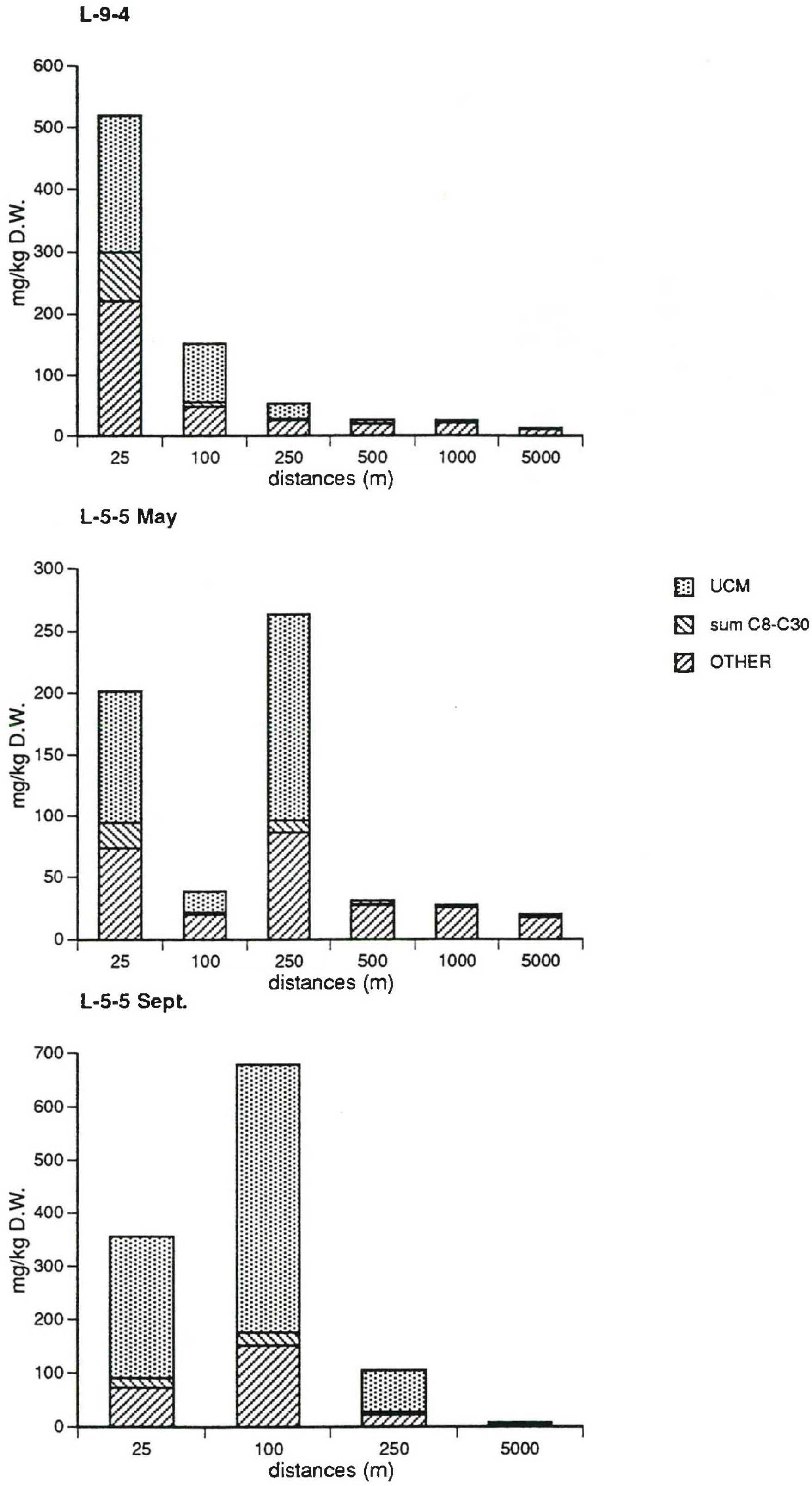


Figure 10: *The partition of the concentration of oil in sediments in the fractions "sum C8-C30", "UCM" and "others", for sediments from the transects in the residual current direction at locations. L-9-4 May (above); L-5-5 May (middle); L-5-5 September (below).*

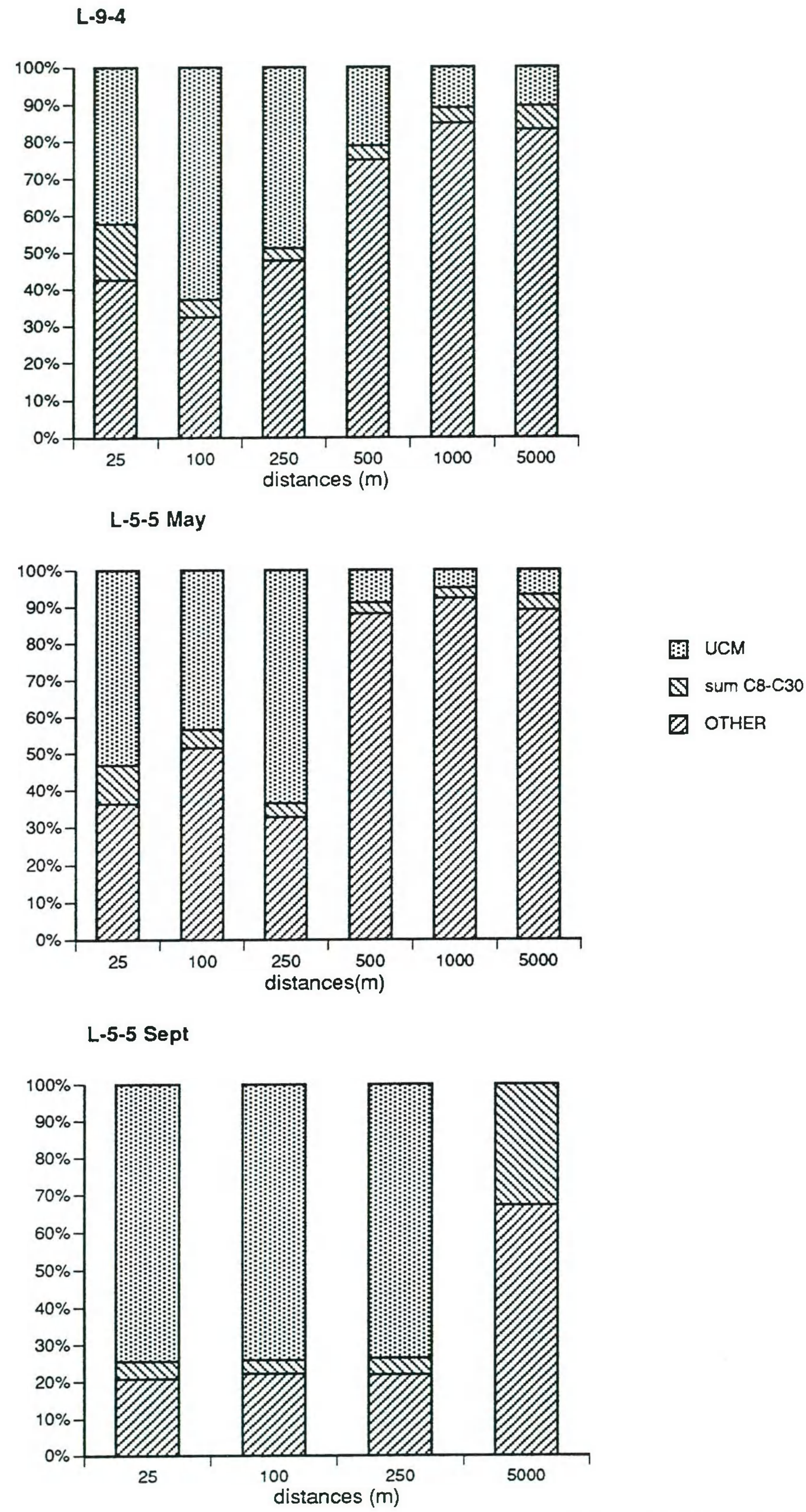


Figure 11: *The percentages of the separate oil fractions "sum C8-C30", "UCM" and "others", for sediments from the transects in the residual current direction at locations. L-9-4 May (above); L-5-5 May (middle); L-5-5 September (below).*

3.2 Boxcosm experiment

The tables 4 and 5 list all data of oil analysis concerning sediments and organisms from the boxcosms. The data are summarized in table 3.

Table 3: *Mean total oil concentration in sediments (mg/kg DW), organisms (mg/kg AFDW) and standard errors, boxcosms collected around location L-5-5.*

Distance from Drilling point	Sediment Boxcosms	*Amphiura filiformis*	*Echinocardium cordatum*
25 m	500 ± 284 (n=4)	663 ± 98 (n=2)	4486 ± 172 (n=4)
250 m	124 ± 59 (n=4)	1265 ± 95 (n=2)	4241 ± 343 (n=3)
5000 m	3 ± 0 (n=4)	119 ± 5 (n=2)	772 ± 62 (n=4)

One way ANOVA showed highly significant differences between sediments ($p=0.0005$), *Amphiura* samples ($p=0.001$) and *Echinocardium* samples ($p<0.0001$). The oil concentrations of sediments and organisms from boxcosms sampled at 5000 m from the drilling point are significantly lower ($p<.05$) than those from 25 and 250 m. The latter two stations are not significantly different. The variation in oil concentration between stations is mainly determined by the UCM fraction.

Reviewing all data we conclude that the accumulated oil concentrations in both testspecies exposed to oil contaminated sediments in boxcosms from the 25 and 250 m stations are exceeding those of the same species in the reference boxcosms (5000 m station), but there are no consistently clear differences between organisms from boxcosms with sediments collected at the 25 and 250 m stations. There is no correlation between the concentration of oil in organisms and in sediments. The relatively high level of accumulated oil in *Amphiura* from the boxcosms with sediment of the 250 m stations is not well understood.

The "total" oil concentrations found in the homogenized sample from 10 replicated van Veen grab samples collected at the same station fall within the ranges observed in the box-corers: 355 mg/kg for station 25 m, 105 mg/kg for station 250 m and 8 mg/kg for station 5000 m. The large differences between replicated boxcorer samples clearly demonstrate the heterogenous distribution (patchiness) of oil in sediments.

Table 4: *Oil concentration (mg/kg DW) of sediments in boxcosms collected near location L-5-5.*

Distance to discharge point	"Total" oil	"UCM"	"Sum C8-C30"	"Others"
25 m - a	1281	986	29	266
25 m - b	43	34	1	8
25 m - c	560	386	14	160
25 m - d	116	80	4	32
250 m - a	40	27	2	11
250 m - b	130	93	5	32
250 m - c	38	24	2	12
250 m - d	290	239	5	46
5000 m - a	3	0	1	2
5000 m - b	3	0	1	2
5000 m - c	3	0	1	2
5000 m - d	4	0	1	3

Table 5: *Oil concentration (mg/kg AFDW) in organisms exposed to sediments collected near location L-5-5.*

Distance to discharge point	"Total" oil	"UCM"	"sum C8-C30"	"Others"
Echinocardium				
25 m - a	4461	3075	280	1106
25 m - b	4954	3463	274	1217
25 m - c	4129	3030	172	927
25 m - d	4398	2895	189	1314
250 m - a	4923	3196	378	1349
250 m - b	3837	2307	381	1149
250 m - c	3963	2533	342	1088
5000 m - a	624	0	137	487
5000 m - b	724	0	179	545
5000 m - c	829	0	232	597
5000 m - d	911	0	234	677
Amphiura				
reference (t=0)	194	0	47	147
25 m - a	761	464	45	252
25 m - b	565	341	66	158
250 m - a	1171	883	46	242
250 m - b	1360	802	63	495
5000 m - a	114	0	15	99
5000 m - b	125	0	30	95

3.3 Active Biological Monitoring

Information on the growth of mussels *(Mytilus edulis)* at L-13-Fd-103 is listed in table 6. All mussels showed a substantial growth of both length (ca. 4 to 5 mm) and weight (ca.0.25 to 0.65 g AFDW per mussel). There are no significant differences in growth of mussels between stations at various distances from the discharge point. The growth of mussels in surface water is different from those exposed near the seabed. At all stations the growth of shell length was slightly faster in deep water compared to surface water. However, the growth of body weight was consistently faster in surface water. The condition index: "body weight"/"length $^{0.65}$" (after Bayne *et al.*, 1985) increased from 0.030 to 0.049-0.062 in deeper waters, and from 0.030 to 0.075-0.082 in surface waters, but is not correlated to distance from the discharge point. The ash content of mussels exposed in deeper waters near the seabed is higher compared to that of mussels exposed in surface waters, indicating a somewhat lower salinity of the surface waters (Kock *et al.*, 1975). Generally, the ash content is decreased during the exposure.

The initial oil concentration in mussels exposed in the ABM survey was relatively high (ca. 400 mg/kg AFDW), compared with former studies (ca. 40 mg/kg, van het Groenewoud *et al.*, 1988). Thus a nett loss of oil (due to depuration exceeding accumulation) from the mussels appeard from 1000 meters onwards.

A gradient was found in the "total" oil concentration in mussels with increasing distance from the discharge point (figure 12). Up to 500 meter from the discharge point the oil concentration of mussels in surface waters exceeds that of mussels from deeper water layers. At 1000 meter from the discharge point this is reversed.

Also in mussel tissues the "UCM" fraction is the best indicator for oil pollution related to discharges of OBM-cuttings. Figure 13 clearly demonstrates the presence of "UCM" up to 1000 m from the drilling platform, and the absence of "UCM" beyond that distance.

Table 6: *Data on number, length, weight, condition and ash content of mussels used in an ABM experiment around drilling location L-13-Fd-103.*

Station	Number	Mean length (mm)	Mean weight (g AFDW/mussel)	Mean weight/ length $^{0.65}$ (condition index)	Ash content (% of dry weight)
Initial sample	98	43.83	0.35	0.030	14.2
Initial sample	99	43.92	0.35	0.030	13.1
Residual current direction					
250 m surface	97	48.30	0.95	0.076	8.9
250 m seabed	99	48.75	0.64	0.051	11.8
500 m surface	91	48.39	1.00	0.080	9.1
500 m seabed	91	48.44	0.75	0.060	11.9
1000 m surface	98	48.56	1.01	0.081	9.1
1000 m seabed	95	48.83	0.78	0.062	10.9
5000 m surface	91	47.68	0.92	0.075	8.9
5000 m seabed	91	48.82	0.75	0.060	11.0
10000 m surface	94	47.83	0.94	0.076	9.5
10000 m seabed	97	48.17	0.61	0.049	12.1
Perpendicular direction					
500 m surface	96	48.20	1.02	0.082	9.3
500 m seabed	93	48.70	0.74	0.059	12.3
Reference					
PEN 9 surface	99	47.70	0.92	0.075	9.8

Table 7: *"Total" oil concentration (mg/kg AFDW) in mussels exposed at several distances from the drilling location L-13-Fd-103. Initial samples (duplo) contained 418 and 366 mg/kg AFDW.*

	Surface water	Deep water
Residual current transect		
250 m	1123	859
500 m	640	457
1000 m	276	413
5000 m	213	260
10000 m	224	230
Perpendicular transect		
500 m	354	214
Reference PEN 9	174	-

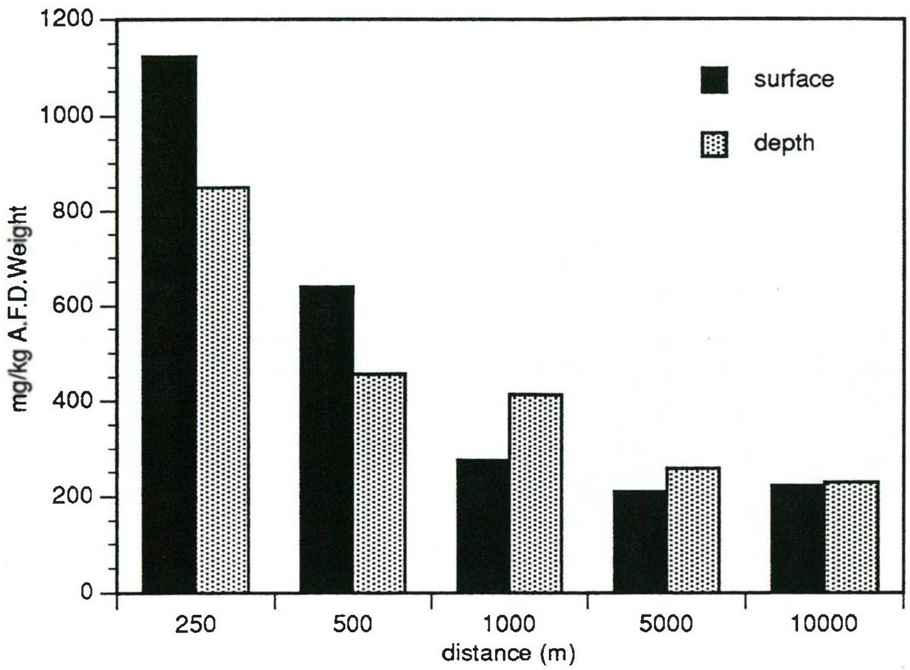
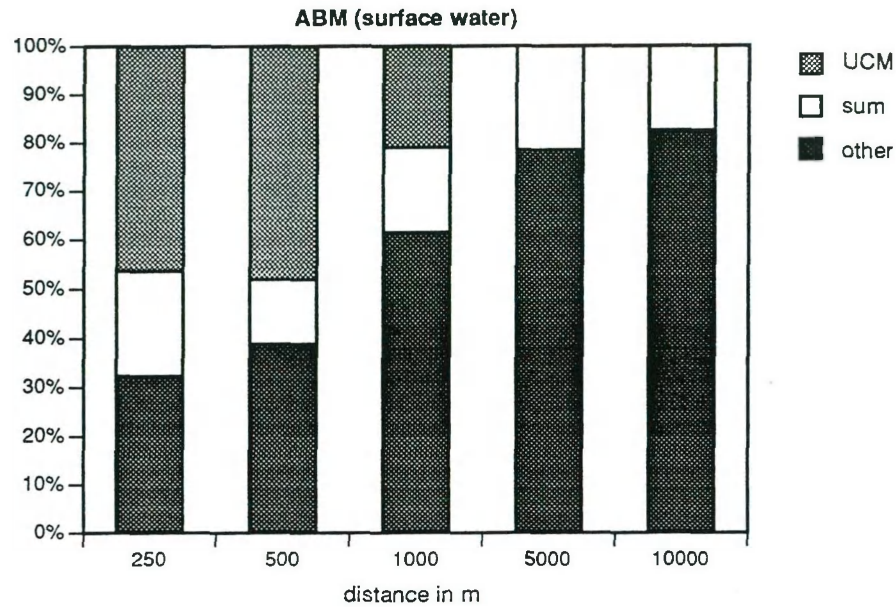


Figure 12: *The concentration of "total oil" in mussels exposed in surface waters or waterlayers just above the seabed, along a residual current transect at location L13-Fd-103.*



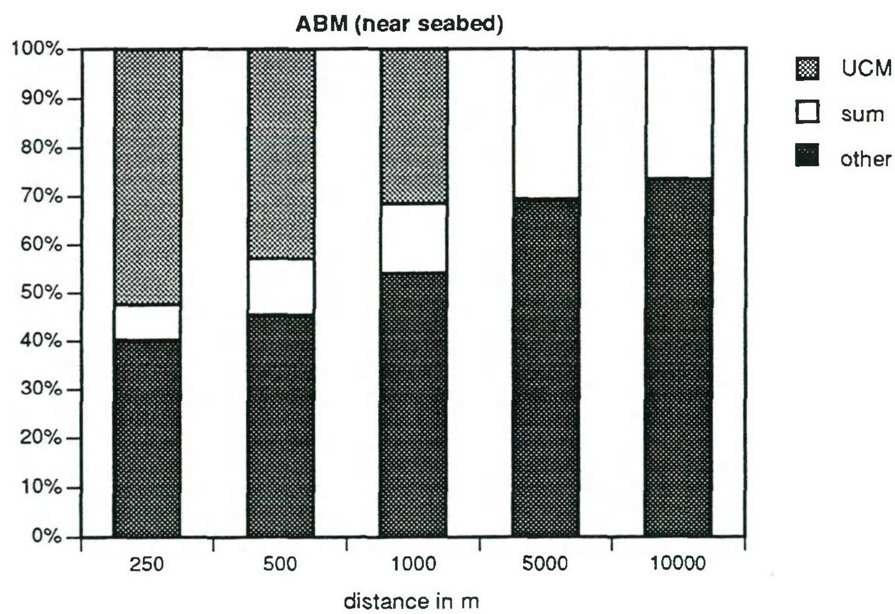


Figure 13: *The percentages of the separate oil fractions "sum C8-C30", "UCM" and "others", accumulated in mussels exposed to surface waters (above) or deeper waters (below).*

4. DISCUSSION

The environmental impact monitoring of offshore drilling activities at the Dutch Continental Shelf in 1989 differs from that of previous years in the sense of having been focused on the discharges of washed cuttings. The main question is therefore: "What is the efficiency of this new technique in helping to reduce the environmental impact of cutting discharges?"
The biological effects are described and discussed by Daan *et al.* (1991). Here we will discuss the impact of the discharges on chemical quality of the water and sediment.
The results of the 1989 surveys will be compared with previous surveys in order to evaluate the environmental benefit of the washing of cuttings before discharge.

Bioaccumulation of oil compounds by mussels, exposed along a transect around the drilling platform at location L-13-Fd-103 during the drilling process where washed drill cuttings were discharged, offers substantial information about the fate of the discharged oil. Up to 500 m from the platform the oil concentration of mussels exposed in surface waters exceeds that of mussels from deeper water layers. This spatial distribution is reversed at 1000 m. These data indicate a tendency of oil, that is easily released from discharged cuttings, to float towards the surface water near the discharge point. Beyond this distance no elevated oil concentration could be observed in the mussels, especially where the characteristic "UCM" fraction (see further in this discussion) is concerned.

This Active Biological Monitoring (ABM) survey with mussels can principally be compared with a similar ABM survey with mussels that has been performed in 1986 around a drilling platform at location L-4-a (van het Groenewoud *et al.*, 1988) during a drilling operation in which unwashed cuttings were discharged (table c, Appendix C). However, we have to keep in mind that a direct comparison is hampered by the fact that the mussels at L-4-a were exposed up to 17 days after the drilling ceased, whereas at L-13-Fd-103 the exposition ended simultaneously with the drilling. At L-4-a depuration of oil compounds after the termination of the drilling activities may have caused a reduction of the oil concentration that was build up during the drilling activities, resulting in an underestimation of the accumulated oil levels in these mussels.
Nevertheless, enhanced "UCM"-levels were found in mussels up to 5000 m from the drilling platform at L-4-a compared to 1000 m at L-13-Fd-103 (table c, Appendix C), indicating a spatially more extended exposure of marine life to oil in the waterphase, released

from discharged cuttings at this location. This could not be due to stronger current rates at L-4-a, but reflects a difference in oil emission: 178 tonnes at L-4-a compared to 17 tonnes at L-13-Fd-103.
The "UCM" concentration in mussels in the vicinity of L-13-Fd-103 (250-1000 m from the platform) is higher then in mussels at comparable distances from the platform at L-4-a. This could be caused by less dispersion of soluble oil from discharged cuttings at L-13-Fd-103, but can also be due to depuration of oil from mussels exposed near L-4-a after drilling has ceased. The elevated oil concentrations in mussels near L-13-Fd-103 did not affect the growth or condition of the mussels.
Table c, Appendix C clearly shows that 0 to 1 mg/kg AFDW is the background range of UCM in mussels, which can be used as reference concentration. From this point of view it seems that washing of cuttings is a successful treatment in reducing the environmental oil contamination during discharges of cuttings, at least concerning the distance at which elevated "UCM"-levels were found in mussels.
Monitoring of sediment pollution is useful for verification this indication.

Analysis of the sediments collected near the abandoned drilling location L-5-5 confirms the very fine texture of the "Frisian Front"-sediments.
From grain size analysis the presence of fine mud or coarse cutting material can not be determined in this area. The fine sediment at location L-5-5 can best be compared with the previously monitored locations in the F-14/F-18 area, somewhat north of the "Frisian Front" in the "Oysterground"-region. The nearby location L-4-a, monitored in 1986/1987 and somewhat south-west of L-5-5 in the "Frisian Front" region, consists of coarser sediments.

The sediments collected near another abandoned drilling location L-9-4, south of the "Frisian Front" region, were much coarser. The sandy sediment near this location could best be compared to previously monitored locations in the K-12, P-6 and P-15 sections of the Dutch Continental Shelf, but was extremely variable within a radius of 5000 m from the discharge point.
As homogeneity of the sediment composition is an important prerequisite for relating contaminant stress to biological survey data, this location was not used for the analysis of faunal assemblages.
The sediment around location L-5-5, where a biological survey (Daan *et al.*, 1991) has been performed, is homogeneous over 5000 meter in each direction from the drilling point.

The selected locations allow us to compare the impact of discharges of washed cuttings on the quality of a silty sediment (L-5-5) with that of a sandy sediment (L-9-4). The presence of fine drill cutting material can not be determined in the silty sediments near location L-5-5, as in the sandy sediment at 100-250 m from the drilling point at L-9-4. Just near this drilling point (25-100m) somewhat coarser material (cuttings) seemed to be present.

There are no indications that the locations differ much from each other, or from the other previously monitored locations with respect to the fate of barium or oil from discharged drill cuttings.
More barium has been found in sediments around the locations K-12-a and F-18-9 (table a, Appendix C), but this was correlated to a larger amount of cuttings being discharged at these locations (de Jong *et al.*, 1991). In conformity of former surveys, elevated barium levels could be detected up to at least 1000 m in the direction of the residual currents.
Since the next station is at 5000 m, which is used as reference station, no information is available on the exact maximal distance at which elevated barium levels do occur. It is recommended to include one or more stations between 1000 and 5000 m from the drilling point in future monitoring programs.

The main distribution of barium follows the tidal currents, especially in the residual current direction. In the directions perpendicular to the tidal currents less barium has been found at both locations. These findings are analogous to those of earlier studies. Similar to what was found at other locations the elevated barium levels at the 100 m station are found down to a depth of 30 cm in the sediment, probably due to physical turbation.

The oil pollution level around L-5-5 and L-9-4 at the 250 m stations is relatively low when compared to locations K12a in 1986-1987, P-15-a in 1985 and at F18-9 in 1988 in previous monitoring studies (tabel b, Appendix C). This is also reflected in the relatively low "total" oil/barium ratio, although this is also due to the use of water based muds.
Only station L-4-a was less polluted at 250 m. This was due to the low dispersion of oil polluted cuttings at this location (van het Groenewoud, 1991). At this location most of the oil was found within 100 m from the drilling point, where the oil/barium ratio ranged from 0,3 to 0,7. K12a became less polluted in 1988, i.e. three years after the first sampling exercise.

These results emphasize that washing of cuttings in a reduced the exposure of marine biota to oil from discharged cuttings in comparison to discharges of unwashed cuttings, as they are less polluted with oil.
This is in line with the observations of Daan *et al.* (1991), who found a reduction in the intensity of adverse biological effects within some hundreds of meters from the drilling point at L-5-5, compared to formerly surveyed locations where unwashed cuttings had been discharged.

The bioaccumulation of oil from washed cuttings accumulated in fine sediments from the "Frisian Front" area (L-5-5) is comparable to the bioaccumulation of oil from unwashed cuttings accumulated in fine sediments from the F-18-9 location (Tabel d, Appendix C).
From these findings it can be concluded that bioaccumulation during the short term exposure of biota to oil from the sediment is not enhanced when cuttings are washed or when cuttings are accumulated in fine "Frisian Front" sediments. The relative mobility of the oil is not affected by one of these factors. Hence, the oil pollution might be just as harmful as already observed for unwashed drill cutting discharges.

The echinoderms *Echinocardium cordatum* and *Amphiura filiformis* are weak indicators for quantifying the oil release rate on the basis of the accumulated oil levels. Although the "UCM" concentration of test species exposed to polluted sediments clearly exceeds those of test species exposed to reference sediments, no consistent relation can be found between bioaccumulation and the oil pollution levels of the sediments. This might be explained by a relatively efficient oil breakdown and release system in the echinoderms, that keeps the internal oil concentration below a maximum level that can be reached at even the lowest exposure levels (den Beste, 1991).

It is therefore better to use sediment oil concentration as (external) dose for the quantification of the toxicity of the polluted sediments, instead of using bioaccumulation data (internal dose) for species like the used echinoderms. From tabel d, Appendix C it is clear that there is a better dose-effect response concerning sediment concentrations rather then bioaccumulation levels. Moreover, the toxicity level differs between both boxcosm experiments.

These findings show that appropriate test species concerning the sediment toxicity (e.g. *Echinocardium cordatum;* Daan *et al.*, 1990; Daan, 1991; Adema, 1991) are not necessarily appropriate test species bioaccumulation studies directed to quantify the actual exposure of biota to oil pollution from sediments. Contrary, in former studies (van het Groenewoud *et al.*, 1988; van het Groenewoud, 1991) it was found that the appropriate species for active biological monitoring, the mussel *Mytilus edulis*, was not a good species for toxicity monitoring based on stress-indicating parameters.

Of all organisms, exposure of mussels at several waterdepths yields the best information on the water and sediment quality. The concentration of chemicals in mussel tissues is related to the concentration of the bioavailable fraction of the chemicals in the waterphase or in the proximate sediments integrated over the exposure time.
It is therefore strongly recommended to pursue the sediment ABM using mussels as test species. The level of contaminants accumulated in mussels that are exposed to the water-layers near the sediment surface strongly reflects the release of mobile contaminants from the sediments, thus quantifying the actual contaminant exposure of bottom dwelling biota. The mussel can be used both in boxcosm-bioassays (mussels placed in the overflow water) and field surveys (caged mussels brought to the sediment surface with the help of an anchorstone), allowing for a direct field verification of the exposure levels in mesocosm-bioassays, that has been used to quantify field toxicity levels.

This methodology of using mussels to link results of ecotoxicological mesocosm studies with field monitoring have already been practiced by the TNO Laboratory of Applied Marine Research. In their mesocosm studies, in which various selected target species are being tested for toxicological effects, mussels have been used to quantify the exposure level of the test species. From this, exposure (mussel bioaccumulation) - effect (target species) responses are deduced, which are used to evaluate the field-exposure levels quantified with mussels in an ABM-survey.

A second advantage of the use of mussels in an ABM to quantify contaminant exposure levels for sediments, is that a direct link with the ABM used for waterquality assessment is guaranteed. There are proper mussel-bioaccumulation models available to relate the internal concentration in the mussels to the mean external concentration in water and/or sediments (Kooijman and Van Haren, 1991; Schepers *et al.*, 1991). A special version for oil accumulation (MUSSEL) is under development.

Monitoring surveys in the field are generally limited in detecting the extra contamination exposure at larger distances from the discharge site as a result of variation in "background" data from chemical analysis, due to large temporal or spatial variation in concentrations.

In principle, an exposure to chemicals from a particular source can be distinguished from background exposures by characterization of the "fingerprint" of chemical compounds present in the mussel tissue. The "fingerprint" should include all chemicals that, compared to other chemicals, cause a relative elevation in environmental concentration due to the dumping. A "fingerprint" can be defined from an analysis of the discharges for compounds that are relatively rich or poor contributors as compared to general background chemistry.

In accordance with the previous monitoring surveys (van het Groenewoud *et al.*, 1988; van het Groenewoud, 1991) the "UCM" fraction is determined to be the best indicator for oil pollution related to discharges of OBM cuttings, rather than "total oil" figures. "Background" levels are generally low, so that an elevation is easily detected. An elevation of the "UCM" concentration above "background" levels is recognizable at distinctly larger distances than other oil compounds or barium.

The "UCM" fraction also proved to be the best detectable compound in bioaccumulation studies, both in ABM surveys and in boxcosm-bioassays. The "UCM" fraction is likely to consist of isomers of alkanes (van het Groenewoud, 1991).

In this study it is also clearly demonstrated that the barium concentration of sediments on the basis of the dry weight of the fraction < 63 µm has a higher resolution power than that expressed on the basis of total dry weight. Differences from "background" levels are better detectable when the first expression is used, especially when the sediment composition is heterogeneous around a drilling location.

For time series the "oil"/"barium" ratio could be used as an index for oil breakdown. The persistent element barium is a good indicator for the dispersion of discharged cuttings but barium is not subject to breakdown processes. The ratio can also be used to verify the relative level of oil pollution of discharged cuttings, either due to treatment or to the use of waterbased muds.

It is strongly recommended to implement the "oil"/"barium"-index as a standard parameter in the presentation and interpretation of sediment analysis within the environmental impact monitoring of discharged cuttings. The resolution power of this index can be optimized when oil is expressed as the concentration of the "UCM" fraction and barium is expressed as the concentration on basis of the < 63 µm fraction.

The patchiness of oil in sediments is already discussed in Van het Groenewoud (1991). The large differences between replicated boxcorer samples clearly demonstrate again the heterogeneous distribution of oil in sediments. The oil concentration in homogenized samples from replicated Van Veen grab samples collected at the same stations fall within the range of concentrations found in the boxcorer samples. Again, these results clearly emphasize the importance of strictly defined sampling procedures and replicate sampling at one station in order to get reliable data.

From this point of view it is debatable whether mesocosm scale toxicity bioassays have to be performed with the varying sediment samples taken from the field, or with artificially (dosed) polluted sediments simulating the field situations as best as possible. The latter is preferred because the exposure level (to which the biological effects have to be related in order to get useful toxicity data) can be controlled, provided that imitated “weathered” cuttings can be used. The difficulties of the toxicological interpretation of the present bioassay set-up, following the former option, are discussed by Daan *et al.* (1991).

The patchiness of oil in the sediment on the other hand will be of crucial importance for the exposure of biota to oil in the field situation. From videoshots it is demonstrated that most benthic organisms will escape oil polluted sediments and crawl to unpolluted stretches, thus avoiding exposure to oil and resulting potential toxicity. The avoidance behaviour is also observed in several bioassays with oil polluted sediments (Adema, 1991; Kuiper *et al.*, 1986).

Another point of discussion is the use of the Van Veen grab in taking sediment samples for chemical analysis. Comparison of the results of barium analyses of samples taken with the Van Veen grab and the boxcorer at the same stations indicates large differences between the two sampling methods. The barium content in the upper 10 cm of the boxcorer samples (1800 and 2000 mg/kg for the 100 m stations at L-5-5 and L-9-4 respectively) is substantially higher than what is found in homogenized samples from sediment collected by Van Veen grabs (150 resp. 1050 mg/kg). Although this difference might be related to small scale patchiness in the distribution of barium, the systematic difference indicates a sampling error.

The upper sediment layer is probably not quantitatively sampled with the Van Veen grab, due to slashing when the grab is hitting the bottom. Because of the gradient of decreasing barium content with increasing sediment depth, this will cause an exclusion of the sediment layer with the highest barium content, and therefore lead to an underestimation of the mean

barium level in the upper 10 cm. This might be another factor causing the large variance between Van Veen grabs (van het Groenewoud, 1991).
Boxcorer sampling might be more accurate, but is on the other hand more labourous. With the necessity of replicate sampling in a patchy polluted area, this could be a practical limitation. Anyhow, one should always use the same sampling technique to allow reliable comparison of data.

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Drs.L.de Jong	(RWS, Directie Noordzee) secretary
Ing. M. de Krieger	(RWS, Directie Noordzee)
Drs. E. Stutterheim	(RWS-DGW)
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M. Mulder	(NIOZ-BEWON)
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APPENDIX A: WORKING PROCEDURES

A1: Analyses procedure- Grain size distribution.

In order to determine the grain size distribution, 100-150 g of wet sediment was sieved over 63 μm, using water. From the fraction < 63 μm a subsample of 50-500 ml was filtered over a dried and pre-weighed filter (Schleiger und Schull Schwarzband), dried for 24 hours at 90°C and weighed on a Mettler H30 balance.

In another subsample (20 ml) the particle size distribution was determined by means of an electronic particle data counter (Particle Data Inc. Celloscope), using a 120 μm orifice tube. The residue that remained on the 63 μm sieve was dried for one day at 90°C and placed in the sieves of a mechancial sieve shaker (80-125-160-250 μm) for 15 minutes. The resultant fractions were weighed using a Mettler PK 300 balance.

A2: Analyses procedure- Barium content

About 10 grams of sediment were dried during 2 hours at 105°C, after which 2 grams were homogenized and destructed by means of sulphuric acid and hydrogen peroxide. After settling, the barium content of the destruate was determined using inductive coupled plasma-atomic-emission spectrometry (ICP-AES).

A3: Method for measuring oil in sediment.

A 10 gram subsample of the sediment was (simultanously) steam-distilled during 12 hours and extracted with 10 ml hexane (nanograde). Of the clean extract 1 microliter was injected into the gas chromatograph (GC) and detected by means of a flame ionisation detector. The condition of the chromatograph was as follows:

Column	:	12.5 m x 0.2 mm i.d. fused silicate covered with 0.33 micrometer crosslinked dimethylsilicone
carrier gas	:	helium, 100 kPa; lineair gasflow 16-21 cm/s
splitflow	:	helium 50 ml/min injection temp:250 °C
detection	:	flame ionisation
detector temp	:	300 °C
temp. program	:	50 °C during 1 min., thereafter 20 °C/min. upto 300 °C and then another 10 min.

The oil is difficult to quantify due to the many components present. To overcome this the following procedures have been followed:

1) quantification of the different components by mean of their peaks.
2) quantification of the UCM fraction

ad 1.

The detected peaks were identified on the basis of retention time and quantified by means of well-known standards. The not-identified peaks (others) are quantified by the response factor of the first previous peak in the chromatogram of the standard mixture. (see also baseline figure a.)

ad 2.

The UCM (Unresolved Carbon Matter) are components in the oil which are not sufficiently separated as to form a distince peak; instead, they form a "hill" in the chromatogram.
The UCM is quantified as total by means of the response factpors of the standard mixture (see also baseline figure b.).

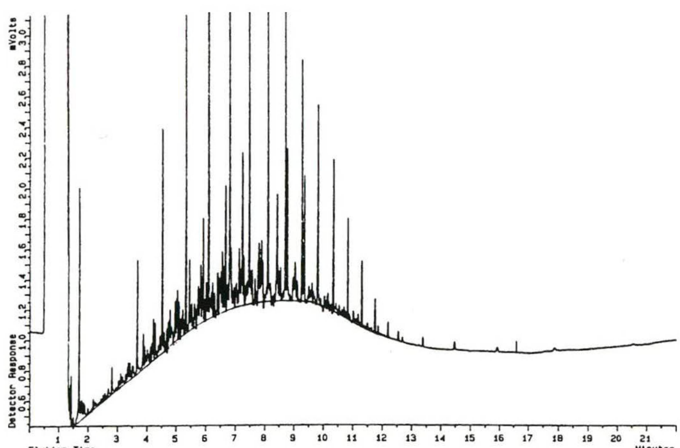

Figure a: *baseline for calculating oil components*

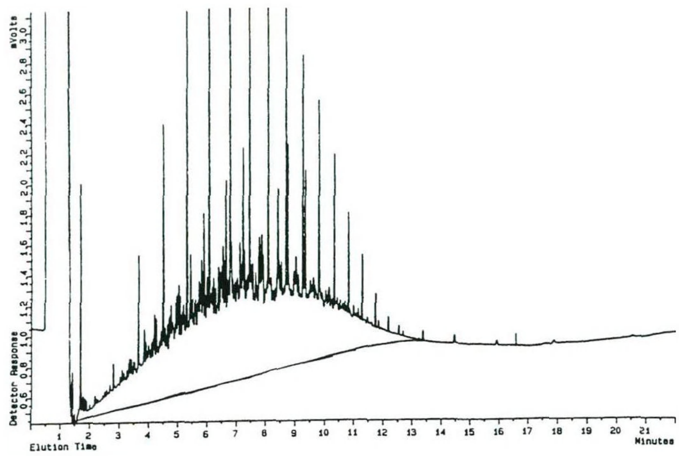

Figure b: *baseline for calculating UCM.*

A4: Method for measuring oil in organisms.

About 5 grams of homogenized material was taken for analysis.

This sample was destructed, using a pepsine solution, by stirring in a waterbath at 37 °C during one night (12hr.). After destruction the sample was treated as described in appendix A3.

APPENDIX B: RAW DATA

B1: Concentrations of oil in sediments at L-5-5 in mg/kg wetweight

	may 1989						september 1989			
distance ->m	25	100	250	500	1000	5000	25	100	250	5000
Component										
C9	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.49	0.44
C10	0.06	<0.01	0.03	<0.01	<0.01	<0.01	0.70	0.11	0.25	<0.01
C11	0.25	0.03	0.20	<0.01	<0.01	<0.01	0.11	0.22	0.03	0.06
Naphtalene	0.50	0.09	0.66	<0.02	<0.02	<0.02	0.89	1.40	0.24	<0.02
C12	3.21	0.15	1.51	0.02	<0.01	<0.01	1.30	3.37	0.31	<0.01
C13	7.95	0.27	3.03	0.03	<0.01	<0.01	1.35	7.04	0.45	<0.01
C14	2.67	0.13	0.90	0.02	<0.01	<0.01	1.55	2.29	0.28	0.02
C15	0.48	0.06	0.25	0.02	<0.01	<0.01	0.51	0.34	0.05	0.03
C16	0.05	0.02	0.04	0.02	<0.01	<0.01	0.16	0.12	0.03	0.04
C17	<0.01	0.02	0.03	0.02	<0.01	<0.01	0.04	0.04	<0.01	0.02
PRISTANE	0.02	<0.01	0.05	<0.01	<0.01	<0.01	0.09	0.34	0.03	<0.01
C18	0.03	0.03	<0.01	0.02	<0.01	<0.01	<0.01	0.03	<0.01	0.05
PHYTANE	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.07	0.19	0.04	0.06
C19	<0.01	0.02	0.02	0.02	<0.01	<0.01	<0.01	0.03	<0.01	0.30
C20	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.04	0.05	0.02	0.16
C21	0.02	0.10	<0.01	<0.01	<0.01	<0.01	0.12	0.13	0.04	0.04
C22	<0.01	0.03	<0.01	0.02	0.02	<0.01	0.19	0.13	0.02	0.02
C23	0.02	0.04	0.02	0.02	<0.01	<0.01	0.36	0.18	0.02	<0.01
C24	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.61	0.29	0.03	0.02
C26	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.47	0.19	0.07	0.02
C27	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.53	0.27	0.02	0.02
C28	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.26	0.13	0.10	0.10
C29	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	2.64	0.49	0.66	0.24
C30	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	0.30	0.30	0.30	0.30
sum C8-C30	15.3	1.0	6.8	0.2	0.0	0.0	12.3	17.7	3.5	1.9
OTHER	54.8	14.2	62.0	19.9	18.8	12.9	54.0	109.0	17.0	4.1
UCM	80.0	12.0	120.0	2.0	<1	<1	193.0	362.0	57.0	0.0
TOTAL	**150.1**	**27.2**	**188.8**	**22.1**	**18.8**	**12.9**	**259.3**	**488.7**	**77.5**	**6.0**

B2: Concentrations of oil in sediments at L-9-4 in mg/kg wetweight

	may 1989					
distance ->m	25	100	250	500	1000	5000
Component						
C9	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C10	0.25	0.08	<0.01	<0.01	<0.01	<0.01
C11	2.57	0.65	0.12	<0.01	<0.01	<0.01
Naphtalene	2.09	0.41	0.09	0.02	0.02	<0.01
C12	14.6	1.18	0.13	0.03	0.02	<0.01
C13	19.7	1.53	0.17	0.04	0.03	<0.01
C14	9.2	0.68	0.09	0.03	0.02	<0.01
C15	2.78	0.13	0.04	0.03	0.02	<0.01
C16	0.92	0.04	<0.02	<0.02	<0.02	<0.02
C17	0.42	0.02	0.02	0.02	0.02	<0.01
PRISTANE	0.33	0.06	<0.01	0.02	<0.01	<0.01
C18	0.33	0.02	0.02	<0.01	0.02	0.02
PHYTANE	0.18	<0.01	<0.01	0.02	<0.01	<0.01
C19	0.07	<0.01	<0.01	<0.01	<0.01	<0.01
C20	0.07	<0.01	<0.01	<0.01	<0.01	<0.01
C21	0.03	<0.01	0.09	<0.01	0.11	0.04
C22	0.1	<0.01	<0.01	0.02	<0.01	<0.01
C23	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
C24	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
C26	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C27	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C28	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
C29	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
C30	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24
sum C8-C32	53.7	4.8	0.8	0.2	0.3	0.1
OTHER	151.0	35.1	18.6	14.1	15.4	7.9
UCM	150.0	68.0	19.0	4.0	2.0	<1
TOTAL	**354.7**	**107.9**	**38.4**	**18.3**	**17.7**	**8.0**

APPENDIX C: REVIEW OF DATA 1986-1989

For comparison with previous monitoring surveys, table a and b lists all data on the barium respectively oil content at the 250 m station in the residual current direction of all locations monitored in the period 1986-1989
Tables c and d lists all the bioaccumulation data from all ABM surveys respectively box-cosms experiments in this period.

Table a: *Barium content of sediments at 250 m from the drilling locations in the residual current direction in the upper 10 cm, taken by Van Veen grabs.*

Location	Year	Barium content (mg/kg dw)
K-12a	1986	1700
	1987	412
	1988	345
L-4a	1986	439
	1987	486/528
F-14-6	1988	80
F-18-9	1988	1150
L-5-5	1989	640
L-9-4	1989	342

Table b: *"Total" oil content and "total"-oil/barium-ratio of sediment at 50 m from the drilling locations in the residual current direction.*

Location	Year of monitoring	Type of cuttings	"total" oil (mg/kg)	"total" oil/barium	emission of oil (tonnes)
K-12-a	1986	unwashed	377	0,22	393
	1985	unwashed	460	-	-
	1987	unwashed	289	0,70	-
	1988	unwashed	30	0,09	-
L-4-a	1986*	unwashed	5	0,01	178
	1987	unwashed	4/32	0,02/0,06	
P-6-b	1985	unwashed	96	-	?
P-15-a	1985	unwashed	440	-	?
F-14-6	1988	unwashed	96	1,20	?
F-18-9	1988	unwashed	441	0,38	283
L-5-5	1989	washed	104	0,16	44
L-9-4	1989	washed	54	0,16	35

*) during drilling

Table c: *The concentration of "UCM"-oil in ABM-mussels (mg/kg AFDW), exposed at several distances from the discharge point in the residual current direction.*

Distance m	L13-Fd103 during drilling surface water	L13-Fd103 during drilling deeper water	L-4a during drilling	L-4a 7 months after drilling
0	-	-	190	127
250	520	445	166	1
500	307	196	81	1
1000	58	131	61	1
5000	0	0	20	1
10000	0	0		
Reference	0	-	1	1
Initial	0	0	1	1

Table d: *Mean concentration of the "UCM" fraction in sediments and organisms in the boxcosm experiments in 1988 (F-18-9) and 1989 (L-5-5).*
n.d.=not detectable due to natural fauna in boxcosms

Box type		Sediment	Echinocardium		Amphiura	
		UCM mg/kg DW	UCM mg/kg AFDW	Mortality after 97 days %	UCM mg/kg AFDW	Mortality after 97 days %
F-18-9	50 m	283	2521	85	1057	68
L-5-5	25 m	372	3115	48	403	n.d.
F-18-9	100 m	29	3069	15	609	18
L-5-5	250 m	96	2679	75	843	n.d.
F-18-9	5000 m	0	9	0	8	6
L-5-5	5000 m	0	0	3	0	n.d.