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060 Dispersion and Fate of Oil from Oil-based Drilling Muds near Sable Island, Nova Scotia

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Dispersion and Fate of Oil from Oil-Based Drilling Muds at West Venture C-62 and South Des Barres O-76, Sable Island, Nova Scotia

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SUMMARY

A sediment grab sample collection and analysis program has been successfully carried out at two east coast rig sites, West Venture C-62 and South Des Barres O-76, to monitor the characteristics, behaviour, and fate of hydrocarbons introduced into the benthic environment by the use of oil-based drilling muds. This report describes the methods used for extraction and gas chromatographic analysis of aliphatic and aromatic hydrocarbon content in the samples collected before and after the discharge of oiled cuttings at each site in May and October, 1984, respectively. Summary tables and figures delineate the spread of oil from each well-head and detailed results for each analysis are provided.

Three months later, additional samples collected by divers from the West Venture site showed much reduced oil concentrations and there was no visible sign of the original cuttings pile. The oiled cuttings were either dispersed or buried, but because of the shallow (16-m) depth, dispersal is more likely to have occurred. Higher aliphatic concentrations measured around the South Des Barres site, and the oceanographic regime suggest that oil from the cuttings may persist longer in a deep-water environment.

The results of the field studies were compared to those of a computer model which simulated the dispersion and fate of the cuttings. The model agreed with field results which estimated the size of the cuttings mound for both the West Venture and South Des Barres well sites. The model also compared favourably with field results at the South Des Barres well in predicting the direction of travel and the total hydrocarbon concentration in the sediments. However, while the general direction of dispersal at the West Venture well was correctly predicted by the model, the total hydrocarbon concentration was under-estimated. Mixing and/or burial of the oiled cuttings with natural sediments was likely the main reason for the discrepancy.

A sensitivity analysis was undertaken for both well sites to identify the consequences of uncertainties in the input data. The results point to a lack of quantitative description of the particle-size distribution of the discharged material as a principal source of the uncertainty in predictions.

The results of this study suggest that oil-based drilling muds formulated with mineral oil reduced in aromatic hydrocarbons, combine with significant contributions of PAH from the formation hydrocarbons during the actual drilling processes. If this is indeed the case, the final toxicity of the oiled cuttings may be dependent on the individual well and even on the formation being drilled. Future work would have to include long-term post-drilling monitoring to determine the fate of the saturate and aromatic hydrocarbons that were documented in this study.

For a full understanding of the effects of oil-based muds in the Canadian marine environment, information is still required on the persistence of the oil and on the effects of the oil on biota at deeper water sites such as the South Des Barres location. A more complete budget of the absorption of oil on cuttings and of the amount of oil discharged with cuttings from the drilling rig needs to be established so that a mass balance of the discharged oil in the receiving environment may be calculated.

RESUME

Un échantillonnage de carottes sédimentaires a été réalisé aux environs de deux plateformes pétrolières de la côte. Est pour contrôler les caractéristiques, le comportement et le devenir des hydrocarbures introduits dans l'environnement benthique par le rejet des boues de forage. Ca rapport décrit les méthodes utilisées pour l'extraction et l'analyse par chromatographie en phase gazeuse (CPG) des hydrocarbures aliphatiques et aromatiques contenus dans les échantillons collectés avant et après le déversement des déblais en Mai et Octobre 1984, respectivement. Les résultats des analyses sont établis de façon détaillée et les données sur la dispersion du pétrole á partir de chaque puit sont présentées de façon synthétiques.

Après trois mois, des échantillons supplémentaires collectés par plongée au site de West Venture montrent des concentrations moindres de pétrole, et il n'y a plus de signe visible de l'amas initial des déblais de forage. Les boues pétrolières semblent avoir été dispersées ou ensevelies mais la dispersion est vraisemblablement le phénomène dominant á cause de la faible profondeur (16 m). Les fortes concentrations en aliphatiques mesurées autour du site de South Des Barres et le régime hydrodynamique indiquent que le pétrole des déblais peut résider plus longtemps dans un environnement profond.

Les résultats des études sur les deux puits pétroliers sont comparés á ceux d'un modèle informatique de simulation de la dispersion, établi par l'ASA consulting de Dartmouth, Nouvelle Ecosse, qui comprend aussi une modélisation sur le devenir des déblais.

Des échantillons représentatifs ont fait l'objet d'analyses complémentaires par CPG/FID et par CPG/SM par le Laboratoire de Recherche de Battelle New England á Duxbury, Massachusetts. Cette étude suggère que le pétrole contenu dans les déblais est composé d'huiles minérales, á faible teneur en hydrocarbures aromatiques, aux quelles s'ajoutent des HAP á fortes concentration formés lors du forage. Si ceci est le cas, la toxicité finale de ces déblais peut être dépendante de chaque puit, de même que du type de forage utilisé. Une surveillance á long terms après forage devrait être entreprise pour déterminer le devenir des hydrocarbures aliphatiques et aromatiques.

Une analyse de la sensibilité a été réalisée sur les deux sites de forages pour identifier l'erreur sur les données utilisées. La principale source d'incertitude dans les prédictions est due á l'absence de données quantitatives sur la distribution de taille des particules contenues dans les déblais.

Pour use meilleure compréhension des conséquences des boues pétrolières sur l'environnement marin Canadien, d'autres études sur la persistance et l'impact du pétrole sur les organismes pour des sites á eaux profondes tels que South Des Barres seront necessaires. Un budget plus complet sur l'absorption du pétrole dans les déblais et sur la quantité de pétrole déversée á partir de l'appareillage de forage a besoin d'être établi de telle sorte qu'une balance en masse des hydrocarbures introduits dans l'environnement soit calculée.

INTRODUCTION

The use of oil-based drilling muds in offshore drilling operations has a number of advantages over more traditional water-based muds, including better lubrication, improved drilling rate, and decreased formation damage. However, earlier formulations were often considered as toxic because of the high percentage of aromatic components in the diesel oil used as a base oil. More recently, low-toxicity mineral oils with less than 0.3% aromatics have been used but, because of the paucity of information on these oils, particularly from Canadian waters, a concern still exists as to the long-term fate and effect of oil from mud adhering to cuttings discharged to marine waters.

As a result of this concern, Dobrocky Seatech Ltd. designed and carried out a study under the auspices of the Environmental Studies Revolving Funds (ESRF), to monitor the characteristics, behaviour, and fate of hydrocarbons introduced to the benthic environment as a result of the use of mineral oil-based muds. The sampling, analytical, and interpretation phases of the project were designed to:

- measure the areal extent of base oil hydrocarbons around each well;
- examine the characteristics and weathering of the base oil hydrocarbons in the benthic environment; and
- compare the measured hydrocarbon concentrations to the concentrations predicted by a distribution model for the discharged cuttings.

The study objectives did not include an examination of effects on biota, although any animals obtained during sampling were saved for possible analysis.

The final program submitted to, and accepted by, the ESRF committee called for post-drilling collection of sediment samples for hydrocarbon analysis at two locations near Sable Island (Figure 1) and pre- and post-drilling collections at a site on the Grand Banks of Newfoundland. A mineral oil-based mud was planned to be used at all of these sites. Samples collected prior to drilling operations at the Sable Island sites were carried out by the operators and were stored frozen for subsequent analysis and comparison with the post-drilling samples. The Grand Banks phase of the study was cancelled.

The modelling phase of the project was subcontracted to ASA Consulting Ltd. of Dartmouth, N.S. They performed a simple simulation of the expected cuttings dispersion for both the West Venture C-62 and South Des Barres O-76 well sites and the results outlined in this report are an extension of their report (de Margerie 1986). The results point to a lack of quantitative description of the discharged material as a principal source of uncertainty in predictions.

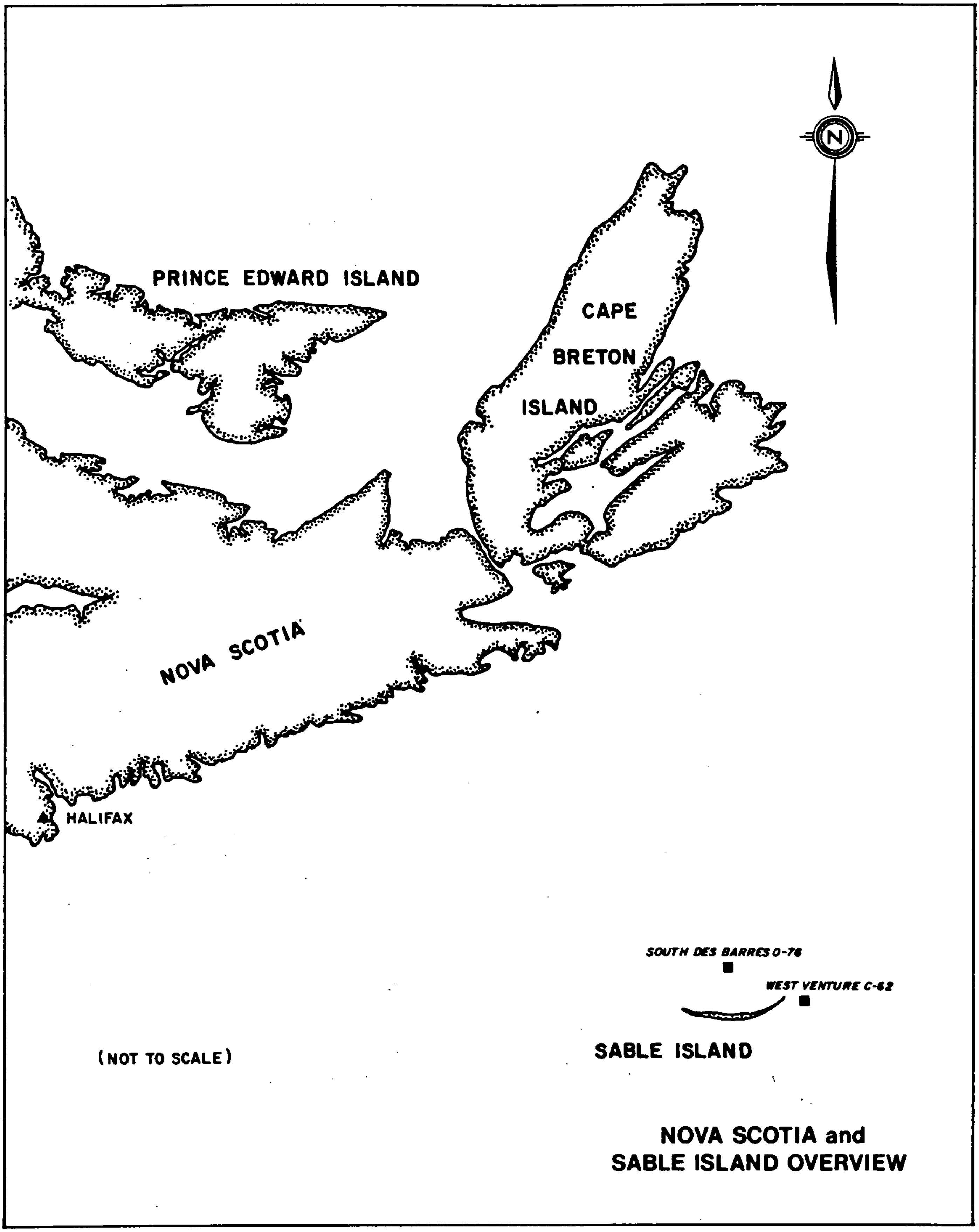


Figure 1. Location map for Sable Island and two rig sites.

SAMPLING PROGRAM

The two areas under study were substantially different. The Mobil West Venture C-62 site was located in about 16 m of water along the south side of the eastern bar of Sable Island which meant that the bottom sediments were well mixed by wind and wave action. The Shell South Des Barres O-76 site was located about 19 km north of the middle of Sable Island in about 70 m of water. At this site the bottom sediments were not influenced to a large extent by wave action during the six months (in summer and fall) required to drill the well. A cruise report (Dobrocky Seatech Ltd. 1984) outlines in detail the sample collection and storage procedures prior to delivery at the laboratory. The station positions (± 5 m) and numbers for each site are shown in Figures 2 and 3 and in greater detail in Appendix 1.

The two areas provide a contrast in the expected modes of transport and dispersal of the oiled cuttings. The West Venture site was in shallow water with considerable wave energy and sediment transport. The deeper-water South Des Barres site was influenced to a lesser extent by wave energy. Because the initial distribution of the cuttings, as they fall from the rig, is almost entirely determined by the prevailing currents, this site was therefore an excellent location for the study of the dispersal of oiled cuttings by ocean currents.

Positioning for the pre-drilling sampling at the West Venture site was by Argo and for the South Des Barres site by radar bearing to the rig and by Loran C.

Post-drilling sampling was carried out from the 46.5-m MV *Arctic Prowler*. The vessel was equipped with a Syledis (UHF frequency band 436 MHz) navigation system, which enabled precise positioning (±5 m) of each station location with respect to the well-head discharge point. Distances were measured between the antenna on the *Arctic Prowler* and three stations located on Sable Island. The distances were determined based on the propagation time between each shore station and the vessel. All replicate grabs were collected within 50 m of the pre-designated station location. The position of each sample is plotted in Appendix 1.

For both the West Venture and South Des Barres sites, samples were taken along eight radial lines. For the West Venture program, grab samples were taken at distances about 200 m, 500 m, and 1,000 m and for South Des Barres, distances were about 0, 200 m, 800 m, and 1,500 m (see Figures 2 and 3). For both areas, control samples were taken 3 km away from the well-head in the expected "upcurrent" direction (southwest and west respectively). A 0.1-m^2 Smith-McIntyre grab was used for all collections; the station position was recorded when the grab hit the bottom . This grab proved to be excellent in the sandy bottoms found at both sites, particularly during heavy seas, because the trip mechanism was not affected by the pitch and roll of the ship.

Surface samples (sediment depth 0-5 cm) were collected at every station. For some of the stations (chosen randomly), a replicate surface sample or a depth sample (5-10 cm), or both, were collected. All samples were placed in oven-baked (400°C) glass jars with a piece of clean Teflon or aluminum foil under the lid. The remainder of the sample was subsampled for

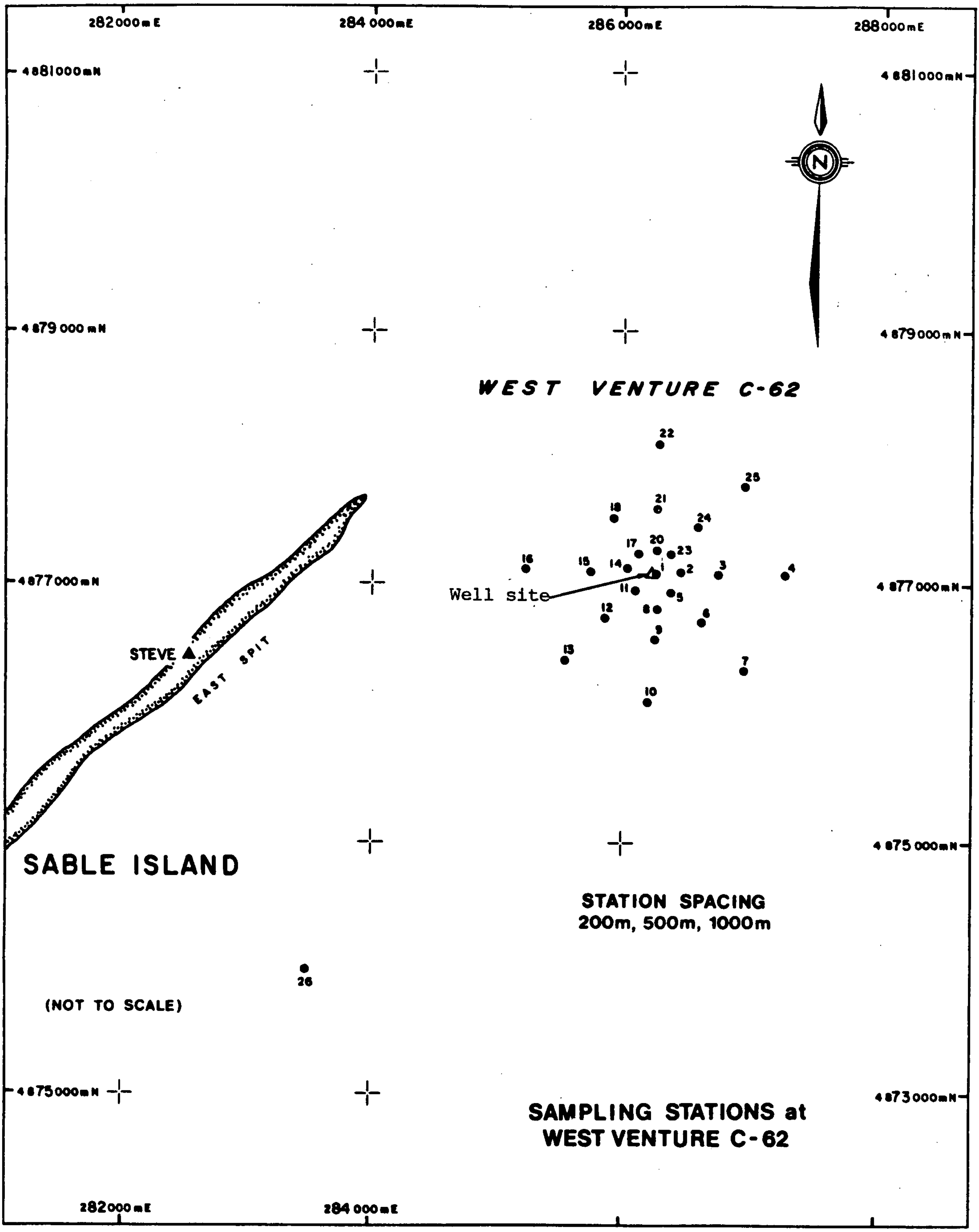


Figure 2 Station positions and numbers for the West Venture Site.

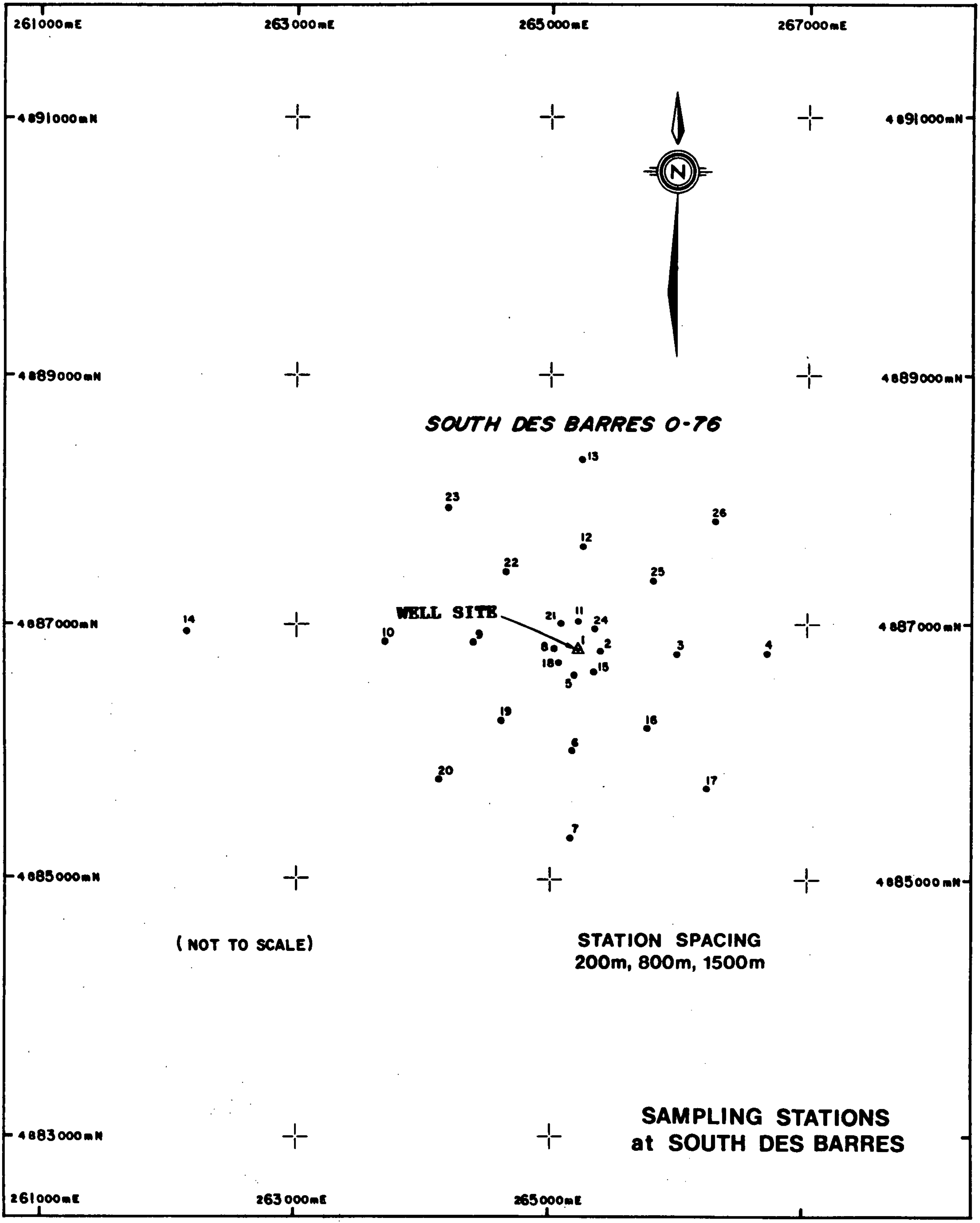


Figure 3. Station positions and numbers for the South Des Barres site.

sediment particle-size analysis. These operations were performed as quickly as possible to avoid shipboard contamination. Care was taken to collect the sediment from the centre, away from the walls of the grab. The grab was rinsed well after each sample, either with a mixture of pesticide-grade hexane/acetone (1:1), if the previous sample was suspected of being heavily oiled, or with clean sea water. As a minimum, the grab was washed well with solvent between stations that were located at different distances from the well-head. All samples were permanently and unambiguously marked and were frozen immediately.

Well-head (0 m) samples for West Venture were taken by divers on 4 November 1984 when the rig was still in position. At this time, the area covered by drill cuttings was reported to be an ellipse 24 m x 20 m and to be about 30 cm deep (i.e., about 110 m^3). The thickness was reported to be uniform except at the edges; samples for hydrocarbon analysis were collected near the centre of the pile. On 1 February 1985, divers collected more sediment samples and reported that the oiled cuttings were completely absent.

Key samples were selected for further GC/FID and GC/MS (gas chromatography with mass spectrometric detection) analyses by the Battelle New England Research Laboratory of Duxbury, Massachusetts. Battelle was contracted to perform detailed GC/FID analyses for aliphatic hydrocarbons and GC/MS analyses for polynuclear aromatic hydrocarbons (PAH) on selected sediment and cuttings extracts, as well as on the Conoco ODC base oil used in the drilling mud formulations. In addition to quantifying the hydrocarbon components that were most likely to contribute to the acute toxicity of the muds (i.e., the PAHs), the intention was also to examine the environmental partitioning and degradation of the oil in the ocean environment.

ANALYTICAL PROCEDURES

HYDROCARBON EXTRACTION METHOD

Effective measurement of hydrocarbons in marine sediments requires standardized extraction procedures that are efficient and reproducible. In the past, hydrocarbon extractions from sediment used solvent reflux and often involved freeze-drying; both of these methods pose difficulties for the efficient processing of large numbers of samples (Brown et al. 1980). The ambient temperature method that we used for the Sable Island study involves the extraction of sediment in Teflon bottles at room temperature and is both quantitative and efficient (Barrick et al. 1980). It also lends itself to the rapid processing of a large number of samples at once and avoids the unnecessary costs and hazards associated with boiling solvents.

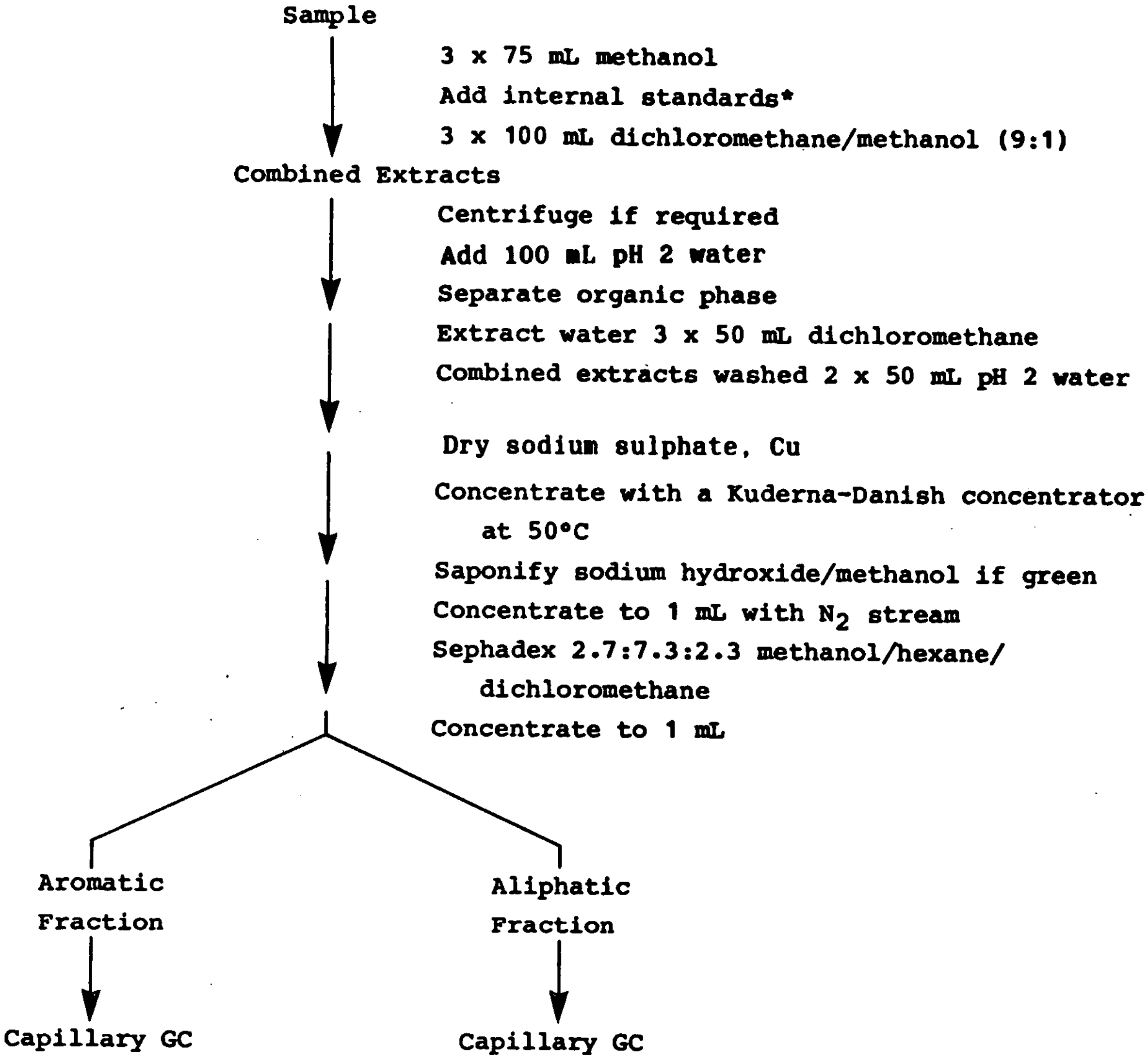
We have made a significant number of improvements in existing methods to optimize the extraction and quantification procedures for the volatile Conoco ODC base oil used in the drilling muds. This base oil is now marketed under the name Vista ODC, but Conoco ODC, the name in use at the time that the wells were drilled, is used throughout this report. All of the solvents used in the extraction and chromatography procedures are low-boiling. Only dichloromethane and hexane/methanol azeotrope (bp 40°C and 50°C, respectively) are evaporated away from the sample. Use of a Kuderna-Danish concentrator keeps the evaporation temperature low and ensures that samples do not become dry. The final concentration steps are done with a "blanket" of dry nitrogen without heating. These steps ensure that there are no significant losses of the low-boiling hydrocarbons, and that the analytical results provide a realistic assessment of the total mineral oil hydrocarbon content of the samples.

The extraction method for the fused silica capillary GC analysis of sediment samples was based on the methods of Brown et al. (1980) and Boehm et al. (1982) as modified and optimized by Dobrocky Seatech Ltd. Sediment samples were thawed and well-mixed before analysis.

Approximately 100 g of wet sediment subsample were weighed into a 250-mL Teflon jar and were dried by extracting three times with methanol using a rotary mixer. A second 10-20 g portion of the wet sediment was dried at 105°C to obtain a dry weight. A known amount of four internal standards, perdeuterated decane, perdeuterated naphthalene, androstane, and o-terphenyl, were then added to the sediment and the extraction was continued as shown in Figure 4.

The sediment samples were analysed in batches of 24. As a quality control measure, each batch contained two blanks and two sediment duplicates chosen at random in addition to 20 sediment samples. Blank run analyses were conducted concurrently with sediment sample analyses using identical methods of extraction and column chromatography. The batch numbers are shown in Appendix 2 as part of the detailed hydrocarbon results.

After Kuderna-Danish concentration, most of the South Des Barres sediment extracts showed an opaque green colour resulting from biolipids and pigments. These pigments interfered with the column chromatography by



* Internal Standards used

A. Extraction Recovery Standards
Aliphatics androstane ($C_{19}H_{32}$) and n-decane-d_{22}
Aromatics o-terphenyl ($C_{18}H_{14}$) and naphthalene-d_8

B. GC Internal Standard
hexacosane (n-$C_{26}H_{54}$)

Figure 4. Outline of the extraction method.

contaminating the Sephadex gel and by providing a green colour to eluted fractions. The green pigments were removed by saponification at 50°C with 10 molar aqueous NaOH/methanol, followed by extraction with hexane.

The columns used for the Sephadex gel, permeation chromatography were equipped with a cooling water jacket to ensure a stable temperature and hence consistent separation. This step became necessary when high summer temperatures in the laboratory started to produce bubbling and cracking in the Sephadex columns as well as a degradation in the efficiency of the separations. Batches 1-5 were separated before the heat became a problem; batches 6-10 were all processed using the jacketed columns.

The chromatography solvent mixture used was chosen both because of its ability to separate the aromatics from the aliphatics, as well as the low boiling points of the constituent solvents. The 2.7:7.3:2.3 methanol hexane/dichloromethane mixture separates into a mixture of dichloromethane and hexane/methanol azeotrope (bp 40°C and 50°C, respectively) on distillation.

The Sephadex LH-20 columns were calibrated using a standard solution containing decane, naphthalene, o-terphenyl, and androstane. Decane-d_{22} and androstane were used to define the aliphatic (first) fraction, and naphthalene-d_8 and o-terphenyl were used to define the aromatic (second) fraction. Columns were rechecked periodically with the standard mixture to ensure that the elution volumes had not changed significantly. The column was washed with sufficient solvent between samples to ensure that no cross contamination would occur.

The column fractions were concentrated to < 1.0 mL using a stream of pure dry nitrogen and no heat. The fractions were made up to 1.0 mL using dichloromethane, then transferred to a 1.5-mL storage vial and capped and stored cold until GC analysis.

QUANTITATION OF AMOUNTS OF HYDROCARBONS USING THE INTERNAL STANDARD METHOD

Fused silica capillary gas chromatography and flame ionization detection (FID) were used to quantify and characterize the aliphatic and aromatic hydrocarbon fractions in each sample. As mentioned previously, the internal standards androstane, o-terphenyl, and perdeuterated decane and naphthalene, were added to the sediment just after the methanol drying stage. With the exception of a few of the most concentrated samples, the Conoco ODC mineral oil did not interfere with either of the primary internal standards androstane or o-terphenyl. Perdeuterated materials were used for the decane and naphthalene standards so that they could still be quantified by gas chromatography with mass spectrometric detection (GC/MS) if they were obscured by Conoco oil; in most cases these standards were at least partially covered when Conoco oil was present in the sample. The standards were carried through the extraction procedure and were separated at the Sephadex chromatography stage: the decane-d_{22} and androstane eluted with the aliphatic fraction and naphthalene-d_8 and o-terphenyl eluted with the aromatic fractions.

Because deuterated decane and naphthalene are more volatile than most of the mineral oil components, they were intended to serve as a continuous check on the loss of volatile material from the aliphatic and aromatic fractions respectively, and during the extraction procedure. Androstane and o-terphenyl served as internal standards for the quantitation of the amounts of aliphatics and aromatics respectively. In the latter part of the study hexacosane (n-$C_{26}H_{54}$) was added to some of the sediment extracts just before GC analysis to assess the recovery of the androstane and o-terphenyl by the extraction process. The addition of this internal standard did not interfere with the determination of either the amount of mineral oil or the hydrocarbon background levels in the sediments.

The recoveries of the deuterated decane and naphthalene internal standards were, in general, low (about 25% for decane and 40% for naphthalene) indicating that some loss of the more volatile fractions had occurred in spite of the elaborate precautions taken. Relative to hexacosane, the calculated amounts of the androstane internal standard showed wide variation even though the androstane peak areas were relatively consistent from sample to sample. Because the hexacosane was added to each final 1-mL GC sample as a 1-µL spike of a standard hexacosane solution in dichloromethane, most of this variation apparently results from the actual dispensing of the standard.

The amounts of the major aromatic and aliphatic hydrocarbons that appeared as peaks and of the unresolved complex mixture (UCM) of cyclic and branched chain hydrocarbons that appeared as a "hump" (see Results) were quantified using the internal standards. The Varian Vista 401 integration software provided accurate, reproducible, and separate integrations for the UCM and for the individual peaks in the GC fraction. The UCM is defined as the area enclosed by the chromatographic zero baseline and a tangential skim at the base of chromatographically resolved peaks.

Two separate peak area calculations were performed for each sample. To obtain the total hydrocarbon concentration, the area of each peak was calculated relative to a horizontal baseline that was essentially the same as the chromatographic zero baseline. The peak areas were then summed. To obtain the resolved hydrocarbon concentration, the area of each peak was calculated relative to a baseline that extended tangentially from valley to valley between the resolved peaks, with the peak areas being summed. This latter method allowed the calculation of a total area for the resolved peaks that stick out of the "hump." Subtraction of this total area from the total area obtained for the first method gave the total area of the unresolved complex mixture. Similar methods were used to correct for any baseline drift towards the end (the higher temperature range) of the chromatogram.

The concentration of internal standard expected in each sample was input into the integration method at the time that the sample was analysed and the GC results for the sample were reported in terms of concentration units of the internal standards. For the aliphatics samples results were expressed in terms of ng of androstane per µL injected and for the aromatics in terms of ng/µL of o-terphenyl injected. All unknown peaks were assumed to have the same relative response factors as the internal standards. However, a series of calibration injections were performed to quantify the actual relative response of the internal standards to each other.

Standard samples of Conoco ODC mineral oil were used to quantify the GC/FID response of the androstane internal standard in terms of equivalent total amounts of Conoco ODC oil. Final aliphatics results were expressed in terms of the amounts of Conoco ODC mineral oil extracted from the sediment in µg/g dry weight. Because of the difficulties that would be encountered in isolating and quantifying the aromatic fraction of the Conoco oil, a calibration of the aromatics in terms of the Conoco oil could not be performed and aromatics results were expressed in terms of o-terphenyl equivalents. All calibration curves used are shown in Table 1.

The weight of material in Conoco oil equivalents necessary to produce a given detector response (and hence peak area) was about five times greater than the weight of material in o-terphenyl equivalents necessary to produce the same detector response. This difference is reflected in the quoted limits of detection; aromatic detection limits in o-terphenyl equivalents were approximately 0.01 µg/g dry weight while aliphatic detection limits in Conoco oil equivalents were approximately 0.05 µg/g. Both limits of detection assume 80 g of sample used. The limits of detection were not rigorously determined; the detection limit was set by taking half of the lowest concentration that was measured reliably by the detector.

REAGENTS AND CLEANING PROCEDURES

All organic solvents used were BDH Omnisolv grade and were redistilled in glass through a fractionating column packed with 43 cm of raschig rings before use. Solvents to be used for Sephadex chromatography were first redistilled as the 2.7:7.3 methanol/hexane azeotrope. The elution mixture was then prepared by adding redistilled dichloromethane to produce a final mixture of 2.7:7.3:2.3 methanol/hexane/dichloromethane. Solvents used for cleaning glassware were also redistilled Omnisolv grade. The hydrochloric acid used for acidifying the quartz distilled water was Baker Instra-Analyzed grade. The internal standards used were the best available grade and were obtained as follows:

n-decane-d_{22}	MSD
5-alpha-androstane	Sigma
naphthalene-d_8	Sigma
o-terphenyl	Analabs

Nitrogen used to blow down solvents was pre-purified grade for batches 1-5 and K grade filtered through molecular sieves for batches 6-10. Teflon-backed silicon rubber GC septa were used. They were soxhlet extracted with pentane overnight and baked at 300°C under a vacuum for 4 h before use.

All glassware was cleaned with Sparkleen, rinsed with tap water to remove all detergent, and then rinsed twice with distilled water. Glassware was then baked at 420°C in a muffle furnace for a minimum of 4 h and was stored with all joints and openings covered by baked aluminum foil.

Sephadex LH-20 was soxhlet-extracted with acetone and then with methanol. The gel was air-dried at room temperature and was swelled with the chromatography solvent before use.

TABLE 1

Calibration curves used for the aliphatic and aromatic fractions

---

A. Aliphatics

In terms of <u>androstane equivalents</u>:

linear range from 0.1 - 207 µg/µL Conoco oil

or 25 - 71,000 ng androstane equivalents

$$\underset{\text{equivalents ng}}{\log \text{androstane}} = 1.026697 \; \underset{\substack{\mu\text{g}/\mu\text{L Conoco oil}\\ \text{equivalents}}}{\log \text{concentration}} + 2.604103$$

$r = 0.9943$ $n = 14$ pairs

In terms of <u>peak area</u>:

linear range from 2 - 207 µg/µL Conoco oil. This calculation was only used if androstane was not reliably quantified.

$$\underset{\text{area}}{\log \text{peak}} = 1.019427 \times \underset{\substack{\mu\text{g}/\mu\text{L Conoco oil}\\ \text{equivalents}}}{\log \text{concentration}} + 2.116326$$

$r = 0.9968$ $n = 10$ pairs

The <u>final calculation</u> for aliphatics is:

$$\underset{\substack{\mu\text{g/g}\\ \text{weight}}}{\text{concentration}} = \underset{\substack{\mu\text{g}/\mu\text{L}\\ \text{Conoco oil}\\ \text{equivalents}}}{\text{concentration}} \times \frac{\text{dilution}}{\text{dry weight}} \times 1000$$

B. Aromatics

The <u>final calculation</u> for aromatics is:

$$\underset{\substack{\mu\text{g/g dry}\\ \text{weight}}}{\text{concentration}} = \underset{\substack{\text{ng}/\mu\text{L}\\ \text{o-terphenyl}}}{\text{concentration}} \times \frac{\text{dilution}}{\text{dry weight}}$$

All Teflon parts, including Teflon jars, vial caps, stopcocks, and all volumetric glassware were cleaned with RBS detergent, were rinsed with distilled water, and then were solvent cleaned with one rinse of methanol and two rinses of dichloromethane. All baked glassware was rinsed with a small amount of dichloromethane before use to prevent analyte adsorption onto active surfaces.

The 10 molar aqueous NaOH used for saponifications was extracted with six portions of dichloromethane and six portions of hexane before use.

SEDIMENT EXTRACTION

All sample manipulations up to the GC stage were carried out in a clean room supplied with high efficiency particulate air (HEPA) filtered air and were performed by trained personnel wearing clean suits. Samples were removed from the freezer and were thawed overnight at room temperature. Each wet sample was completely transferred to a baked, aluminum pan. After thorough mixing, a 100-g subsample (±0.002 g) was placed in a clean, 250-mL Teflon jar. At this time an additional 10-20 g were weighed into a small, aluminum pan for dry weight determination at 105°C. The samples were dried by extracting three times for 0.5 h with 75 mL of methanol using a rotary mixer. The supernatant liquid was decanted into a 1-L, baked, Erlenmeyer flask and covered with aluminum foil. The dried sediment was then extracted three times with 100 mL of dichloromethane/methanol (9:1) by mixing for a minimum of 4 h. Prior to the first mixing with the dichloromethane/methanol mixture, a known amount (50 or 100 µL) of four, internal standards (n-decane-d_{22}, 5-alpha-androstane, naphthalene-d_8, and o-terphenyl) were added to each sample. All solvent extracts were then combined.

One-litre separatory funnels were used for all extractions. Quartz-distilled (QD) water was acidified to pH 2 using hydrochloric acid, and 100 mL of this acidified water was poured into the separatory funnel prior to sample addition. The sediment extracts were added to the separatory funnel and the 1-L flask was rinsed three times with about 30 mL of dichloromethane.

Sediment extracts that contained large amounts of finely divided particulates were decanted into the separatory funnel until about 30 mL remained in the flask. This residue was then transferred in three portions into a 15-mL test tube using a disposable, Pasteur pipet and was centrifuged in an IEC 428 Clinical Centrifuge at a setting of 4 for about 3 min. The solvent was then pipetted into the separatory funnel. The sediment plug was washed with 10 mL of clean dichloromethane, centrifuged as before, and the solvent then transferred to the separatory funnel. The 1-L flask was rinse as before with dichloromethane (3 x 30 mL).

After shaking, the dichloromethane layer was drawn off and the aqueous methanol phase extracted three times with 50 mL of dichloromethane. All extractions were shaken for 1 min. All of the dichloromethane extracts were combined and washed with two 50-mL portions of pH 2 QD water. The extracts were then stored overnight over sodium sulphate (20-25 g) and activated copper powder (4-5 g, for removal of sulphur).

All sample concentrations were performed using Kuderna-Danish apparatus to minimize the loss of low-molecular-weight hydrocarbons. The baked Kuderna-Danish apparatus was assembled using solvent-washed Teflon tape to seal the lower joint and then secured with elastic bands. Each sample extract (300-400 mL) was poured into the concentrator along with three 30-mL rinses of the flask containing the sodium sulphate drying agent. The apparatus was then assembled and placed in a 50°C water bath until approximately 5 mL remained. This volume was further reduced to 1.5 mL using a stream of pure, dry nitrogen and a cool water bath. Samples collected in the West Venture area appeared clear yellow in most cases.

Samples from the South Des Barres area usually concentrated to an opaque green. These samples were saponified in a 50-mL glass tube with a Teflon-lined cap. The dichloromethane was first displaced with methanol, and then the sample was transferred to a 50-mL glass tube using 10 mL of methanol. After the addition of 4 mL of 10 molar aqueous NaOH, the tube was capped and heated overnight at 50°C. The cooled mixture was extracted three times with 15 mL of hexane and the combined extracts dried over sodium sulphate and evaporated to 1.5 mL with a stream of dry nitrogen.

COLUMN CHROMATOGRAPHY

The 1.5 mL of sample was transferred to the top of a 45-cm x 1-cm Sephadex LH-20 column using a disposable pipette and three rinses of the chromatography solvent. Note that a 30-cm x 1-cm column was used only for the West Venture 200-m and 500-m samples, batch 1. After batch 5, jacketed columns cooled by tap water were used to ensure a consistent separation and to avoid formation of bubbles in the column. Each column was eluted using a 2.7:7.3:2.3 methanol/hexane/dichloromethane mixture and separate aliphatic and aromatic fractions were collected. Both fractions were evaporated to 1.0 mL, transferred to a 1.5 mL vial with a Teflon-lined cap, and stored cold until GC analysis. The first 30 mL eluted from each column were discarded and the column was washed with a further 25 mL of solvent after the aromatic fraction had eluted, for a total wash between samples of 55 mL.

Prior to the chromatography of actual samples, the columns were calibrated using 100 µL of a standard solution containing decane, androstane, o-terphenyl, and naphthalene in 1.5 mL dichloromethane. The standard was eluted with the same solvent system as the samples, and gas chromatograms of the eluted fractions were used to delineate the column volumes containing aliphatic species and aromatic species. Decane-d_{22} and androstane were used to define the aliphatic (first) fraction and naphthalene-d_8 and o-terphenyl were used to define the aromatic (second) fraction. The cut points varied slightly among the three columns used, but typically the aliphatic fraction eluted with 30-55 mL of solvent and the aromatic fraction eluted with 55-100 mL of solvent.

PREPARATION OF INTERNAL STANDARDS

A solvent-cleaned volumetric flask (either 10 mL or 50 mL) was tared on an analytical balance. The standards 5-alpha-androstane, o-terphenyl, and naphthalene-d_8 were added using a baked spatula and were weighed to 0.00001

g. n-Decane-d_{22} was added to the volumetric flask using a 50-µL syringe and was also weighted to 0.00001 g. The flask was made up to volume using dichloromethane. Standard solutions were transferred to a number of 10-mL Teflon vials and were stored in a refrigerator.

Three sets of standards were used throughout the analysis of samples from batches 1-5 to minimize the possibility of contamination or change in concentration with time. For batches 6-10 one internal standard was subdivided into a number of different vials, and after opening each vial was only used for a brief period of time.

To determine the relation between the internal standards (primarily androstane) and the actual amount of Conoco oil present, a series of Conoco calibration standards were prepared to cover the range of sample concentrations encountered. Varying amounts of Conoco oil were weighed into solvent-clean, 10-mL, glass volumetric flasks and were diluted to volume with distilled dichloromethane. The lower concentration standards were prepared by serial dilution of these solutions. All calibration solutions contained 100 µL of an internal standard solution.

The calibration data obtained are shown in Table 2. Note that no values are provided for the resolved aliphatics at higher Conoco oil levels because of the fall off in resolution at high column loadings.

The Conoco oil used to prepare these standards was a subsample of Conoco ODC Drilling Fluid Base Oil that was supplied to Dobrocky on 3 October 1984 by Technifluids Ltd.

GAS CHROMATOGRAPHY

Instrument conditions are listed in Table 3. A Hamilton 7101N 1- µL syringe equipped with a Chaney adaptor was used for all injections. A custom-made syringe guide was attached to the septum retainer nut of the GC and was used to ensure the reproducibility of syringe needle placement for all analyses.

Before each injection the syringe was washed three times with dichloromethane and rinsed at least three times with the sample to be injected. The syringe was pumped three times to remove air bubbles and the plunger drawn up to 1 µL. The septum purge was turned off, the sample injected over 10 s, and the temperature program started. The syringe needle was then removed from the septum guide after 10 s and rinsed at least 10 times with dichloromethane. The septum purge was turned on again after 1 min.

The column was usually baked out at 240°C overnight with all FID gases flowing.

TESTING OF THE ANALYTICAL METHOD WITH REPLICATE SAMPLES OF CONOCO ODC OIL

Reagent blanks were spiked with known amounts of a standard solution of Conoco ODC oil and these spiked solutions were carried through all of the extraction, chromatography, and GC analysis steps. The results of this experiment are shown in Table 4. The analytical results for the aliphatic

TABLE 2
Calibration of the amount of Conoco oil present in a sample in terms of the internal standard androstane

Concentration of Conoco oil (µg/µL)	Total aliphatics		Resolved aliphatics	
	Androstane equivalents (ng)	Peak* area	Androstane equivalents (ng)	Peaks area
0.09529	23.7611	3.62516	9.6343	1.46196
	26.0313	4.22652	10.9548	1.7704
0.9529	483.8582	84.1548	181.1099	31.4486
	490.2105	88.1146	192.0268	34.1613
9.529	5,545.1300	936.7666	1,896.250	335.8369
	5,479.5280	951.3457	1,912.087	329.3780
20.81	13,007.3	3,340.24	2,960.43	757.894
	13,394.1	3,266.52	2,827.29	691.240
51.74	20,695.2	8,426.55		
	21,216.5	8,330.66		
102.7	38,948.5	14,069.13		
	38,785.6	13,491.27		
207.3	71,516.9	25,809.55		
	74,997.3	28,103.12		

*Peak area values have been standardized to a single attenuation level.

TABLE 3

Analytical conditions used for the fused silica capillary gas chromatography/flame ionization detection

Instrument:	Varian 3700 with capillary injector
Data system:	Vista 401
Inlet:	Splitless
Detector:	Flame ionization
Column:	0.25 mm i.d. x 30 m DB5-fused silica (J&W Scientific)
Gases:	
Carrier:	Helium high purity 2 mL/min
Make-up:	Nitrogen pre-purified 30 mL/min
Detector:	Air 300 mL/min Hydrogen 25 mL/min
Temperatures:	
Injection port:	250°C
Detector:	350°C
Column oven:	40°C for 1 min, 40°-290° @ 8°C/min
Quantification:	Internal standard A. Extraction recovery standards Aliphatics androstane ($C_{19}H_{32}$) and n-decane-d_{22} Aromatics o-terphenyl ($C_{18}H_{14}$) and naphthalene-d_8 B. GC internal standard Hexaconsane (n-$C_{26}H_{54}$)
Reporting format:	Aliphatics µg/g dry weight of Conoco ODC mineral oil extracted from sediments Aromatics: µg/g dry weight of aromatics in terms of o-terphenyl extracted from sediments

TABLE 4
Results of the extraction and analysis of spiked solutions of Conoco ODC oil

Theoretical spiked concentration µg/µL Conoco oil	Analytical replicate	Concentration measured µg/µL Conoco oil	Mean recovery (%)	Equivalent concentration µg/g dry weight Conoco Oil*
0.9997	a	0.36		
	b	1.26		
	mean ± sd	0.81 ± 0.64	81	10.1
9.997	a	5.78		
	b	10.40		
	c	4.14		
	mean ± sd	6.77 ± 3.25	68	84.7
99.97	a	95.56		
	b	81.34		
	c	86.20		
	mean ± sd	87.70 ± 7.23	88	1,090

* Assuming 80 g dry weight of sample.

and aromatic fractions were added together without any correction for relative detector response to obtain the measured Conoco oil concentrations.

The best and most consistent recoveries were obtained for the samples with the highest Conoco oil concentrations. At the low and medium concentrations the variations between samples were quite large, which suggests that there may have been problems with the initial spiking of the blank solutions. However, when the mean recoveries obtained for each concentration were considered, it was concluded that the analytical methods were working well enough to satisfy the goals of the study.

As an aid to interpreting these results, the mean Conoco oil concentrations obtained (in µg/µL) have been converted to µg/g dry weight by assuming 80 g dry weight of sample.

VARIATIONS WITHIN SINGLE GRABS AND BETWEEN ANALYTICAL REPLICATES

The variation between samples taken side by side in the same grab is shown in Table 5. The differences in values obtained for the low-concentration samples at the West Venture site likely reflect both environmental and analytical variations. For the higher concentration South Des Barres well-head samples however, the differences are large. Most of this variation is likely from environmental inhomogeneity, although it is possible that there is a fall off in extraction efficiency at these high concentrations.

The variation between analytical replicate samples is shown in Table 6. These samples were prepared, by hand, by mixing a sample of sediment from either one or two grabs and then subsampling the mixture into two portions for analysis. Because the Conoco oil is unlikely to be homogeneous in the sediments, and because a thorough mechanical mixing was not performed, it is likely that many of the variations obtained between replicate samples are due to a spotty distribution of the oil in the sample. This assertion is supported by the fact that the variations observed are smallest for the samples that contained little or no Conoco oil; the variation in these cases would be due mostly to analytical variation.

For all of the samples shown in Tables 5 and 6, the variation either within grabs or between replicates is small enough so that the goals of the study can be met.

COMPARISON OF WET AND DRY WEIGHTS FOR THE HEAVILY OILED SAMPLES

All the concentrations presented in the Results (see Tables 12 and 13) and in Appendix 2 are based on dry weights which were obtained after drying each sample overnight at 105°C. This temperature was chosen because it is the standard temperature for drying marine sediments and because no strong case could be made for changing the temperature for the heavily oiled samples.

A number of drying problems arise when working with oiled cuttings and drilling mud residues. The Conoco oil contains many hydrocarbon components which are volatile at 105°C and their loss could contribute a significant

TABLE 5
Variation between samples taken side by side in the same grab

Station	Grab	Total aliphatics in µg/g dry weight Conoco: Range	Total aliphatics in µg/g dry weight Conoco: Difference between subsamples*
West Venture 200 m post-drilling			
M14	1	4.12 - 34.02	29.90
M14	2	19.70 - 41.90	13.73
M20	1	5.13 - 20.55	15.42
M20	2	5.86 - 11.24	5.38
South Des Barres well-head post-drilling			
S1	3	26,280 - 104,800	78,520
S1	4	9,170 - 53,100	42,910

* Note that if more than one analytical replicate was analyzed for a grab subsample, the mean was used to calculate the difference between subsamples.

TABLE 6
Variation between analytical replicate samples

Station	Grab	Total aliphatics in µg/g dry weight Conoco	
		Range	Difference between replicates
West Venture well-head post-drilling			
M1 4 Nov 1984	1	146,500 - 168,900	22,400
M1 4 Nov 1984	2	136,900 - 153,600	16,700
M1 1 Feb 1985	2	641.9 - 693.4	51.50
West Venture 200 m post-drilling			
M2	1	6.48 - 9.21	2.73
M14	2	19.70 - 36.65	16.95
M23	1	5.02 - 9.18	4.16
West Venture 500 m post-drilling			
M21	1+2	3.98 - 4.85	0.87
West Venture 1,000 m post-drilling			
M10	1+2	1.36 - 2.33	0.97
West Venture control post-drilling			
M26	1	0.53 - 0.95	0.23
M26	3	1.79 - 3.04	1.25
West Venture pre-drilling			
M1	2	0.48 - 1.31	0.82
M15	2	0.38 - 0.79	0.41
M26	3	1.61 - 1.72	0.11
South Des Barres well-head post-drilling			
S1	1	85,370 - 91,320	5,950
S1	2	141,100 - 230,600	89,500
S1	4	26,900 - 151,800	124,900
S1	4	50,940 - 53,100	2,160

TABLE 6 (continued)

Station	Grab	Total aliphatics in µg/g dry weight Conoco Range	Difference between replicates
South Des Barres 200 m post-drilling			
S2	2	15,440 - 18,160	2,720
S21	1+2	18.92 - 72.24	53.32
S24	1	790.3 - 1,557	766.7
South Des Barres 800 m post-drilling			
S16	1+2	18.30 - 38.67	20.36
South Des Barrres 1,500 m post-drilling			
S26	1+2	9.17 - 16.79	7.62
South Des Barres control post-drilling			
S14	2	3.49 - 5.40	1.91
S14	3	1.91 - 3.93	2.02
South Des Barres pre-drilling			
S1	3	110.6 - 220.2	109.6
S2	3	12.78 - 16.46	3.68
S9	5	4.43 - 5.31	0.88
S11	1	6.94 - 11.58	4.64
S14	2	3.02 - 4.64	1.62

error to the dry weight when the sample contains large amounts of oil. Balancing this is the consideration that drilling muds contain significant amounts of hydroscopic clays and a temperature of at least 105°C is required to dehydrate these materials. Thus, a temperature either lower or higher would not improve the drying procedure and the standard temperature of 105°C was therefore used. This point is discussed further in the results.

CONSTRAINTS ON THE ANALYSIS OF HEAVILY OILED SAMPLES

Because the extraction method used was designed and optimized for part per million levels of hydrocarbons, the heavily oiled samples presented a number of problems. For these highly concentrated samples a high attenuation was usually required on the gas chromatograph (even with dilution or reduced amounts of sediment sample) and the internal standard peak was often too small to be reliably integrated. As a result external standard, peak-area calibration procedures had to be used. Although this method can be expected to produce internally consistent results, there could be a bias relative to the results from the internal standard calculations, and there is likely to be a bias in the external standard results relative to the results produced by other methods.

ADDITIONAL ANALYSIS OF SELECTED CUTTINGS AND SEDIMENT EXTRACTS

Fifty-six fractionated sediment extracts (aliphatic and aromatic hydrocarbon fractions of 28 samples) and one Conoco oil sample were shipped to Battelle New England Research Laboratory from Dobrocky Seatech Ltd., Sidney, British Columbia. Upon receipt at Battelle, each sample was assigned a chemistry laboratory identification number, and all information on the original sample label was recorded on a chemistry laboratory Sample Custody and Identification Form. The samples were stored refrigerated until analysis.

Particularily in the case of the very oily cuttings and well-head samples, some sample extracts possibly experienced column breakthrough during the original fractionation, in which some of the aliphatic hydrocarbon components were eluted with the aromatic fraction. To alleviate any analytical discrepancies resulting from incomplete fractionation, the two fractions of each sample were recombined, transferred to hexane, and weighed on a Cahn 25 electrobalance in preparation for column chromatography. In addition, a solution containing 50 mg Conoco oil in 0.5 mL hexane was prepared with 5-alpha-androstane and o-terphenyl added as internal standards. Internal standards were not added to any of the sample extracts, because 5-alpha-androstane and o-terphenyl had already been added by Dobrocky Seatech Ltd.

The combined sample extracts and the Conoco oil solution were charged to a 100% activated silica gel/5% deactivated alumina/activated copper (11 g, 1 g, 2 g) chromatography column (1 cm inside diameter (i.d.)). The column was wet-packed in dichloromethane and prepared by eluting with 30 mL each of dichloromethane and hexane. Each sample of no more than 50 mg extract weight in 0.5 mL hexane was charged to the column. The column was eluted with 25 mL of hexane followed by 21 mL of hexane;dichloromethane (1:1) to isolate the saturated hydrocarbons (f_1) and unsaturated (including PAH) compounds (f_2) respectively. The PAH (f_2 fractions) from two to five rings were analysed directly by fused-silica capillary GC/MS. A Finnigan MAT Model 4530 GC/MS system was used for all GC/MS determinations. A 30-m DB-5 column (0.25 mm i.d., J&W Scientific) was used in all GC/MS and GC/FID analyses. Parent ion (M+) total ion currents from GC/MS were computer-integrated, and amounts of PAH were computed by internal standard (o-terphenyl); relative response factors generated from GC/MS analysis of quantitative standard mixtures were used.

At Battelle, a Hewlett-Packard 5880 GC/FID with a Shimadzu C-R3A computer data system was used to analyse the f_1 fractions for aliphatic hydrocarbons. Individual aliphatic hydrocarbon concentrations (n-C10 to n-C30) were calculated versus the internal standard (5-alpha-androstane); response factors generated from the analysis of authentic standard mixtures were used. The concentration of the unresolved aliphatic hydrocarbons (UCM) was determined using the Shimadzu computer integrator that accurately measures the area of the UCM "hump" and quantifies it by comparison with the internal standard.

At Battelle initial GC/FID analysis of the saturated hydrocarbon fractions of half of the samples showed amounts of internal standard (5-alpha-androstane) at levels too low to quantify accurately. Consequently, an external standard (5-alpha-cholestane) was added and the fractions were reanalysed. Aliphatic hydrocarbon concentrations of these samples were then quantified by comparison with the external standard.

Quality control procedures for the analysis of the sediment extracts covered a wide range of activities, from daily calibration of all instruments with analytical standard solutions, to specific analyses of quality control samples. Quality control samples included the analysis of two blanks and two fortified blanks consisting of i) an alkane standard mix (n-C10 to n-C30) and ii) a PAH standard mix containing two- to five-ring aromatic hydrocarbons.

SEDIMENT PARTICLE-SIZE ANALYSIS

A homogenized sub-sample of the field sample was wet-sieved through a 4.0-phi (62.5 µm) screen. The water and mud fraction that passed through the screen was retained and allowed to settle. Most of the water was then decanted, and the amount of water made up to 140 mL. The mud and water was agitated and a volume of 20 mL removed for future Laser Granulometer analysis; the remainder was dried. The recorded weight of wet-sieved mud took into account the amount removed for Laser Granulometer analysis. The gravel and sand fractions were dried and sieved at 0.5 phi intervals, and their weights recorded.

COMPUTER SIMULATION OF THE CUTTINGS DISPERSION AND FATE

One of the objectives of this work was to compare the results of the field studies to the results of a computer model simulation of the expected cuttings dispersion and fate. The results point to a lack of quantitative description of the discharged material as a principal source of uncertainty in predictions.

MODEL DESCRIPTION FOR CUTTINGS DISPERSION AND FATE

The near-field dynamics of the cuttings discharges were assumed to be negligible because of the relatively low exit velocity and low output volume of the cuttings. The released particles, therefore, rapidly reach their terminal velocity independently of the small-scale, dynamic processes of the discharge. Also, for particle sizes of typical cuttings, the fall time is relatively short compared to the time scales of change in oceanic currents. An appropriate approach to model particle settling and resulting bottom distribution of cuttings is, therefore, to divide the cuttings into discrete size classes, each with a fall time based on fall velocity and water depth. Given the joint probability of depth-averaged current speed and direction, the horizontal distribution of each particle class can be computed for each direction class as a function of speed. Summing over particle size, direction and velocity classes yields an estimate of the cuttings distributions on the sea bed.

This procedure yields an estimate of the initial deposition of cuttings on the bottom; however, once deposited, the cuttings are influenced by local sediment transport processes. Transport on the continental shelf is, in most cases, dominated by the effects of waves. Waves themselves do not contribute significantly to the net motion of sediments; however, waves can suspend sediments which can then be moved by the weaker bottom currents.

The most complete theory describing the combined effect of waves and currents on sediment transport is that of Grant and Madsen (1979) and Grant and Glenn (1983). This theory, adapted to predict the fate of dredged spoil mounds (ASA 1983), was used to obtain a qualitative assessment of the eventual fate of the cuttings mound. From a simple, dimensional argument, a time scale for erosion or burial of the mound can be given by:

$$T = V/(B \times Q)$$

where Q is the mean rate of sediment transport with units of m^2/y; B is the horizontal dimension of the mound; and V is the mound volume. Q can be assessed from the wave and current climate, using the methodology of Grant and Madsen (1979). In view of the uncertainty in any estimate of Q, and of the simplistic model used here, the computed time scale, T, is only intended as an order of magnitude estimate and should only be used as such.

DISCHARGE PROPERTIES

A summary of the drilling program and of the cuttings discharges for the South Des Barres and West Venture wells is given in Table 7. For South Des Barres, the estimate of the total solids generated was obtained by calculating the theoretical hole volume, multiplying by 10% to account for sloughing and adding an estimate of barite lost. Particle-size distributions for a sample of cuttings from each of South Des Barres O-76 and West Venture C-62 are shown in Table 8 and by curves labelled "d" and "e" in Figure 5. The cuttings samples were washed numerous times by mixing with acetone and then by decanting the liquid after the solids had settled. When most of the oil had been removed, the samples were wet sieved at 63 µm (phi = 4.0) using acetone, and a portion of the mud fraction was dried to obtain the weight percentage of the fines. The sand and gravel fractions were then dried, sieved at 1.0-phi intervals, and weighed.

The South Des Barres cuttings sample, in particular, was found to contain substantial amounts (over 72%) of fine material (see Table 8 and curve "e" in Figure 5). In addition, particle-size analyses of sediment samples collected in the region of the South Des Barres discharge point (samples S1-2 and S1-3, Appendix 3) provided further evidence for the presence of substantial amounts of material finer than the shaker screens. Mud fractions (i.e., the fraction smaller than 63 µm) for these two samples were 84.5% and 82.8%. These results conflict with evidence from solids management systems (see Table 7) which indicated that about 90% of the released material was intercepted by shakers with a mesh size of about 63 µm (phi = 4).

The hypothesis was investigated that each grain was coated with a uniform thickness of drilling mud, perhaps governed by some equilibrium process. However, the thickness of the coat necessary to prevent particles from passing through the shakers implied that the volume of drilling fluid released was over 100 times that of the solid particles, and this clearly was not the case. This observation suggests that agglomeration of the oiled cuttings, or possibly screen blinding, had allowed the discharge of substantial amounts of fine material. Note that material as fine as that observed in samples S1-2 and S1-3 would be expected to remain suspended in the water column for a number of hours and large accumulations of this fine material around the discharge point would not be observed unless the material had been present as larger particles before discharge.

Shell Canada Ltd. (1986) has provided information that the South Des Barres cuttings were extremely sensitive to hydration and subsequent degradation once they were exposed to water. Large cuttings (>0.64 cm) removed from the oiled mud were observed to disintegrate quickly when dropped into a beaker of water; this was particularly prevalent for cuttings from the wide bore (44.5-cm; 17.5-in) hole. Because the large-diameter hole accounted for 62% of the theoretical total cuttings discharged, it is likely that a substantial portion of the fine material found near the South Des Barres well-head was this large-diameter cuttings material that had broken down to finer material in water. The remainder of the discharged fine material could be accounted for if the fine material had agglomerated due to the oil; this material would be cohesive enough to pass over the shakers, but would break down either on contact with sea-water (at either the washing

TABLE 7
Summary of the oiled mud drilling program and of the cuttings discharges for South Des Barres 0-76 and West Venture C-62

Interval	Distance (m)	Theoretical Volume (m^3)	Total solids Generated (m^3)
South Des Barres 0-76			
17.5-in hole 864-2736 m	1,872		
Plus side track 864-1024 m	160		
Plus side track 840-1059 m	219		
	2,257	350	
12.25-in hole 2736-5076 m	2,340	178	
8.38-in hole 5076-6036 m	963	34	
TOTAL	5,560	562	684

It has been estimated that 90% of the total gauge hole material was discharged from the shaker screens (>59 µm) and 10% of the total material was discharged from the centrifuge (2-62 µm). The centrifuge was used steadily for the 17.5-in hole (at least for the upper sections) and about 2 h/day for the 12.25-in hole. Estimates of the total solids discharged were provided by the solids-control engineers.

Material discharged from the shakers was washed with sea-water, combined with the centrifuge discharge and directed into a single discharge chute. The cuttings then dropped about 20 m from the rig deck to the water.

West Venture C-62			
17.0-in hole 860-2853 m	1,992	292	313
12.25-in hole 2853-4791 m	1,939		143
Plus side track 4499-4580 m	81	154	
	2,020		
TOTAL	3,931	446	456

Solids-control equipment included shaker screens (>63 µm) and desilters and a centrifuge (2-63 µm). The total solids removed were measured by the solids-control engineers. An estimate was made that the shakers removed over 90% of the material. All material was combined and discharged together from the rig deck (15-m drop).

TABLE 8
Results of the partical size analysis of oiled cuttings samples from West Venture C-62 and South Des Barres 0-76

Size Fraction (phi)	Weight Percentage Retained	
	West Venture* %	South Des Barres %
-1.0	0.41	0.19
0.0	6.64	1.03
1.0	6.49	2.15
2.0	5.32	3.24
3.0	13.73	3.62
4.0	33.39	17.62
Fines	34.01	72.15
Total	100.00	100.00
Gravel	0.41	0.19
Sand	65.58	27.66
Mud	34.01	72.15

*Cuttings sample number 41 supplied by COGLA to Dobrocky Seatech Ltd. was used in each case.

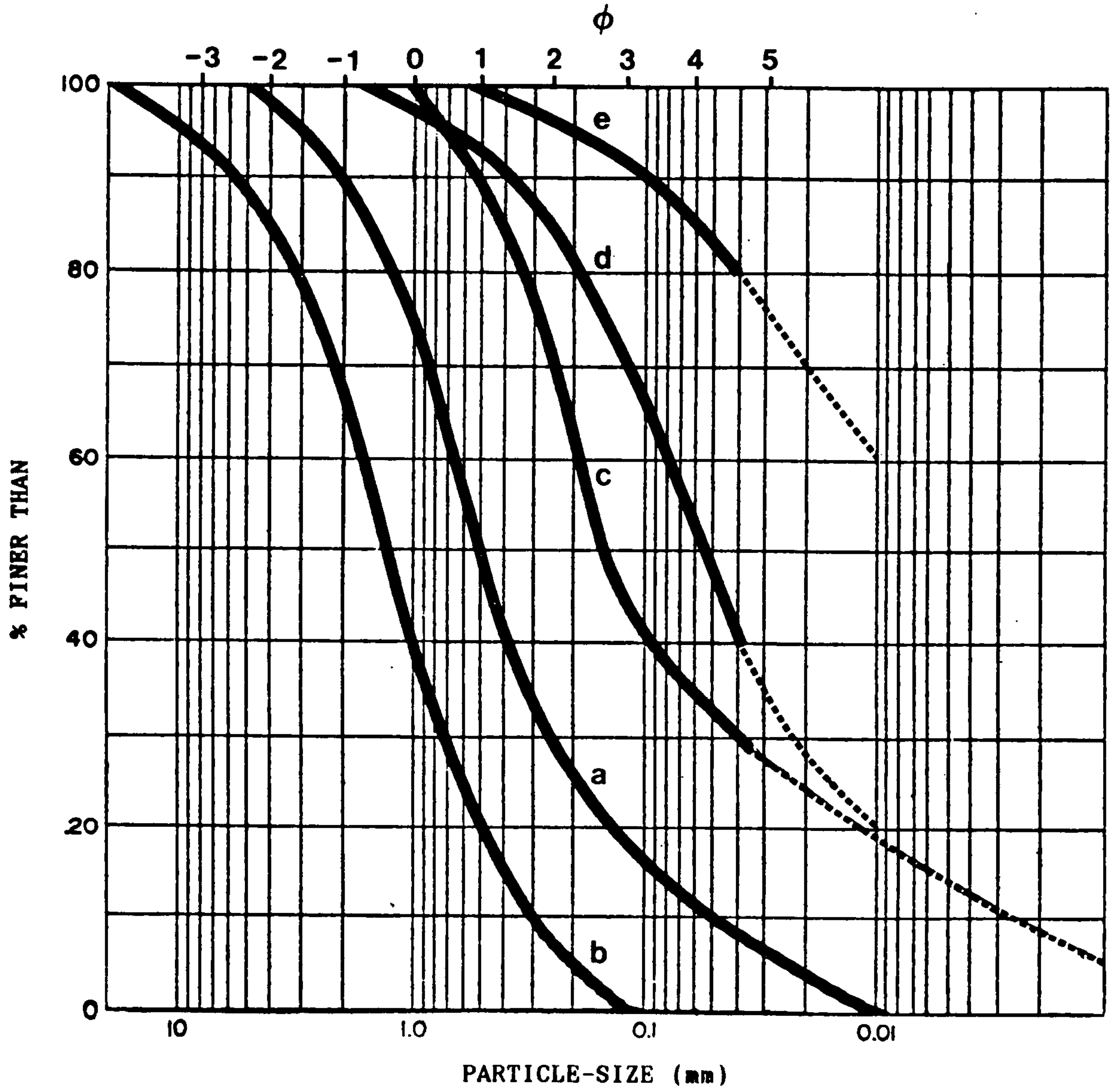


Figure 5. Particle-size distributions:

a) used as a working hypothesis
b) coarser distribution (from Addy et al. 1983)
c) finer distribution (from Addy et al. 1983)
d) particle-size analysis for West Venture C-62
e) particle-size analysis for South Des Barres O-76.

or discharge stages) or during the mechanical agitation necessary for particle-size analysis.

The difficulty now remains however, that no information is available on the actual size distribution of the particles that were discharged from each rig site. As a working hypothesis a particle-size distribution intermediate between the extremes given by Addy et al. (1983) for the North Sea was used. The lower end of the curve "a" (see Figure 5) was fixed so that 10% of the material would pass through a screen size of less than 63 µm (4 phi units). The drilling fluid was approximately 33% oil, 18% water, 44% barite, and 5% salts, clays, and emulsifiers by weight, for a net specific gravity of about 2.4 kg/L. The net oil concentration in the discharged material was measured at about 13% by weight (Chenard et al. 1985). The total amount of material discharged, estimated from the hole volume, was increased by 50% to account for the drilling fluid adhering to the cuttings and will thus exceed the estimates of total solids generated provided by the solids-control engineers (see Table 7).

The total material discharges were estimated at 1700 and 1400 tonnes wet-weight for South Des Barres and West Venture, respectively (based on borehole size and depth drilled, and a density of 2.0 kg/L). Because the mud density was close to that of the cuttings (2.2 kg/L), no further density adjustment was made. Note that the density of the discharged material was not used in the model. The sensitivity of the results to particle-size distribution was examined by considering the two extreme curves of Addy et al. (1983), labelled "b" and "c" in Figure 5.

Discharges from the shakers and centrifuges were combined into one manifold, released at deck level, and fell to the water surface. This method of release could have modified the particle-size distributions further before they entered the water column. In any case, the particles could be expected to reach a terminal velocity soon after entry into the water. The dynamics of the impact of particles on the water were neglected and the model considered only a simple, surface discharge.

The model did not consider the temporal behaviour of currents; it was assumed that the ocean current could be considered constant during the particle settling time. Particles of sizes smaller than 125 µm (phi = 3) have a settling rate less than 0.01 m/s and can take many hours to settle to the bottom. Currents cannot be considered constant over such long periods and this model was not directly applicable for those sizes. These particles, however, were not likely to settle because turbulence levels (for currents greater than 0.15 m/s) are generally sufficient to keep the material in suspension. This is further supported by the general paucity of such fine materials on Sable Island Bank. Fine particles are, therefore, best considered as a dispersion problem within the water column, a problem which was outside the scope of the present work.

OCEAN CURRENT CLIMATE

South Des Barres O-76

The distribution of currents by speed and direction for South Des Barres is given in Tables 9 and 10. Two Aanderaa instruments were moored at depths of 34 m and 60 m from 15 August 1984 to 2 October 1984, in a total water depth of 72 m.

The two data sets differ substantially. We have considered the possibility that the upper current meter could have been affected by wave action because 50% of the waves measured had periods above 5 s and these waves could induce substantial orbital motions at 34 m. The heights of these waves, however, were such that the velocities that they caused were generally below 0.10 m/s. Although this was sufficient to cause some signal contamination, it could not explain the large differences between the data from 34 m and from 60 m. Further examination showed that both current meter records exhibited strong tidal signals of about the same amplitude, but that the upper observations included a mean flow of 0.11 m/s toward the east, which was absent in the 60-m data. This mean flow explains most of the difference between the two sets of observations. The source of this mean flow (with substantial vertical shear) is undetermined but likely contributes significantly to the depth-averaged flow at South Des Barres.

In the model used, the depth-averaged current was required to compute particle displacement as settling occurs. Here, the mid-depth (34-m) data was considered to be representative of the depth-averaged current. A better estimate could be obtained from further analysis of the current meter data; however, the uncertainty in particle-size distribution has a much greater influence on the results and detailed oceanographic analyses cannot be recommended at this point. To examine the sensitivity of the results to the current regime, the effects of changing currents by ±20% were considered. This uncertainty was representative of the uncertainty found in the depth-averaged currents.

West Venture C-62

At the West Venture site, current measurements (Table 11) were available only from the 14-m depth (1 m above the bottom). This close to the bottom, currents are significantly affected by the bottom boundary layer. Depth-averaged currents can be expected to be 25-100% higher than those observed 1 m from the bottom. The structure of the boundary layer depends on bottom roughness, wave climate, and current regime. Observed current profiles would have been useful in assessing the shape of the current profile, but in their absence the observed velocities were augmented by two-thirds (66%) as an estimate of the depth-averaged current. Sensitivity analysis was undertaken with the observed currents increased by 25% and 100%.

TABLE 9
Current percent frequency by speed (m/s) and direction at 34 m at South Des Barres O-76

Direction	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	Sum
N	1.2	0.7	0.1	0.1	0.0	2.0
NNE	1.8	2.5	0.6	0.0	0.1	4.9
NE	2.7	5.8	2.5	0.5	0.1	11.5
ENE	3.5	11.7	5.5	1.7	0.6	23.0
E	3.7	12.1	4.2	2.1	0.9	23.0
ESE	3.1	5.9	2.1	0.5	0.0	11.7
SE	2.6	2.7	0.5	0.1	0.0	5.9
SSE	2.0	1.7	0.2	0.1	0.0	4.0
S	1.3	1.1	0.1	0.1	0.0	2.7
SSW	1.5	0.8	0.1	0.1	0.0	2.5
SW	0.8	0.9	0.0	0.1	0.0	1.8
WSW	0.5	0.9	0.0	0.1	0.0	1.5
W	0.4	0.7	0.1	0.1	0.0	1.2
WNW	0.5	0.3	0.2	0.1	0.0	1.0
NW	0.7	0.9	0.1	0.0	0.0	1.7
NNW	0.9	0.4	0.1	0.1	0.0	1.5
Sum	27.2	49.1	16.4	5.7	1.6	100.0

Source: MacLaren Plansearch Limited 1985.

TABLE 10
Current percent frequency by speed (m/s) and direction at 60 m at South Des Barres 0-76

Direction	0-.08	.08-.16	.16-.24	.24-.32	.32-.40	Sum
N	1.7	0.9	0.1	0.1	0.1	2.9
NNE	2.2	3.3	0.7	0.0	0.2	6.4
NE	2.9	3.5	2.9	0.9	0.2	10.5
ENE	3.5	6.0	2.3	1.2	0.1	13.0
E	4.1	5.2	0.9	0.0	0.0	10.2
ESE	3.5	3.3	0.2	0.1	0.0	7.0
SE	2.3	2.3	0.1	0.0	0.0	4.7
SSE	3.2	2.1	0.3	0.0	0.0	5.6
S	2.7	3.4	0.4	0.1	0.0	6.6
SSW	3.4	6.8	2.2	0.2	0.0	12.6
SW	3.2	4.0	1.2	0.1	0.0	8.5
WSW	1.8	1.7	0.6	0.3	0.0	4.4
W	1.5	0.7	0.1	0.0	0.0	2.2
WNW	1.4	0.5	0.0	0.0	0.0	1.9
NW	1.3	0.3	0.0	0.0	0.0	1.6
NNW	1.2	0.5	0.1	0.0	0.0	1.7
Sum	39.7	44.5	12.1	3.2	0.5	100.0

Source: MarLaren Plansearch Limited 1985.

TABLE 11
Current percent frequency by speed (m/s)
and direction at 14 m
at West Venture C-62

Direction	0-.6	.6-.12	.12-.18	.18-.24	.24-.30	.30-.36	Sum
N	1.77	2.49	0.55	0.01	0.00	0.00	4.82
NNE	3.01	4.61	3.62	1.66	0.39	0.06	13.35
NE	3.72	3.02	3.99	1.98	0.71	0.24	13.66
ENE	2.79	2.43	0.97	0.04	0.00	0.00	6.23
E	1.36	0.89	0.00	0.00	0.00	0.00	2.25
ESE	1.42	0.69	0.03	0.00	0.00	0.00	2.14
SE	2.02	0.35	0.00	0.00	0.00	0.00	2.37
SSE	1.51	0.77	0.01	0.00	0.00	0.00	2.29
S	1.39	1.00	0.07	0.00	0.00	0.00	2.46
SSW	2.81	2.40	0.95	0.22	0.00	0.00	6.38
SW	4.11	4.02	3.51	1.93	0.20	0.00	13.77
WSW	3.36	5.52	3.39	0.97	0.12	0.00	13.36
W	1.97	3.31	0.62	0.00	0.00	0.00	5.90
WNW	2.01	2.07	0.24	0.00	0.00	0.00	4.32
NW	2.57	0.71	0.06	0.00	0.00	0.00	3.34
NNW	1.90	1.34	0.12	0.00	0.00	0.00	3.36
Sum	37.72	35.62	18.13	6.81	1.42	0.30	100.00

Source: Atlantic Oceanics Company Ltd. 1985.

WAVE CLIMATE

South Des Barres O-76

Figure 6 shows wave period and height distributions for the drilling period. The wave data enters the model principally in the assessment of the stability of the cuttings mound. From the distribution of wave properties a distribution of bottom orbital velocities was obtained from linear wave theory (Figure 6). The wave orbital velocities were so small at the bottom that they could not cause substantial natural sediment motion.

West Venture C-62

Figure 7a and 7b show the percentage of occurrence and the bottom orbital velocities for the observed waves, as a function of height and period, for West Venture. As can be seen, wave activity was sufficient to mobilize sand-sized particles (the natural bottom material) more than 50% of the time.

SIMULATION RESULTS FOR BOTTOM DISTRIBUTION

South Des Barres O-76

The mound thickness and shape, for the basic case at South Des Barres (particle-size curve labeled "a" from Figure 5 and currents as measured at 34 m), are given in Figure 8. The maximum thickness predicted is about 10 cm near the release location, with a decrease to less than 5 cm within 20 m and to 1 cm within 100 m.

For a thin layer of deposited cuttings, the material is likely to be mixed within the mobile sediment layer. Given an estimate for the thickness of this layer, it is possible to compute the resulting hydrocarbon concentration in the surficial sediments. Field experiments in about 40 m of water on Sable Island Bank have indicated a mobile layer in the order of 10 cm[1], although this active layer can be expected to decrease with depth.

At South Des Barres (72 m deep), however, hydrocarbon measurements indicated that most of the hydrocarbon load was concentrated in the top 5 cm and the expectation is that the hydrocarbons were concentrated perhaps in the top 2 cm at distances much greater than 200 m from the well-head. Because most samples analysed for hydrocarbon content were collected from the top 5 cm of sediment, a mixing layer 5 cm deep was used for calculations, so that comparisons could be made to the field data.

The computed and observed spatial distributions of the hydrocarbon concentrations are shown in Figure 9. As can be seen, observed concentrations are in general agreement with the predictions, except near the discharge site where the model estimates are lower than the field

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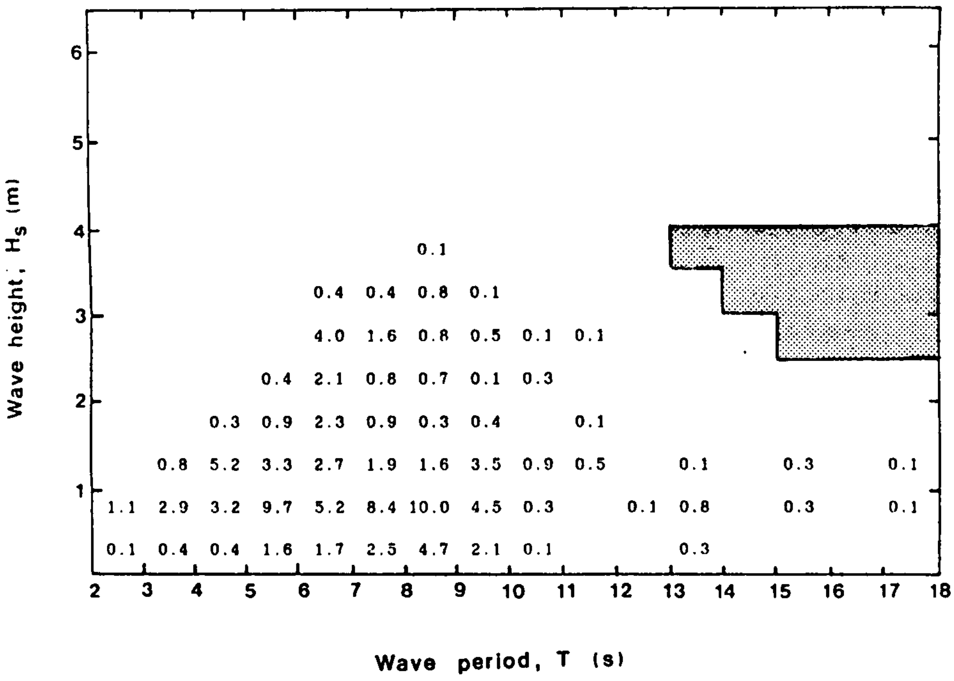
[1] G. Drapeau and C. Amos, Atlantic Geoscience Centre, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, personal communication to S. de Margerie of ASA Consulting Ltd., 1986.



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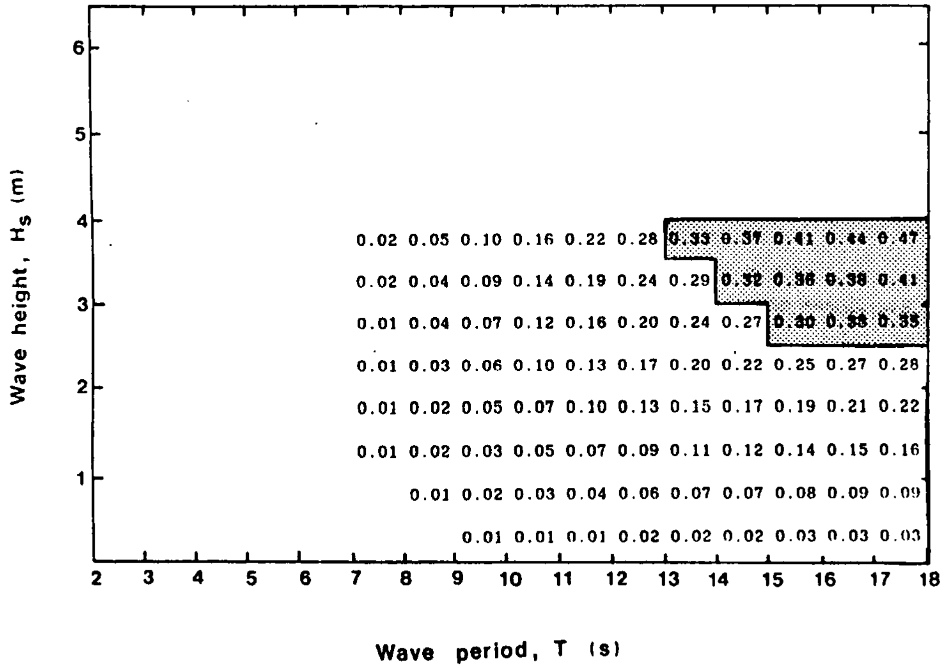
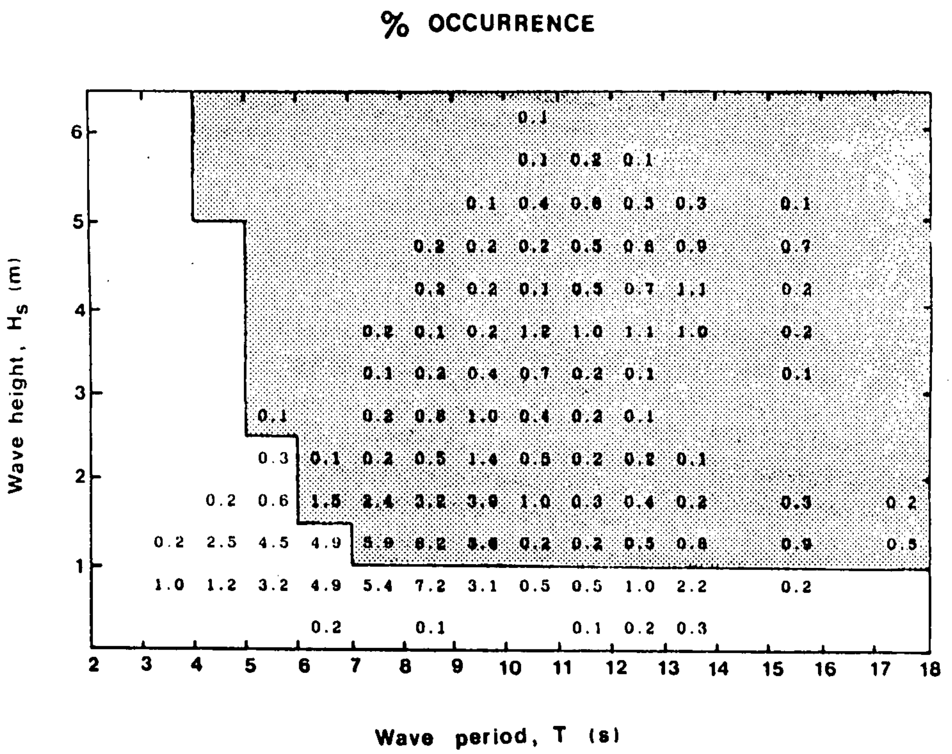


BOTTOM (72 m) ORBITAL VELOCITIES

Figure 6. **Wave period, height distribution, and bottom orbital velocities for South Des Barres O-76. Note: Shaded areas represent waves with sufficient energy to mobilize bottom sediments.**



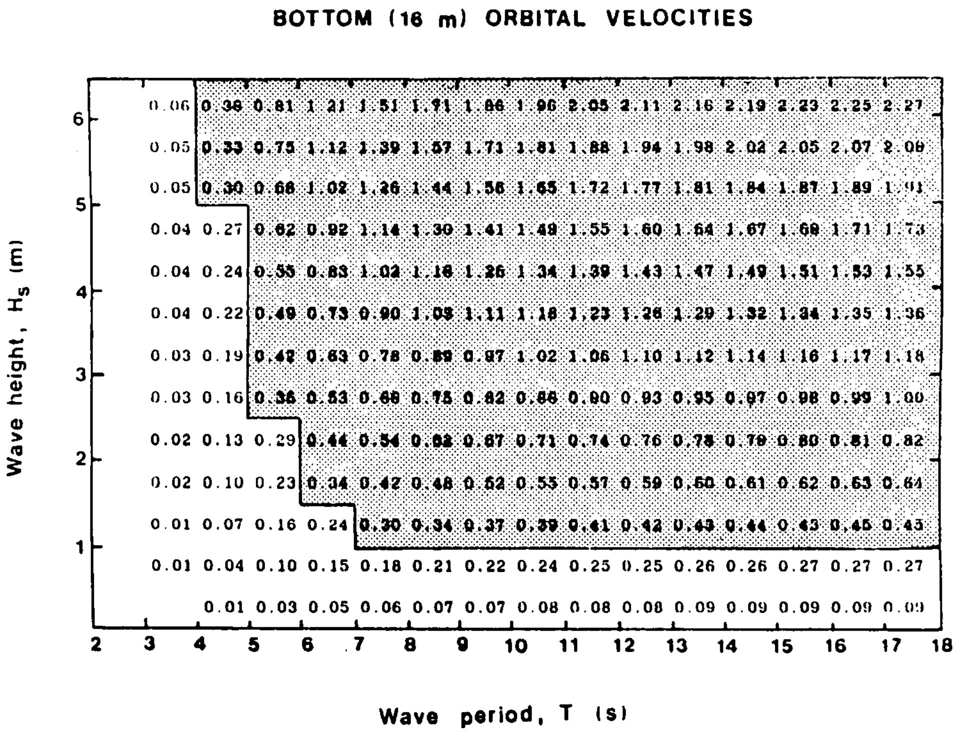


Figure 7. Wave period, height distribution, and bottom orbital velocities for West Venture C-62. Note: Shaded areas represent waves with sufficient energy to mobilize bottom sediments.

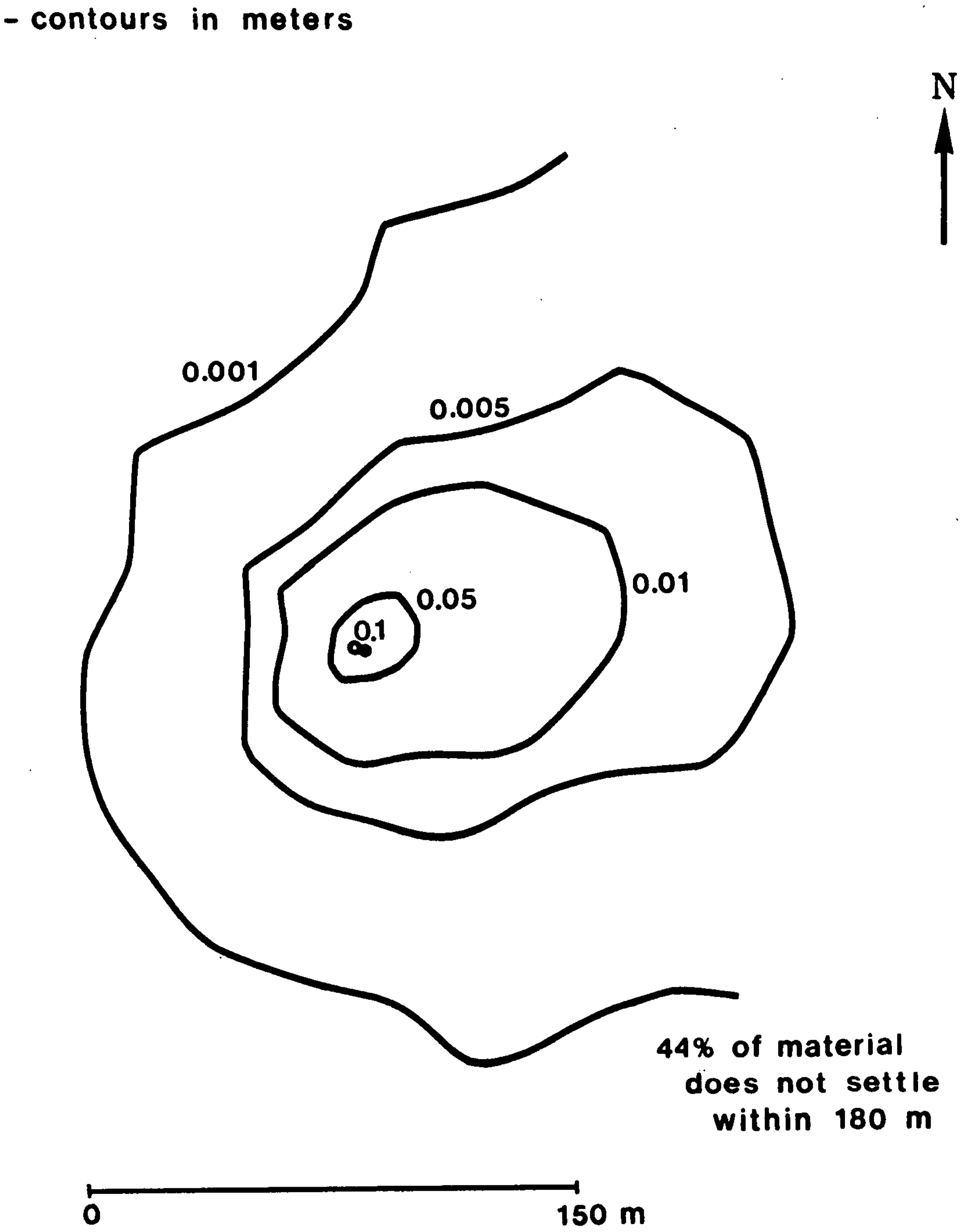


Figure 8. Computed mound shape from thickness distribution for South Des Barres O-76.

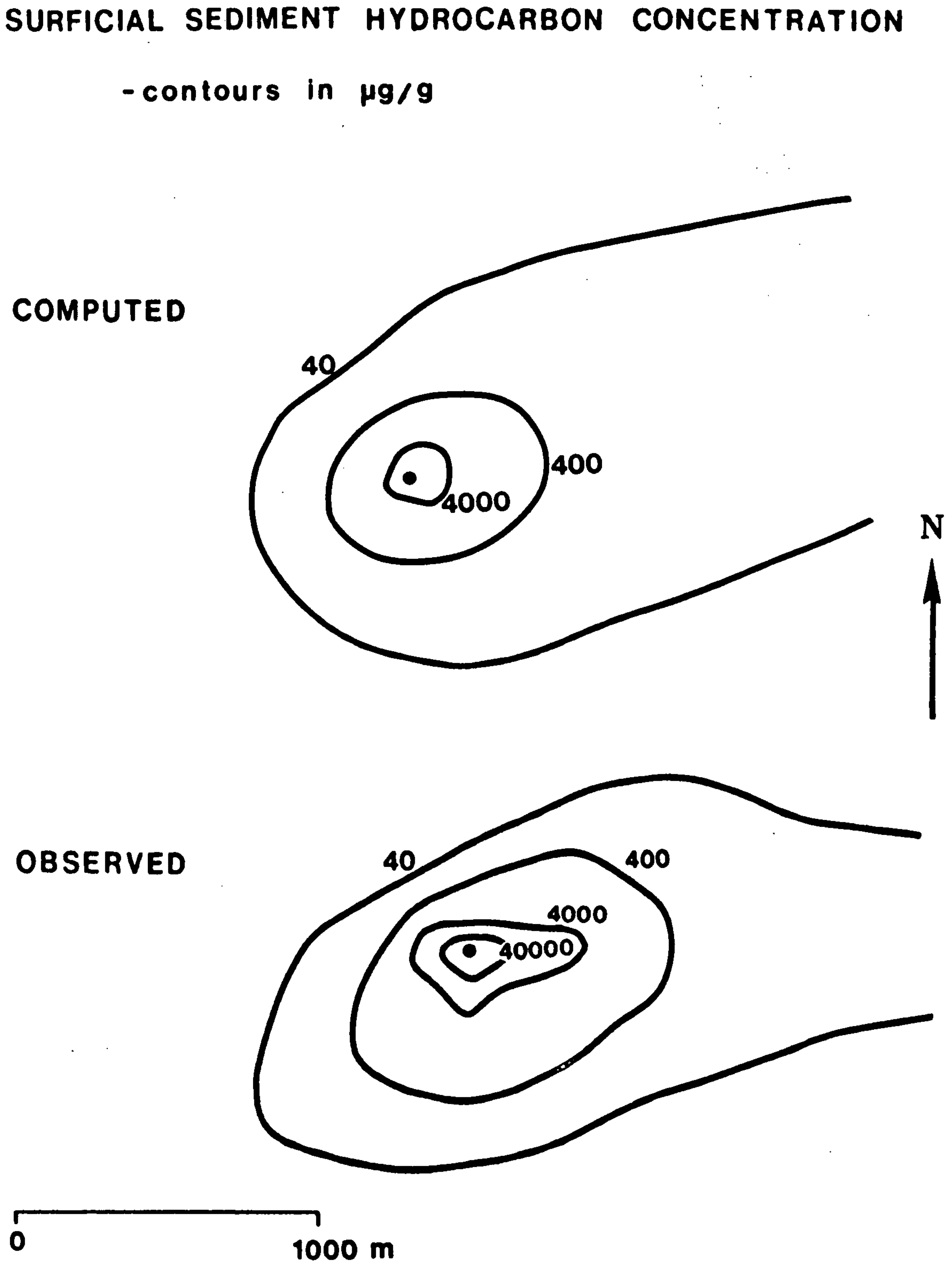


Figure 9. Computed and observed hydrocarbon concentrations in surficial sediment at South Des Barres O-76.

measurements. Part of this underestimation could be due to migration of oil upwards in the cuttings pile (the base oil is about 0.23 kg/L less dense than sea water), thereby producing a higher oil concentration in the surface layer (IOE 1985b).

Integrating the observed distribution (for a thickness of 5 cm), we find approximately 300 m^3 (1,900 bbl) of oil was calculated to be present in the sediment; this is about twice the hypothetical release accompanying the cuttings. This could be explained by either uncertainties in the discharge estimates or, more likely, by the hydrocarbons being concentrated in an average depth range of less than 5 cm over the whole area sampled.

For South Des Barres, both the mound dimension and the hydrocarbon concentration computed by the model are comparable to those observed. Better agreement would be obtained if there was either an increased grain size, or if the mixing depth was decreased.

West Venture C-62

The computed mound shape for the West Venture basic case (grain-size curve labelled "a" from Figure 5 and observed currents augmented by 66%) is shown in Figure 10. Maximum thickness was predicted to be about 10 cm, with a decrease to less than 5 cm within 30 m of the release site.

Figure 11 shows the computed and observed hydrocarbon concentrations based on a 10-cm mixing depth. The areas enclosed by the computed 25 µg/g and the 250 µg/g contours are substantially larger than those observed. Note, however, that although the concentrations at a 1,000 m distance from the well site predicted by the model were not observed, the model did correctly predict the major directions of transport of the oiled material. Conoco ODC oil was observed in the GC trace of one sample collected 1,000 m northeast of the well site and in one sample collected, 1,000 m southwest of the well site. The hydrocarbon concentrations in these two samples (3.9 and 5.6 µg/g, respectively) were just above background.

Integrating the observed hydrocarbon concentrations for a depth of 10 cm we calculate that approximately 4 m^3 (26 bbl) of oil was present in the surficial sediments, which is only a few percent of the hypothetical release accompanying the cuttings. As opposed to the South Des Barres site, this is substantially lower than expected. The low observed concentrations could be explained by a deeper mixing depth or by burial of released material by less contaminated sand in the highly dynamic sediment environment at West Venture, or by both. A further, but less likely, possibility could be remobilization of the oiled cuttings back into the water column with subsequent dispersal.

Both the mound shape and the hydrocarbon concentrations shown do not consider the effects of erosion and sediment transport during the drilling period.

SENSITIVITY ANALYSIS

At each site adjustments were made in the input parameters to examine the sensitivity of the model to uncertainties in these parameters. The model

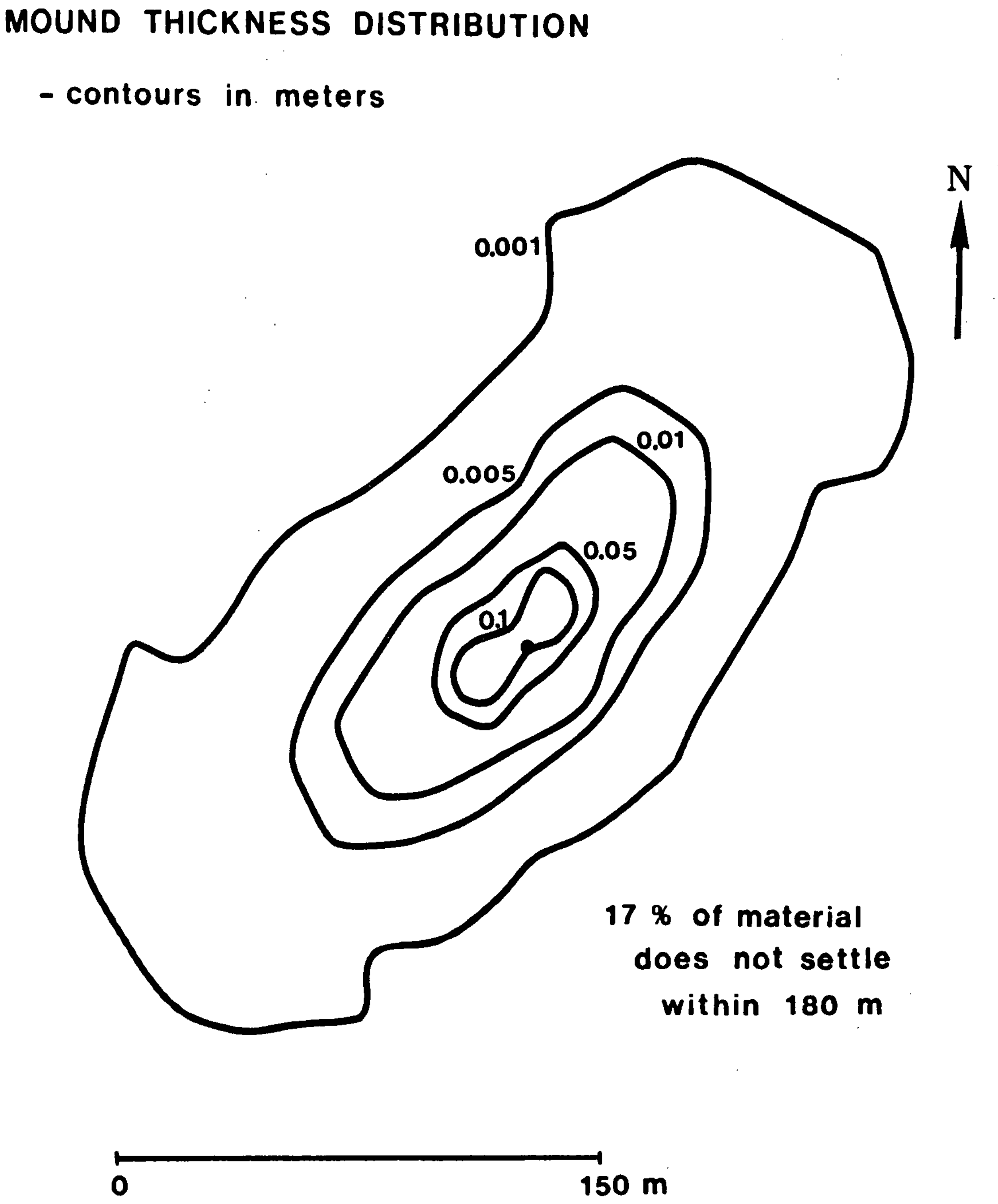


Figure 10. Computed mound shape from thickness distribution for West Venture C-62.

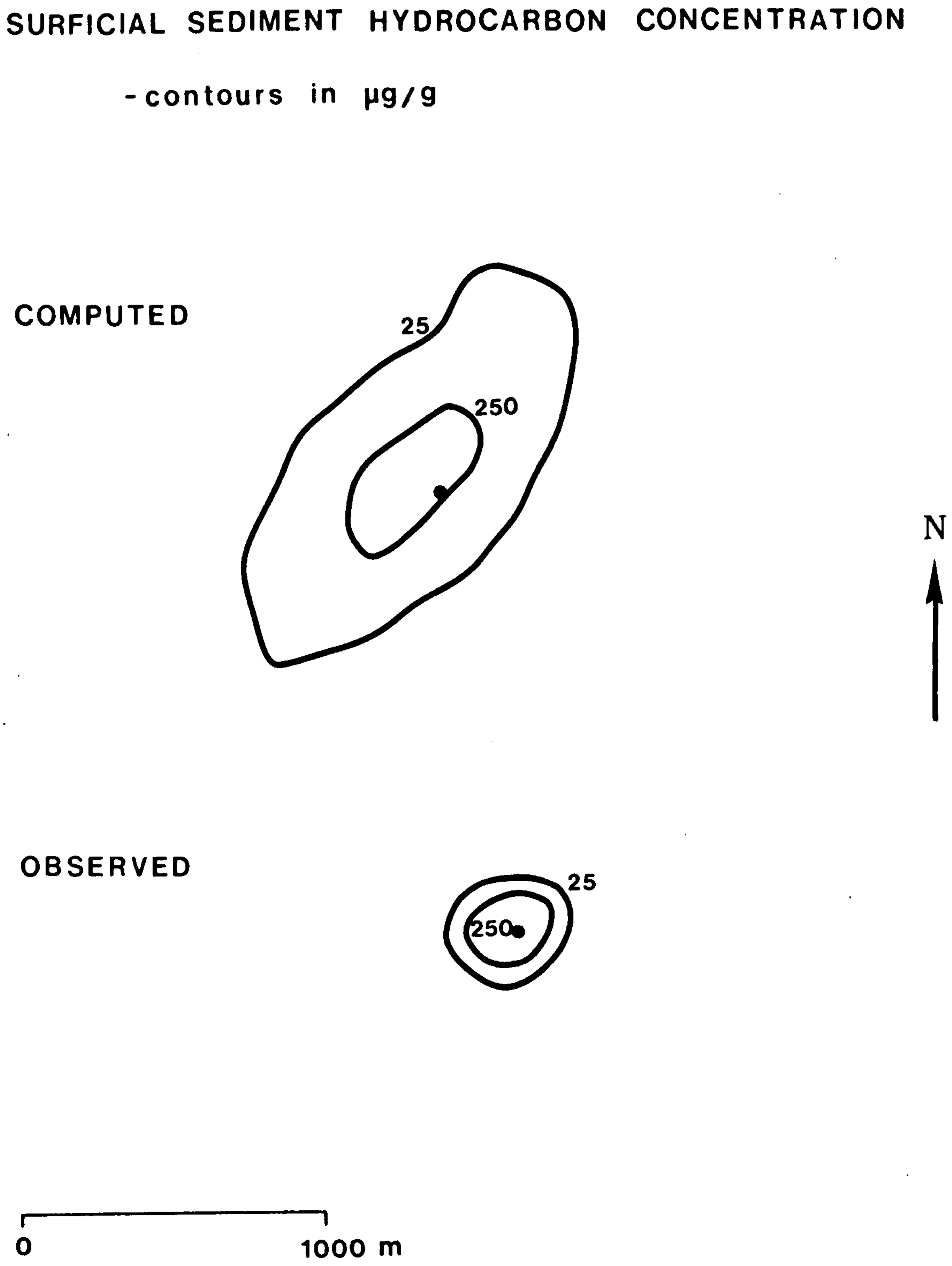
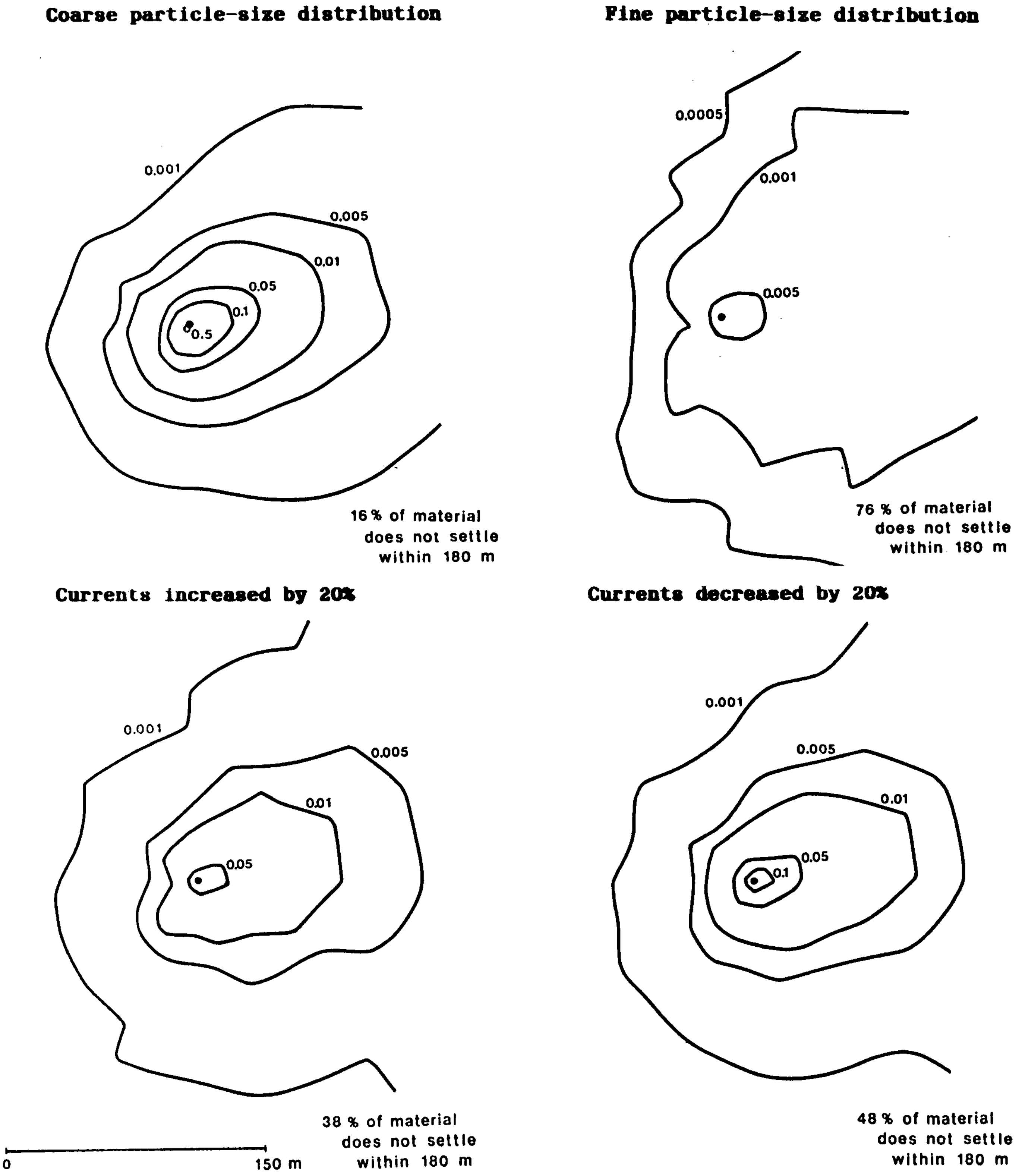


Figure 11. Computed observed hydrocarbon concentration in surficial sediment at West Venture C-62.

was rerun with a coarser and finer particle-size distribution, (see curves "b" and "c" in Figure 5) and with currents increased and decreased by 20% for South Des Barres and increased by 25 % and 100% for West Venture. The mound thickness and shape for these cases is given in Figures 12 and 13. As expected, the uncertainty in particle-size distribution was most critical, with the maximum mound thicknesses varying by up to two orders of magnitude, depending on the distribution chosen. It is therefore apparent that a better knowledge of particle size of the cuttings, as they occur at or near the water surface, is of particular importance in determining the environmental fate and effects of oiled cuttings.

MOUND THICKNESS DISTRIBUTION

- contours in meters



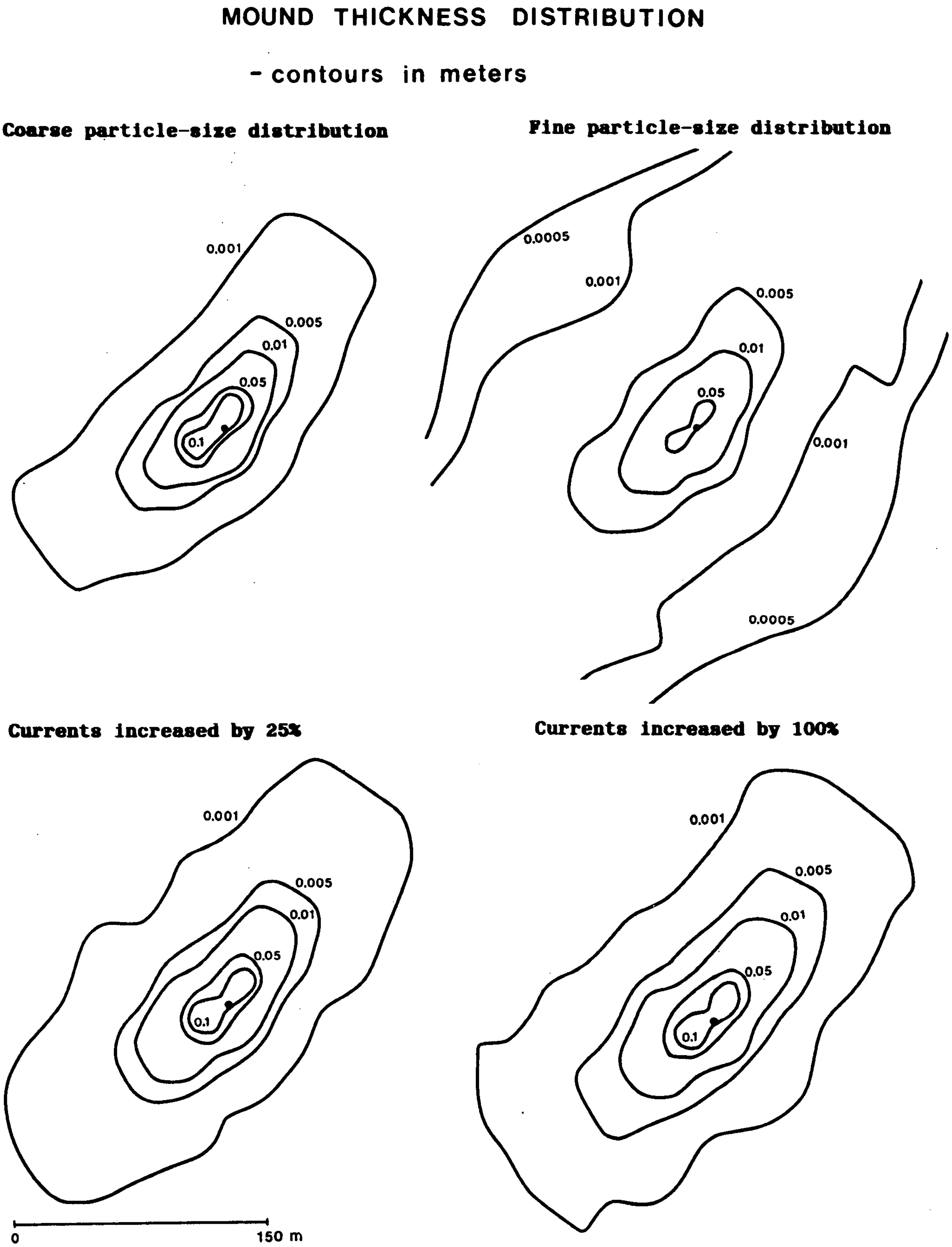
Coarse particle-size distribution

Fine particle-size distribution

Currents increased by 20%

Currents decreased by 20%

Figure 12. Sensitivity of results to particle-size and to current speed at South Des Barres O-76 from mound thickness distributions.



MOUND THICKNESS DISTRIBUTION

- contours in meters

Coarse particle-size distribution

Fine particle-size distribution

Currents increased by 25%

Currents increased by 100%

Figure 13. Sensitivity of results to particle-size and to current speed at West Venture C-62 from mound thickness distributions.

RESULTS AND DISCUSSION

HYDROCARBON CONCENTRATIONS AT THE TWO STUDY SITES

Summary tables showing the mean, maximum, and minimum total aliphatic and total aromatic hydrocarbon concentrations, expressed as µg/g dry weight of sediment for each station sampled, are shown in Tables 12 and 13. Detailed analytical results are given in Appendix 2. When a choice had to be made between grabs at a station or subsamples of a grab, samples for analysis at each station were chosen on a random basis from those available; the results obtained can thus be regarded as providing a realistic assessment of the actual hydrocarbon levels present at each site. Because the total aromatic concentrations in each sample were about 1% of the total aliphatic concentrations, and because a method was not available to express the total aromatics in terms of Conoco oil equivalents, most of the results presented here are given only in terms of Conoco oil equivalents of total aliphatics.

West Venture C-62 Site

At all stations at the West Venture site the sediment was a light brown sand with darker streaks, the latter most likely due to magnetite.

Background levels of total aliphatics were found to be 1.4 ± 0.4 (n = 3) µg/g dry weight at the control station (station 26, see Figure 2). However, the mean background levels of total aliphatics for the West Venture 1,000-m stations that did not show any evidence of Conoco oil in the GC trace were slightly higher at 2.4 ± 0.5 (n = 8) µg/g and a background level of 2.5 µg/g was used for the West Venture site. The two samples that showed GC traces of Conoco oil (i.e., samples M13 and M25 grab 1) which were not used to define the West Venture background levels are marked in Table 12. Values given are the mean plus or minus the standard deviation; n is the number of replicates.

At the West Venture well-head, the samples collected by divers on 4 November 1984 showed Conoco oil aliphatic hydrocarbon concentrations of 151,500 ± 13,500 (n = 4) µg/g dry weight. Three months later, additional samples collected by divers from under the rig on 1 February 1985, showed Conoco oil concentrations of 1,160 ± 1,790 (n = 5) µg/g. In the area where cuttings had been piled up in November, oil concentrations were 668 ± 36 (n =2) µg/g.

A core collected by divers on 4 November 1984 at the West Venture well-head showed the following depth profile:

0 - 3 cm	45,800 µg/g dry weight
3 - 6 cm	30,000
6 - 10 cm	10,700
10 - 15 cm	4,700

The top 3 cm of the core was heavily oiled and contained mostly fine material. All of this material was combined for analysis. From 3 cm to 15 cm the core was composed of consolidated sandy material with streaks of visibly oiled or fine material. Subsamples from this region of the core were

TABLE 12

Compilation of the mean, maximum, and minimum total aliphatic concentration obtained for each station studied*

Station	Total aliphatics in µg/g dry weight Conoco			
	Mean	Standard Deviation	n	Range
West Venture well head post-drilling				
M 1 - Nov 4/84	151,500	13,480	4	136,900 - 168,900
M 1 - Feb 4/85	1,160	1,792	5	32.40 - 4,320
West Venture 200 m post-drilling				
M 2	14.97	12.42	3	6.48 - 29.23
M 5	9.79	5.89	2	5.63 - 13.96
M 8	4.04	1.22	3	2.72 - 5.14
M11	14.68	13.89	4	6.15 - 35.35
M14	33.55	20.60	6	4.12 - 64.92
M17	19.18	13.41	3	4.30 - 30.33
M20 Surface	13.35	8.56	5	5.13 - 23.99
M20 Bottom	7.91	1.46	2	6.88 - 8.95
M23 Surface	33.05	44.01	4	5.02 - 98.43
M23 Bottom	47.30	36.74	2	21.32 - 73.28
West Venture 500 m post-drilling				
M 3	2.57		1	
M 6	12.41		1	
M 9	3.83	1.31	2	2.92 - 4.76
M12	18.34		1	
M15	12.40	2.46	2	10.66 - 14.14
M18	10.82		1	
M21	4.41	0.61	2	3.98 - 4.85
M24	11.99		1	

* Unless otherwise stated all samples analysed were collected from the top 5 cm of sediment. Where sediment samples were taken at different depths, "surface" refers to 0-5-cm depth and "bottom" refers to 5-10-cm depth.

Table 12 (continued)

Station	Total aliphatics in µg/g dry weight Conoco Mean	Standard Deviation	n	Range
West Venture 1000 m post-drilling				
M 4	2.80		1	
M 7	2.58	0.34	2	2.34 - 2.82
M10	1.85	0.68	2	1.36 - 2.33
M13	3.92*		1	
M16	2.35		1	
M22	2.82		1	
M25	4.17	2.38	2	2.48 - 5.58*
West Venture control post-drilling				
M26	1.53	1.14	4	0.53 - 3.04
West Venture well hean pre-drilling				
M 1	1.18	0.63	3	0.49 - 1.74
West Venture pre-drilling				
M11	0.87	0.09	2	0.81 - 0.94
M15	0.58	0.21	3	0.38 - 0.79
M20	0.39	0.31	2	0.17 - 0.61
M22	0.52	0.58	2	0.11 - 0.93
West Venture control pre-drilling				
M26	1.44	0.39	3	0.99 - 1.72

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* These values were not used in determining the West Venture background levels.

Table 12 (continued)

Station	Total aliphatics in µg/g dry weight Conoco			
	Mean	Standard Deviation	n	Range
South Des Barres well head post-drilling				
S 1 Surface	88,300	66,240	11	9,107 - 230,600
S 1 Bottom	89,200	31,820	2	66,700 - 111,700
South Des Barres 200 m post-drilling				
S 2 Surface	21,250	8,840	4	15,440 - 32,400
S 2 Bottom	13,670	11,600	2	5,464 - 21,870
S 5	3,038	1,176	3	2,094 - 4,355
S 8	259.9	234.1	2	94.37 - 425.5
S11	46.98	30.80	3	16.68 - 78.25
S15 Surface	4,059	5,276	4	624.7 - 11,860
S15 Bottom	1,078	905.1	2	1,068 - 2,348
S18 Surface	2,222	1,584	3	860.5 - 3,961
S18 Bottom	692.8	778.1	2	142.6 - 1,243
S21	35.61	28.32	4	8.52 - 72.24
S24	954.9	406.3	4	666.1 - 1,557
South Des Barres 800 m post-drilling				
S 3	91.98	11.77	2	83.66 - 100.3
S 6	10.36	3.90	2	7.60 - 13.12
S 9	11.62		1	
S12	7.46		1	
S16	28.49	14.40	2	18.31 - 38.67
S19	42.67		1	
S22	7.19		1	
S25	40.17		1	

Table 12 (continued)

Station	Total aliphatics in µg/g dry weight Conoco			
	Mean	Standard Deviation	n	Range
South Des Barres 1500 m post-drilling				
S 4	63.35		1	
S 7	11.59		1	
S10	7.45	1.12	2	6.65 - 8.24
S13	4.02		1	
S17	10.03	0.19	2	9.89 - 10.16
S20	13.71		1	
S23	8.26		1	
S26	12.98	5.39	2	9.17 - 16.79
South Des Barres control post-drilling				
S14	3.68	1.43	4	1.91 - 5.40
South Des Barres well head pre-drilling				
S 1 Surface	121.4	96.01	6	27.76 - 255.4
S 1 Bottom	13.59	7.16	2	8.52 - 18.65
South Des Barres pre-drilling				
S 2 Surface	41.51	52.76	6	11.15 - 146.2
S 2 Bottom	9.70	0.92	2	9.05 - 10.35
S 3	10.05	0.01	2	10.05 - 10.06
S 5 Surface	11.14	2.11	4	8.07 - 12.68
S 5 Bottom	7.22		1	
S 8	9.65	1.77	2	8.39 - 10.90
S 9	5.41	1.03	3	4.43 - 6.48
S11 Surface	10.90	3.67	3	6.94 - 14.18
S11 Bottom	8.12		1	
S13	9.77	7.88	2	4.20 - 15.35

Table 12 (continued)

Station	Total aliphatics in µg/g dry weight Conoco Mean	Standard Deviation	n	Range
South Des Barres control pre-drilling				
S14	5.15	2.43	3	3.02 - 7.80
Reagent blanks	<0.63	0.70	21	<0.05 - 2.34

TABLE 13

Compilation of the mean, maximum and minimum total aromatic concentrations obtained for each station studied*

Station	Total aromatics in µg/g dry weight o-terphenyl			
	Mean	Standard Deviation	n	Range
West Venture well head post-drilling				
M 1 - Nov 4/84	1760	1187	4	1014 - 3519
M 1 - Feb 1/85	1.72	2.15	5	0.09 - 4.10
West Venture 200 m post-drilling				
M 2	0.45	0.45	3	0.11 - 0.96
M 5	1.09	0.82	2	0.51 - 1.67
M 8	0.16	0.17	3	0.05 - 0.35
M11	0.13	0.05	3	0.08 - 0.18
M14	0.08	0.09	6	0.03 - 0.26
M17	0.95	1.33	3	0.06 - 2.48
M20 Surface	<0.20	0.29	5	<0.01 - 0.71
M20 Bottom	0.40	0.34	2	0.16 - 0.64
M23 Surface	0.92	1.07	4	0.09 - 2.47
M23 Bottom	1.11	1.39	2	0.12 - 2.09
West Venture 500 m post-drilling				
M 3	0.02		1	
M12	0.10		1	
West Venture control post-drilling				
M26	0.17	0.21	2	0.03 - 0.32

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*. Unless otherwise stated all samples analysed were collected from the top 5 cm of sediment. Where sediment samples were taken at different depths, "surface" refers to 0-5-cm depth and "bottom" refers to 5-10-cm depth.

Table 13 (continued)

	Total aromatics in µg/g dry weight o-terphenyl			
Station	Mean	Standard Deviation	n	Range
West Venture well-head pre-drilling				
M 1	0.05		1	
West Venture pre-drilling				
M11	0.01		1	
M22	0.01		1	
South Des Barres well head post-drilling				
S 1 Surface	887.2	700.7	10	123.1 - 2572
S 1 Bottom	1169	34.65	2	1144 - 1193
South Des Barres 200 m post-drilling				
S 2 Surface	237.3	150.8	4	57.71 - 401.0
S 2 Bottom	836.8	1173	2	7.58 - 1666
S 5	80.3	36.13	3	55.08 - 121.7
S 8	2.34	1.19	2	1.50 - 3.18
S11	0.97	1.41	3	0.06 - 2.60
S15 Surface	16.27	20.01	3	2.21 - 39.18
S15 Bottom	3.33	2.47	2	1.58 - 5.08
S18 Surface	33.42	44.82	3	2.66 - 84.84
S18 Bottom	6.00	4.30	2	2.96 - 9.04
S21	0.36	0.35	4	0.08 - 0.86
S24	2.60	2.69	4	0.72 - 6.60
South Des Barres 800 m post-drilling				
S 3	0.05		1	

Table 13 (continued)

	Total aromatics in μg/g dry weight o-terphenyl			
Station	Mean	Standard Deviation	n	Range
South Des Barres control post-drilling				
S14	0.29	0.11	2	0.21 - 0.37
South Des Barres well head pre-drilling				
S 1 Surface	10.74	11.41	6	2.72 - 32.89
S 1 Bottom	5.11	5.79	2	1.02 - 9.21
South Des Barres pre-drilling				
S 2 Surface	4.78	2.19	6	1.26 - 7.15
S 2 Bottom	12.21	0.48	2	11.87 - 12.55
S 3	21.91		1	
S 5 Surface	6.99	5.57	3	0.56 - 10.24
S 5 Bottom	0.24		1	
S 8	0.05	0.00	2	
S11 Surface	3.71	4.44	3	0.07 - 8.66
S11 Bottom	0.27		1	
Reagent Blanks				
	<0.04	0.06	17	<0.01 - 0.19

taken only from the middle of the core; material that had been in contact with the core barrel was excluded from the samples analysed. From 15 cm to 25 cm the core was no longer intact and was composed of coarse sand material interspersed with clumps of oiled sand and mud. No analyses were performed on this unconsolidated material. Note that it is possible that the core was compacted during either collection or storage.

For both the West Venture and South Des Barres wells, samples of drilling cuttings were taken at regular intervals by the operators and were passed on to Canada Oil and Gas Lands Administration (COGLA) for archiving. For both wells, samples of oiled cuttings from three different drilling intervals were supplied to Dobrocky Seatech Ltd. by COGLA for analysis along with the sediment samples. The West Venture cuttings showed Conoco oil concentrations of 59,400 ± 30,900 (n = 3) µg/g. By t-test (alpha (2) = 0.05), these oil concentrations are the same as the oil concentration in the top 3 cm of the core but differ significantly from the concentration levels obtained for the jar samples collected by the divers.

An examination of these core results shows that the oil concentrations decreased with core depth which suggests that at least a portion of the oil discharged along with the cuttings may have floated to the top of the cuttings pile (IOE 1985b). The divers reported that the jar samples were collected from only the top layer of the cuttings pile, so the higher oil concentrations measured could be explained by the flotation phenomenon. Analytical constraints related to the heavily oiled samples are discussed further in the Results and Discussion.

The total aliphatic hydrocarbon concentrations measured in the sediments collected within 200 m and 1,000 m of the West Venture site are shown in Figures 14 and 15. The dots indicate the positions of each grab sample. Hydrocarbon levels were observed to drop off to a level 10 times above a background of about 2.5 µg/g at about 200 m from the rig site and no predominant direction of spread was apparent. A hydrocarbon level 100 times above background could be estimated by assuming a logarithmic decrease in the oil concentrations relative to the well-head but, because there were no data from within the 200-m contour, the position of this isopleth is only approximate. The "100 times background" isopleth (250 µg/g) is shown with a dashed line in Figures 14 and 15. Hydrocarbon concentrations were less than an order of magnitude above background at distances greater than 200 m from the well-head. The available evidence indicates that the oiled cuttings have been dispersed, or possibly buried, most likely by wave action in these shallow (16 m) waters.

A tremendous advantage of GC analysis is the ability to examine the GC trace and to "see" the types of compounds in the sample. The Conoco ODC oil in particular has a characteristic GC trace and its presence or absence can provide definitive proof of the extent of spread of mineral oil from the discharge of oiled cuttings. Note that even though the hydrocarbon levels at the West Venture site remained below an order of magnitude above background at distances greater than 200 m from the well-head, the Conoco ODC oil was still present in most of the 500-m samples and in two of the 1,000-m samples (Table 14).

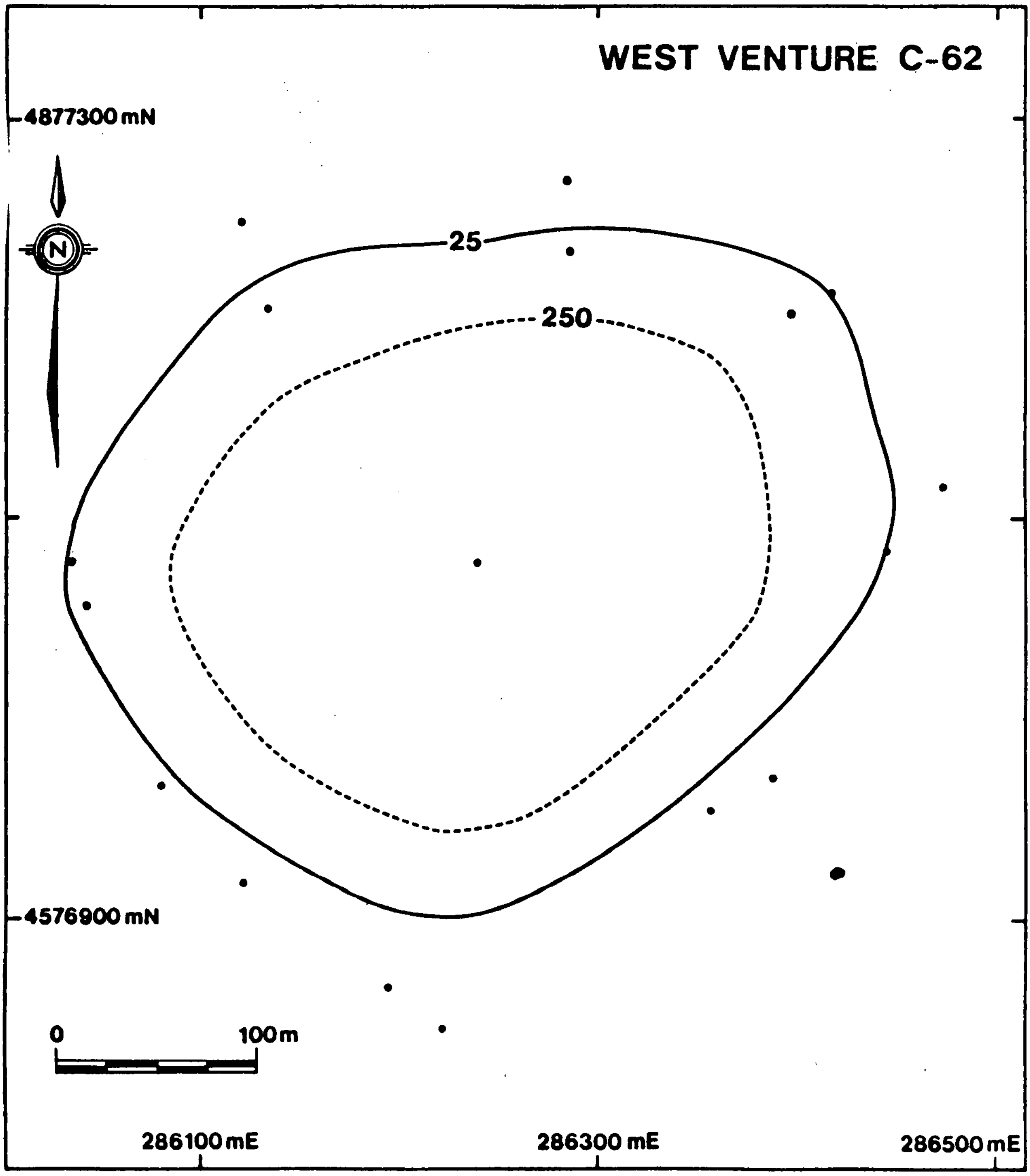

Figure 14. The post-drilling West Venture C-62 site within 200 m of the well-head. Total aliphatic hydrocarbon concentrations shown are µg/g dry weight of Conoco oil and the dots indicate the positions of each grab sample.

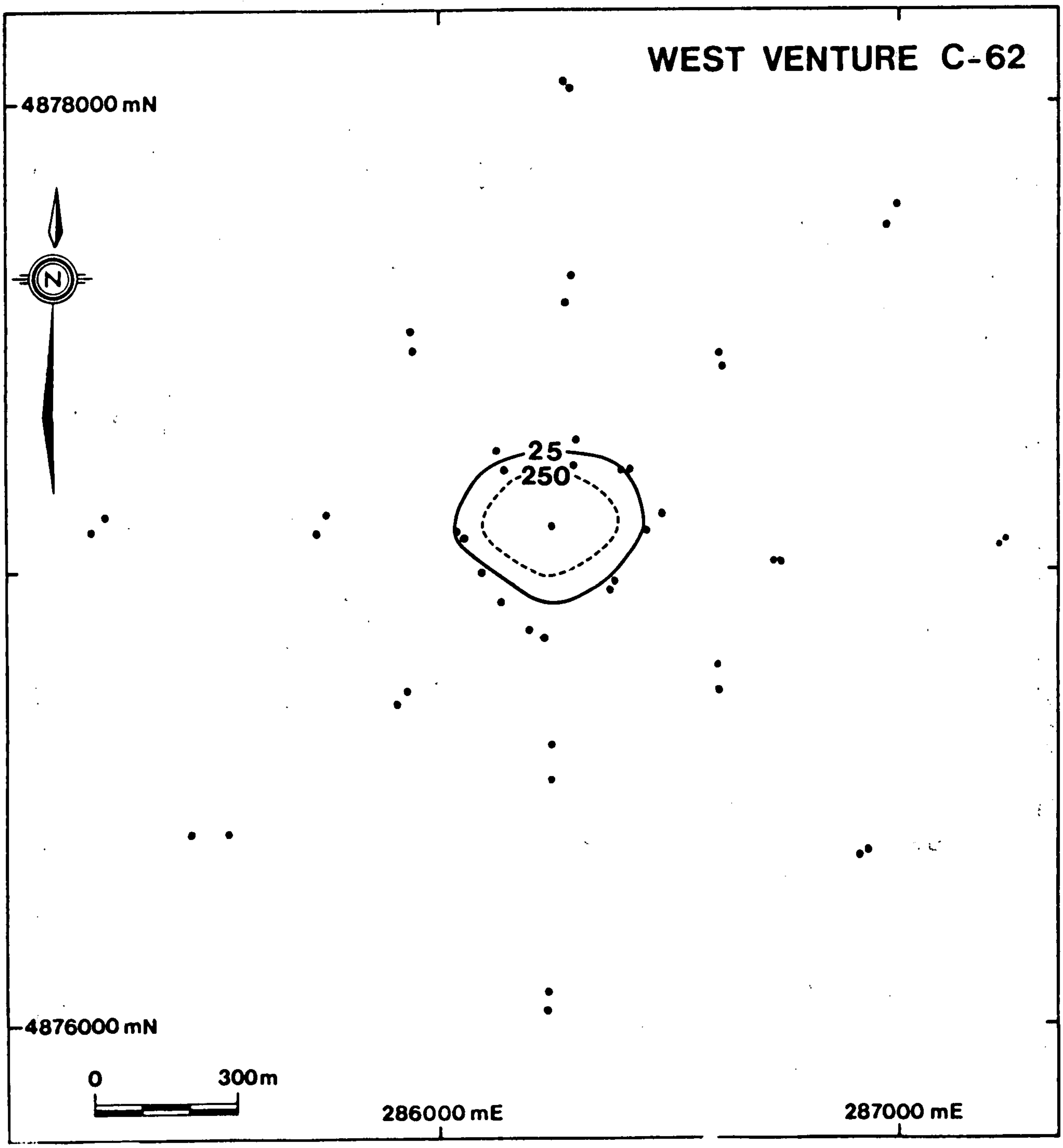

Figure 15. The post-drilling West Venture C-62 site within 1,000 m of the well-head. Total aliphatic hydrocarbon concentrations shown are µg/g dry weight of Conoco oil and the dots indicate the positions of each grab sample.

TABLE 14

Areal extent of Conoco ODC mineral oil as determined from examination of the GC trace from the sample(s) analysed at each station*

Direction	Distance		
West Venture C-62			
	200 m	500 m	1,000 m
N	*[a]	--[b]	--
NE	*	*	*
E	*	--	--
SE	*	*	--
S	*	*	--
SW	*	*	*
W	*	*	--
NW	*	--	Not sampled
South Des Barres O-76			
	200 m	800 m	1500 m
N	*	Trace[c]	--
NE	*	*	*
E	*	*	*
SE	*	*	*
S	*	*	*
SW	*	*	--
W	*	*	Trace
NW	*	Trace	Trace

[a] An asterisk indicates that Conoco ODC oil was evident in the GC trace for that station.

[b] A double dash indicates that the oil was not observed in the GC trace.

[c] Trace indicates that only traces of the oil were observed in the GC trace.

South Des Barres 0-76 Site

At South Des Barres, oily drill cuttings were found at the 0-m well-head station; they appeared as a soft, oily mud. Samples of these oiled cuttings were taken from four stations as much as 60 m apart, which means that the cuttings had accumulated over an area with at least this diameter. It should be noted that these samples were collected nearly a month after drilling had ceased. One of the two grabs taken at the station 200 m east of the well-head also showed visible oil in the grab sample. All other South Des Barres samples were composed of mixed mud and sand. Many samples had gravel present and were dark brown or grey brown in colour. Background levels of total aliphatics were found to be 3.7 ± 1.4 (n = 4) µg/g dry weight at the control station (station 14, see Figure 3). A background level of 4 µg/g was used for the South Des Barres site.

At the South Des Barres well-head, grab samples collected showed Conoco oil concentrations of 88,400 ± 61,200 (n = 13) µg/g dry weight. There was no significant difference (t-test: alpha (2) = 0.05) between samples collected in the top 5 cm of the grab and samples collected in the 5-10-cm depth range. The cuttings samples obtained by Dobrocky Seatech Ltd. from COGLA, had Conoco oil concentrations of 47,500 ± 3,790 (n = 4) µg/g. These oil concentrations are statistically the same (t-test: alpha (2) = 0.05) as the oil concentrations obtained from the grab samples.

The total aliphatic hydrocarbon concentrations measured in the sediments collected around the South Des Barres site are shown for the area within 200 m of the well site (Figure 16) and for the area within 1,500 m (Figure 17). In both figures, the dots indicate the recorded positions where grabs were taken. The isopleths, which represent a change of one order of magnitude above a background of about 4 µg/g, were drawn by assuming a logarithmic change in the hydrocarbon concentrations between grab locations which were different distances from the well-head. This assumption was supported by actual measurements.

The data indicate that the primary direction of transport of hydrocarbons was in an easterly and perhaps to a lesser extent, a southerly direction, and suggest that the oil and cuttings have been dispersed primarily by ocean currents at this deeper (70 m) location. Depending on the direction, the hydrocarbon levels dropped to 10 times above background at distances ranging from 200 m to 1,500 plus m from the well-head. Concentrations three orders of magnitude above background were likely present at distances of about 100 m to about 400 m from the well. Concentrations of over four orders of magnitude above background were confined within an area 200 m of the well-head. These higher concentrations and the oceanographic regime suggest that the oil from the cuttings may persist for a longer time in the deep-water environment.

The areal extent of the Conoco ODC oil at the South Des Barres site as determined from each GC trace is shown in Table 14. The Conoco oil was still present in all of the grab samples collected within 800 m of the well site. At 1,500 m from the well site the Conoco oil was mostly present in samples collected to the east and south from the well-head but only traces were found in samples collected to the west and northwest.

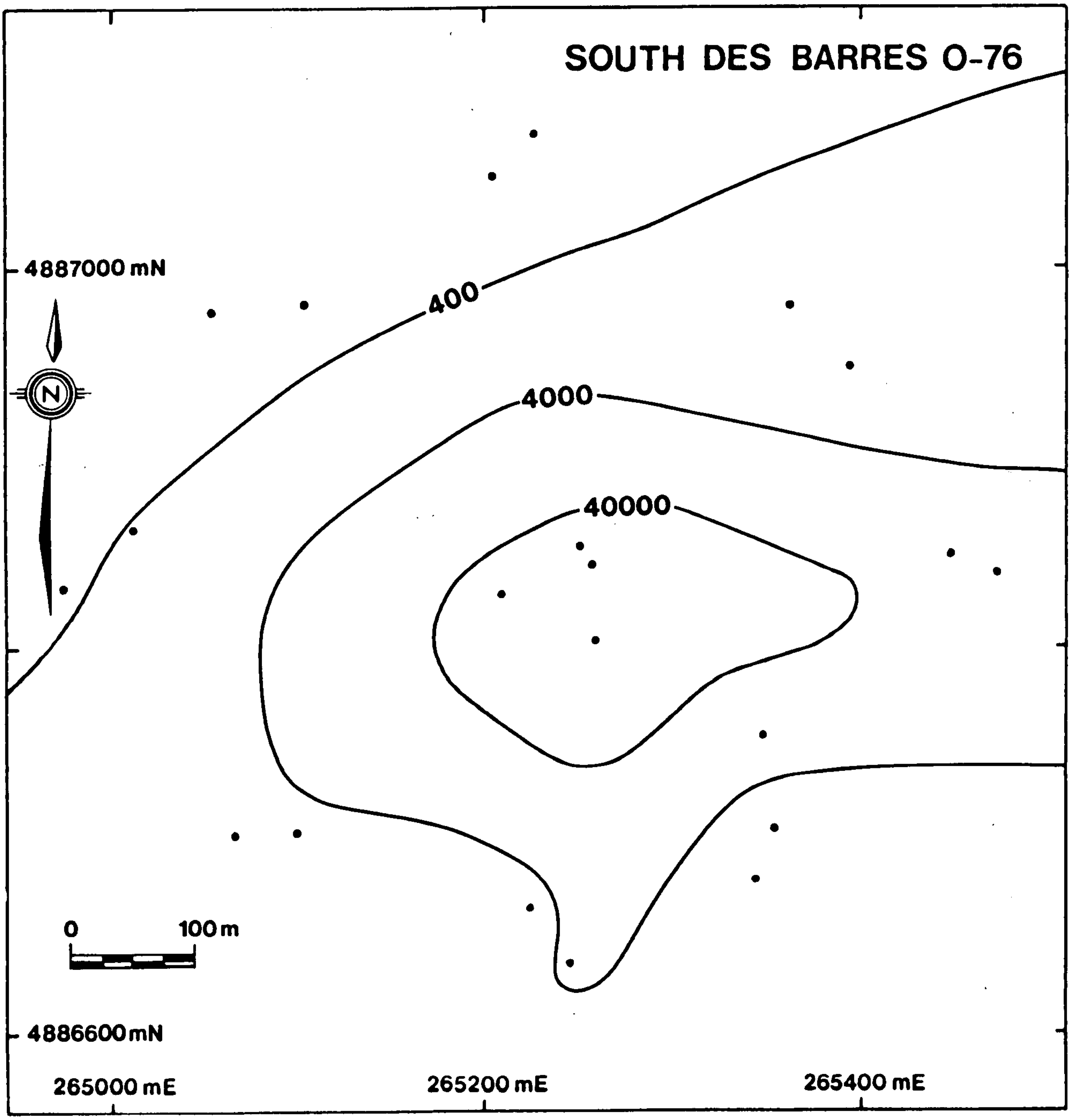

Figure 16. The post-drilling South Des Barres O-76 site within 200 m of the well-head. Total aliphatic hydrocarbon concentrations shown are in µg/g dry weight of Conoco oil and the dots indicate the positions of each grab sample.

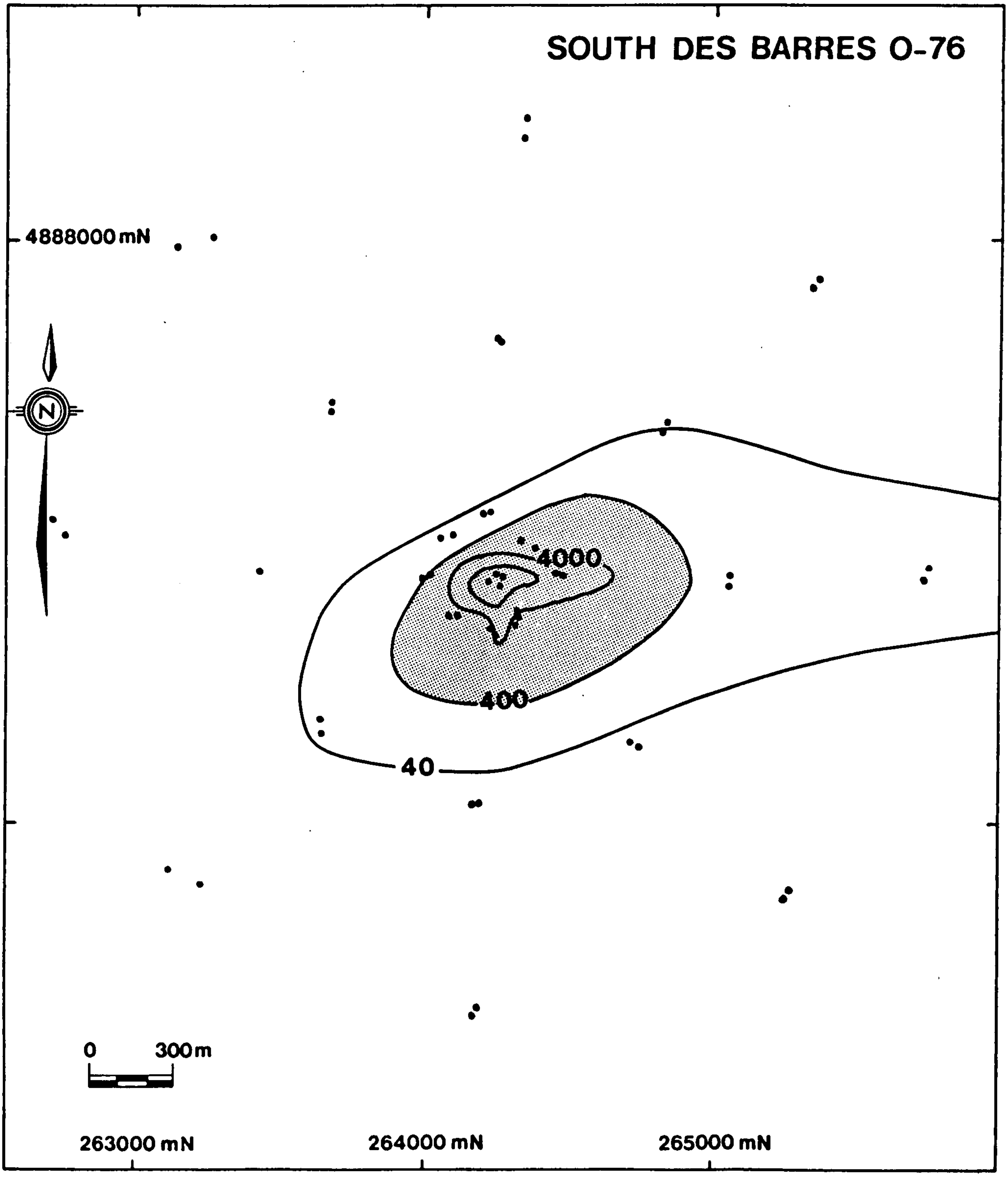

Figure 17. The post-drilling South Des Barres O-76 site within 1,500 m of the well-head. Total aliphatic hydrocarbon concentrations shown are in µg/g dry weight of Conoco oil and the dots indicate the positions of each grab sample.

At the South Des Barres site, the operator switched to an oil-based mud and commenced the discharge of oiled cuttings two days before pre-discharge samples were collected at either the well-head site or the stations to the east of the discharge point. In this time the Conoco oil concentrations rose to above ten times above background in the area that encompassed the well site and the station 200 m east of the well-head (Figure 18).

COMPARISON TO OTHER STUDIES

Review of the Results of Other Studies

The conclusions of a United Kingdom working group on the environmental effects of oil-based mud cuttings are worth reviewing to help put this study into context (Davies et al. 1984). They found that despite both differences in inputs from different platforms, and the variations in sea-bed area at different locations, the sea-bed chemical and biological effects associated with these discharges could be summarized in terms of four zones each of which was affected differently.

Zone I (Davies et al. 1984) is typified by an impoverished and highly modified benthic community (Table 15). Beneath, and in the immediate vicinity of the platform, biological effects are the result mainly of physical burial of the natural sediment which can lead to anaerobic conditions. A number of workers have noted that oil-based mud cuttings are cohesive and undergo little resuspension (Blackman and Law 1981). In the laboratory, it was found that when diesel-based cuttings had an oil content of greater than 4-5% by weight, even those containing angular sand grains aggregated into large pellets which sank rapidly (100-700 m/h). The authors concluded that little absorbed oil was stripped from the solids during settlement but that, after deposition, oil continued to leach slowly to the surrounding water.

The authors reported that oiled cuttings can be compacted to form a bottom pavement and as little as 1 cm of cuttings can have the effect of sealing off the natural sediments. Around the discharge point, the sea bed can consist of cuttings with no benthic macrofauna and sediment hydrocarbon concentrations usually exceeding 1,000 times background. In most cases studied, Zone I was confined within 250 m although an outer limit of 500 m was used to include all fields.

In all North Sea fields studied up to the time of the review, the major deleterious biological effects were confined within the 500-m zone and were associated primarily with (i) burial under the mound of cuttings on the sea bed (immediately adjacent, <100 m, to the platform) and (ii) the organic enrichment associated with the spread of oil from the cuttings. Sea-bed recovery in this first zone is likely to be a long process with layers of compacted cuttings persisting on the sea bed for several years in areas of deep water.

Surrounding the area of major effects is a transition zone (Zone II) in which subtle biological effects can be detected as community parameters return to normal, generally within 200-1,000 m. The benthic community

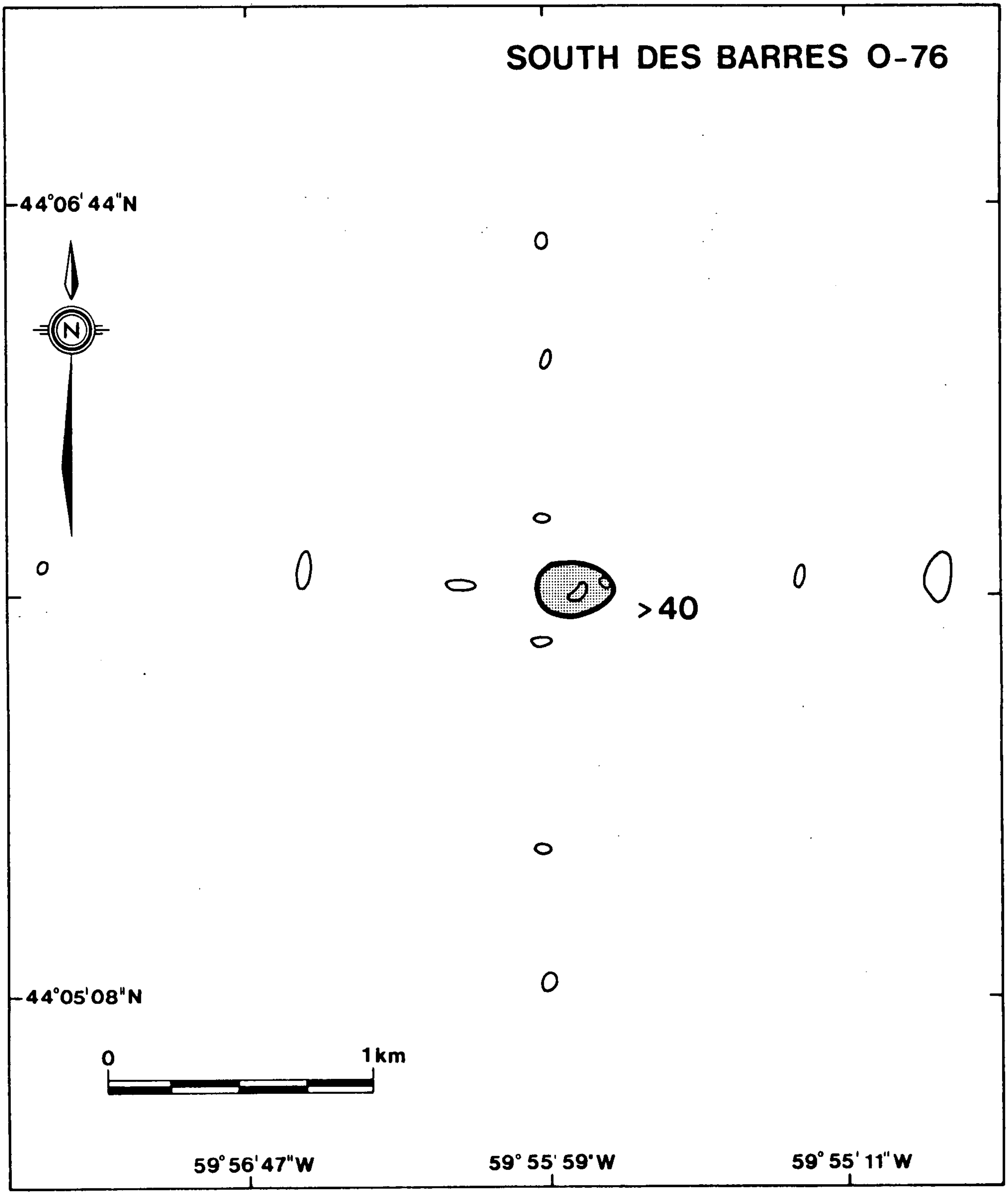

Figure 18. The pre-drilling South Des Barres O-76 site within 1,500 m of the well-head. Total aliphatic hydrocarbon concentrations shown are in µg/g dry weight of Conoco oil and the ellipses indicate the areas where grab samples collected.

TABLE 15

Zones of impact for the environmental effects of discharge of oil-based mud and cuttings (Davies *et al.*, 1984)*

Zone	Maximum Extent Within Range	Biology	Chemistry
I	0 - 500 m (usually <250m)	Impoverished and highly modified benthic community (beneath and very close to the platform the seabed can consist of cuttings with no benthic fauna)	Hydrocarbon (HC) levels high. Sediments largely anaerobic. HC's 1,000 plus x background.
II	200 - 2,000 m	Transition zone in benthic diversity and community structure.	Hydrocarbon levels above background. HC's 10 - 700 x background.
III	800 - 4,000 m	No benthic effects detected.	Hydrocarbon levels return to background. HC's 1 - 10 x background.
IV	> 4,000 m	No benthic effects	No elevation of hydrocarbons.

* This study considered diesel and first generation (i.e., high aromatic) low toxicity base oils only.

exhibits a classic successional response to a point source organic pollution, with a peak of opportunist species occurring in the immediate vicinity of the platform. These species are very important because their abundance and high levels of productivity play an important role in the breakdown of organic pollutants. In this regard, several correlations between chemical and biological parameters (such as sedimentary oil content and species abundance and the diversity/number of individuals) have been reported (Davies et al. 1984; IOE 1985a).

The variable shape and extent of this zone is determined largely by the current regime and the scope of the drilling operation. With greater currents and more extensive drilling this delineation may extend 2,000 m in the direction of residual current. From the few data available, the surface sediments studied in this zone appeared to be aerobic and biodegradation of hydrocarbons seemed to be taking place. A more rapid recovery of the transition zone was expected on cessation of drilling.

In Zone III (800-4,000 m) elevated hydrocarbon concentrations attributable to oil-based mud were detected but no biological effects were found.

Zone IV was the area beyond 4,000 m and no chemical or biological effects were observed. Generally speaking, background levels were reached within 3,000 m, although this distance was extended for fields that produced very fine cuttings. In certain areas of the North Sea, where offshore production platforms have been recently, or are about to be, installed, it is no longer possible to find the "background" levels of sedimentary hydrocarbons that were observed 5-10 years ago. Extensive oil production activity in the East Shetland Basin, for example, appears to be producing elevated levels of sedimentary hydrocarbons (from about two to about five parts per million[2] to the south of this region).

The spread of cuttings has been found to be greatly influenced by particle size. Cuttings resulting from the use of oil-based mud are generally larger than when using water-based mud and tend to fall, as agglomerations, more directly to the sea bed. The U.K. Committee also found that the extent of biological effects was greater from oil-based mud cuttings than from water-based mud cuttings beyond the area of physical smothering (e.g., Zones II and III). These effects of oil-contaminated cuttings may result from organic enrichment of the sediment, or toxicity of certain fractions such as aromatic hydrocarbons, or both. It was estimated that sediment oil concentrations of 100 ppm diesel, or 2 ppm naphthalenes, would be expected to restrict many species of benthic organisms (Armstrong et al. 1979).

Davies et al. (1984) noted that there will be an overlap between the zones in both distance and pollutant levels and that the true picture will be a gradient of change away from the platform. The pattern of cuttings deposition reflects several factors including the prevailing current regime, depth of water, and height of the discharge point above the sea bed. The

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[2] D.J. Thomas, Seakem Oceanography Ltd., Sidney, British Columbia, personal communication, 1985.

distances in Table 15 represent the maximum extent of the zones visualized in 1983, although this is currently under review.

The concept of "zones of effect" proved useful for summarizing the existing effects as of 1982-83. With the large number of highly deviated wells being drilled from one platform in the northern North Sea, and the increasing use of oil-based mud throughout most drilling programs, it may be that the "maximum extent of the highly-modified benthic community" (Davies et al. 1984) will not be contained within a 500-m zone. Similarly, whether the "benthos returns to normal" for the majority of the North Sea fields within 1,000 m remains to be conclusively proven, and the distance at which no benthic effects or elevation of hydrocarbon levels is reached is still to be firmly established.

Long-term recovery of an area following the cessation of discharge is likely to be affected by a number of factors including (Davies et al. 1984):

- redistribution and spreading of cuttings;
- biodegradation or dissolution of the oil on the cuttings; and
- burial of the cuttings and recolonization of the surface sediment.

It should be noted, however, that most of the studies available to the U.K. working group were done at drilling operations that used either diesel oil or high-aromatic-content mineral oil to make up the oil-based mud. The much higher concentration of aromatics in these oils relative to the mineral oil usually used in Canada, is given by most workers as the reason that these oils have a much higher acute toxicity. Although the concentrations, types, and toxicities of aromatics and polycyclic aromatics in either diesel oil-based or low-aromatic oil-based muds are important to know, it is interesting to note that U.K. authorities do not propose to regulate mineral oil-based muds on the basis of aromatic content (Engelhardt et al. 1983). They see little direct correlation between aromatic content and toxicity of the muds or cuttings. This result has been supported by studies carried out in Canada (Hutcheson et al. 1984).

It has been observed that direct leaching of oil from cuttings into sea water appears to be very slow (Engelhardt et al. 1983) with initial rates of 0.1% per day and total losses in the order of 1-4% over a substantial period of time being quoted. Poley and Wilkinson (1983) have suggested that, from laboratory studies, leaching rates of "oil from cuttings" (neither described) would be about 2 g/m^3/day. In spite of this apparent lack of availability, accumulation of non-polar hydrocarbons from low-aromatic-content mineral-oiled cuttings has been observed to occur in parallel with lethal response in a few marine invertebrates tested (Hutchinson et al. 1984). The possible implications of this uptake on potential fish tainting have not yet been fully investigated.

Comparison of the Sable Island Study to Other Studies

Dobrocky Seatech Ltd.'s study of the distribution of mineral oil from oiled cuttings discharged at the two Sable Island well sites supported the conclusions of the U.K. studies for the deeper-water site but found that the U.K. experience would have overestimated the effects for the shallow-water site.

At the West Venture site, hydrocarbon concentrations were observed to drop off to a level 10 times above background at about 200 m from the well site. Thus Zone II (the transition zone, see Table 15) and Zone I (the impoverished zone) extend less than 200 m from the well-head. By extrapolating from the U.K. studies, the region where hydrocarbon levels area greater than 100 times above background could be defined as that in which the benthos is likely to be affected. At the West Venture site this area can only be defined roughly (see dashed line in Figure 14 and 15) because no grab samples were taken closer than 200 m from the well site, and divers did not collect samples outside of the 200 m x 24 m oiled cuttings mound. At this shallow-water site, where considerable mixing and movement of the sediment is likely, the inference is that the effects will be much less than those that could be predicted from the U.K. summary.

At the South Des Barres site the study results are much closer to those inferred from U.K. summary. The affected zones implied at South Des Barres (based on oil concentrations in the sediments) were similar in size to the ones that could be predicted from Table 15. Depending on the direction, the hydrocarbon levels dropped to 10 times above background (the beginning of Zone III, no benthic effects, see Table 15) at distances ranging from 200 m to 1,500 plus m from the well-head. Hydrocarbon concentrations fell to two orders of magnitude above background (i.e., Zone II, the transition zone) at distances ranging from about 150 m to 650 m from the well site. This hydrocarbon isopleth encloses the area where effects on the benthos are likely (see shaded area in Figure 17). Concentrations three orders of magnitude above background (Zone I, the impoverished zone) were likely present at distances of about 100 m to 400 m from the well. It appears that at the deeper-water site, the U.K. summary adequately predicts the hydrocarbon levels, and therefore possible biological effects, resulting from the discharge of mineral-oil cuttings.

CHARACTERISTICS OF THE HYDROCARBONS IN THE SEDIMENT SAMPLES

GC traces of the Conoco base oil are shown in Figures 19 and 20. These samples were prepared by dilution of a standard sample of Conoco ODC mineral oil, supplied to Dobrocky Seatech Ltd. by Technifluids Ltd., and did not pass through any of the extraction or concentration steps of the sample work up. To aid in the interpretation of these GC traces, the positions of the even carbon number normal alkanes (from C8 to C18) are also shown. GC traces of two difference concentrations of the base oil are provided so that details of both the resolved hydrocarbon pattern and the UCM can be seen.

Conoco ODC oil is composed mainly of isoparaffinic and naphthenic hydrocarbons[3]. Analysis of several Conoco ODC samples by gas chromatography-mass spectrometry (GC/MS) has shown bicycloparaffins in the range C_8 to C_{16} comprise the largest portion (about 45%) of the typical base-oil sample. The next most common compound type is the cycloparaffins, followed by isoparaffins and branched paraffins. Together, these four

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[3] D.T. Plummer, Vista Chemical Company, Ponka City, Oklahoma, personal communication, 1984.

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- redistribution and spreading of cuttings;
- biodegradation or dissolution of the oil on the cuttings; and
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It should be noted, however, that most of the studies available to the U.K. working group were done at drilling operations that used either diesel oil or high-aromatic-content mineral oil to make up the oil-based mud. The much higher concentration of aromatics in these oils relative to the mineral oil usually used in Canada, is given by most workers as the reason that these oils have a much higher acute toxicity. Although the concentrations, types, and toxicities of aromatics and polycyclic aromatics in either diesel oil-based or low-aromatic oil-based muds are important to know, it is interesting to note that U.K. authorities do not propose to regulate mineral oil-based muds on the basis of aromatic content (Engelhardt et al. 1983). They see little direct correlation between aromatic content and toxicity of the muds or cuttings. This result has been supported by studies carried out in Canada (Hutcheson et al. 1984).

It has been observed that direct leaching of oil from cuttings into sea water appears to be very slow (Engelhardt et al. 1983) with initial rates of 0.1% per day and total losses in the order of 1-4% over a substantial period of time being quoted. Poley and Wilkinson (1983) have suggested that, from laboratory studies, leaching rates of "oil from cuttings" (neither described) would be about 2 g/m^3/day. In spite of this apparent lack of availability, accumulation of non-polar hydrocarbons from low-aromatic-content mineral-oiled cuttings has been observed to occur in parallel with lethal response in a few marine invertebrates tested (Hutchinson et al. 1984). The possible implications of this uptake on potential fish tainting have not yet been fully investigated.

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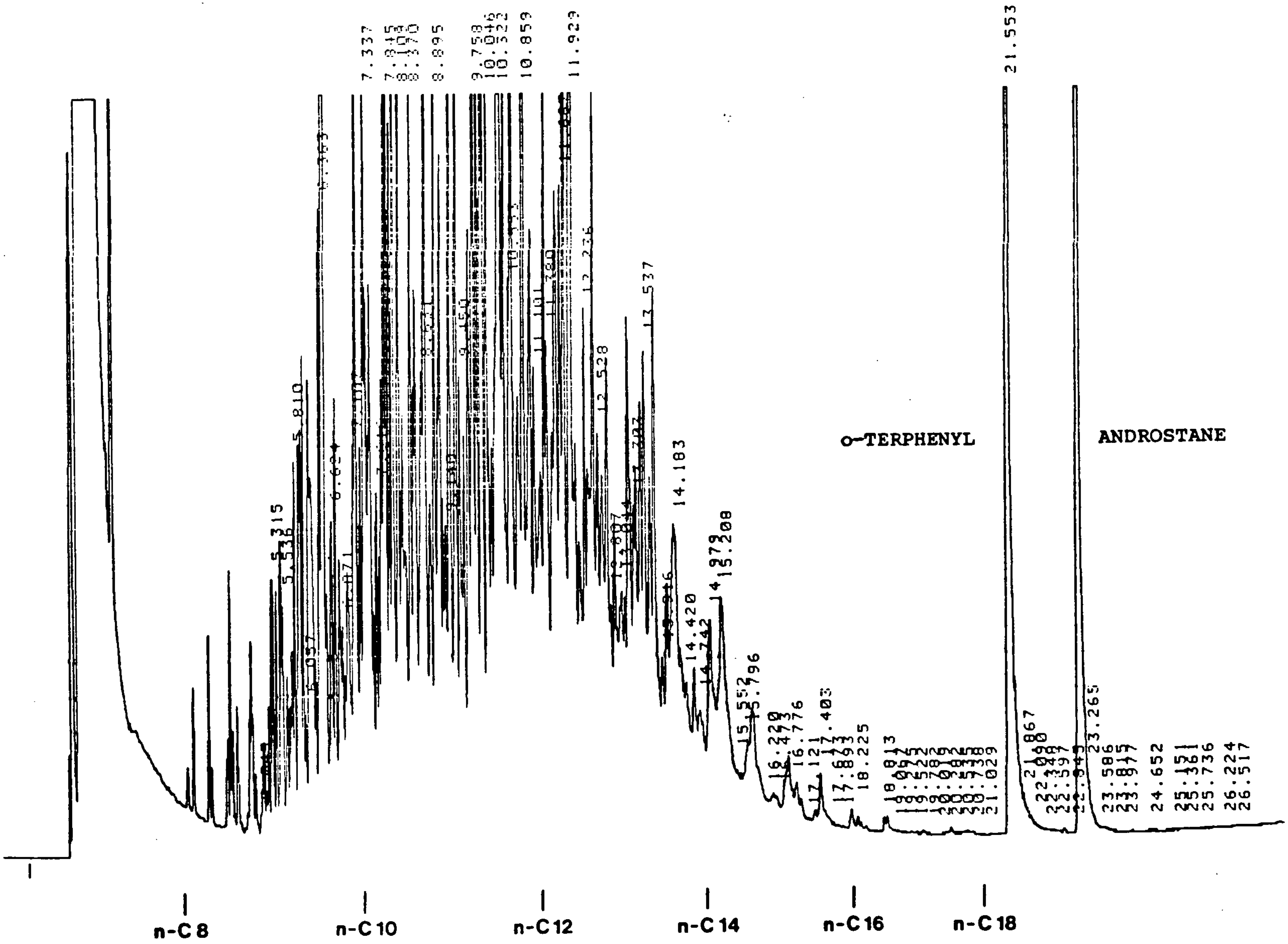


Figure 19. Characteristic GC trace of Conoco ODC mineral oil a concentration of 1.0 μg/μL.

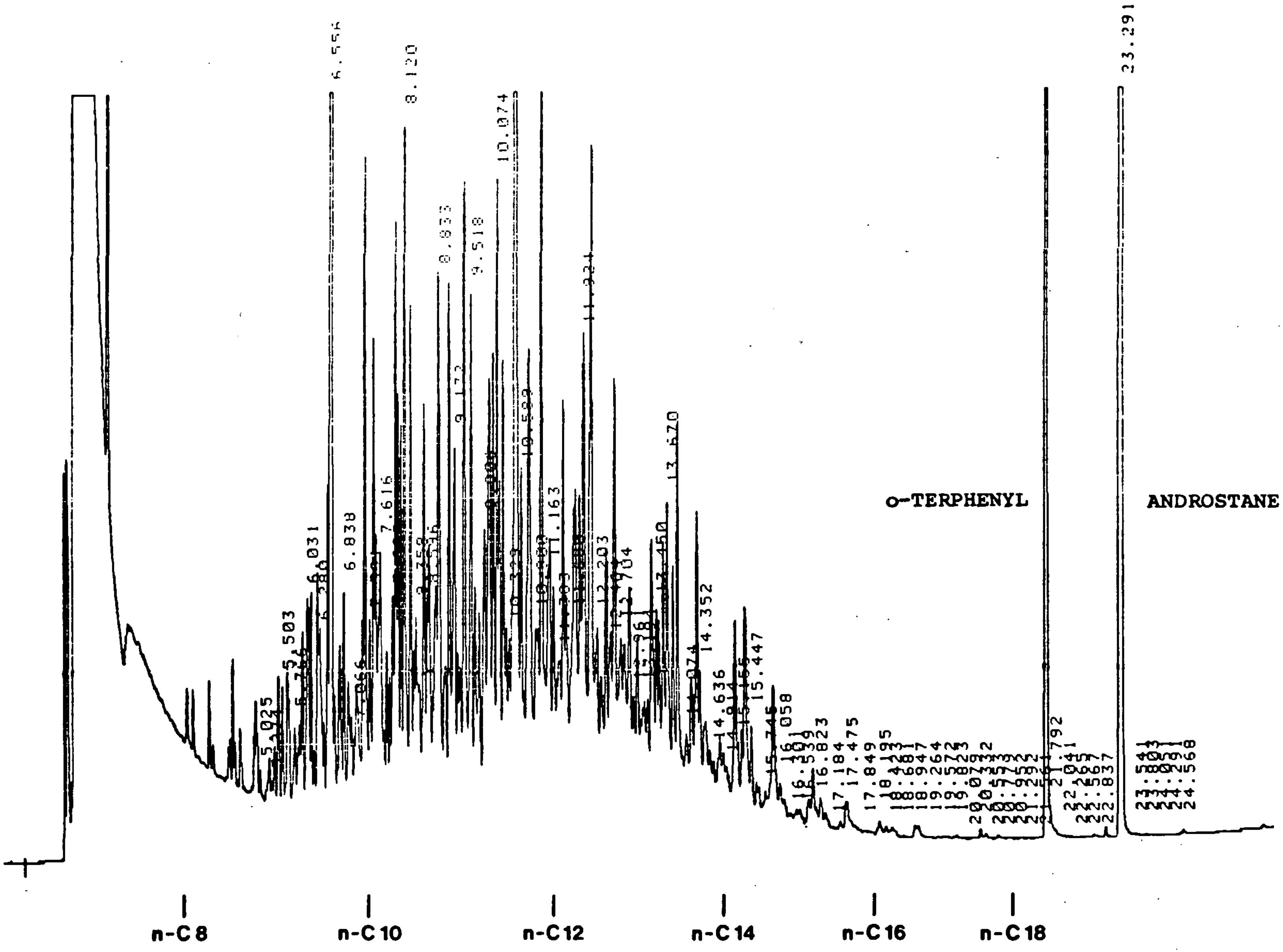


Figure 20. GC trace of Conoco ODC mineral oil at a concentration of 0.5 µg/µL.

compound types make up over 99% of the typical oil. Detailed results of the analysis of the base oil and of the water-soluble fraction of the oil are given in Table 16. The water-soluble fraction was prepared using standard acute aquatic toxicity procedures.

The more detailed GC/MS analyses of the Conoco ODC oil performed by Battelle showed substantially lower amounts of naphthalenes than were reported in Table 16. In addition, the sum of the polynuclear aromatic hydrocarbon (PAH) components reported was about half of the total amount of aromatic hydrocarbons shown in Table 16; the inference is that the Vista Chemical Company GC/MS analyses have overestimated the levels of aromatics in the base oil. Battelle identified the major PAH components in the Conoco oil as benzo(e)pyrene and perlyene with chrysene, benzo(a)anthracene and the phenanthrenes making up the bulk of the remaining PAHs measured.

Samples collected at the West Venture site showed more weathering of the Conoco oil than samples collected at the South Des Barres site. This result is consistent with the increased washing of the sediments by wave action that is to be expected at the shallow (16 m) West Venture site.

Figure 21 shows the GC trace from a sample collected in the top 5 cm from Grab 2 at the West Venture station 200 m northeast of the well-head. The sample showed a truncated envelope relative to Conoco oil with hydrocarbons up to n-C12 washed out of the sample. Data collected by Battelle on this sample confirmed the weathering. In addition to the wash out of the more volatile fraction, the weathering was characterized by an increase in the relative abundance of the isoprenoid alkanes (because of a faster loss of the normal alkanes) and a reduction in the resolved components in the GC trace. The GC trace of the sample from the top 5 cm of the other grab (Grab 1) at the same station also showed weathering with hydrocarbons up to n-C11 washed out of the sample. Figure 22 shows the GC trace from samples collected in the 5-10 cm range at the same station. Relative to Conoco oil, only hydrocarbons from the range of n-C8 to n-C10 are missing from the sample. Because this loss was repeated in all of the buried samples from the West Venture site, and for all of the South Des Barres samples, it is not clear whether these volatile hydrocarbons were lost by dissolution into sea-water or by loss during sample work-up. The 5-10 cm fraction of both of the grab samples from the 200 m northeast West Venture station showed the same GC trace, but the trace for Grab 1 is shown in Figure 22 because more of the peaks were on scale. Battelle data confirmed the lack of substantial weathering of the components above n-C10 in the Grab 2, 5-10 cm sample.

A sample taken from the top 5 cm at the West Venture station 200 m southwest of the well-head showed more extreme weathering of the hydrocarbons (Figure 23). However, samples collected by divers at the West Venture well-head, in November 1984 and February 1985, showed the GC trace presented in Figure 24, with only the hydrocarbons up to n-C10 washed out of the sample. Battelle data confirmed all of these results except for the February 1985 sample. The conclusion seems to be that if the Conoco oil is either bound to cuttings or buried in the sediments, then there will be very little solubilization of hydrocarbons into the water column. On the other hand, if the Conoco oil is exposed to wave action in surface sandy sediments, then

TABLE 16

Composition of the Conoco ODC base oil and of the water soluble fraction of the base Oil (Plummer, 1984).*

GC/MS analysis of Conoco ODC base oil

Component	Area Percent	Carbon range
Normal paraffins	0.5	C_{10}-C_{16}
Isoparaffins	18.3	C_{10}-C_{20}
Cycloparaffins	27.3	C_9-C_{16}
Bicycloparaffins	45.2	C_8-C_{16}
Tricycloparaffins	8.4	C_{10}-C_{16}
Tetracycloparaffins	0.2	C_{12}-C_{15}
Alkylbenzenes	0.1	C_9-C_{11}
Naphthalenes	0.03	C_{10}-C_{15}

Average carbon number = 11.9

GC/FID analysis of the water soluble fraciton of Conoco ODC base oil

Component	Concentration, ug/L
A. Saturated Hydrocarbons	
Normal paraffins	29
Isoparaffins	9.9
Total resolved	118
Total unresolved	260
Total saturated hydrocarbons	378
B. Aromatic Hydrocarbons	
Napthalene	0.03
2-Methylnaphthalene	0.15
1-Methylnaphthalene	0.07
Acenaphthene	0.02
Fluorene	0.02
Total resolved	0.43
Total unresolved	-
Total aromatic hydrocarbons	0.43

* Note that Conoco ODC oil is now marketed under the name of Vista ODC oil.

Source: D.T. Plummer, personal communication, 1984.

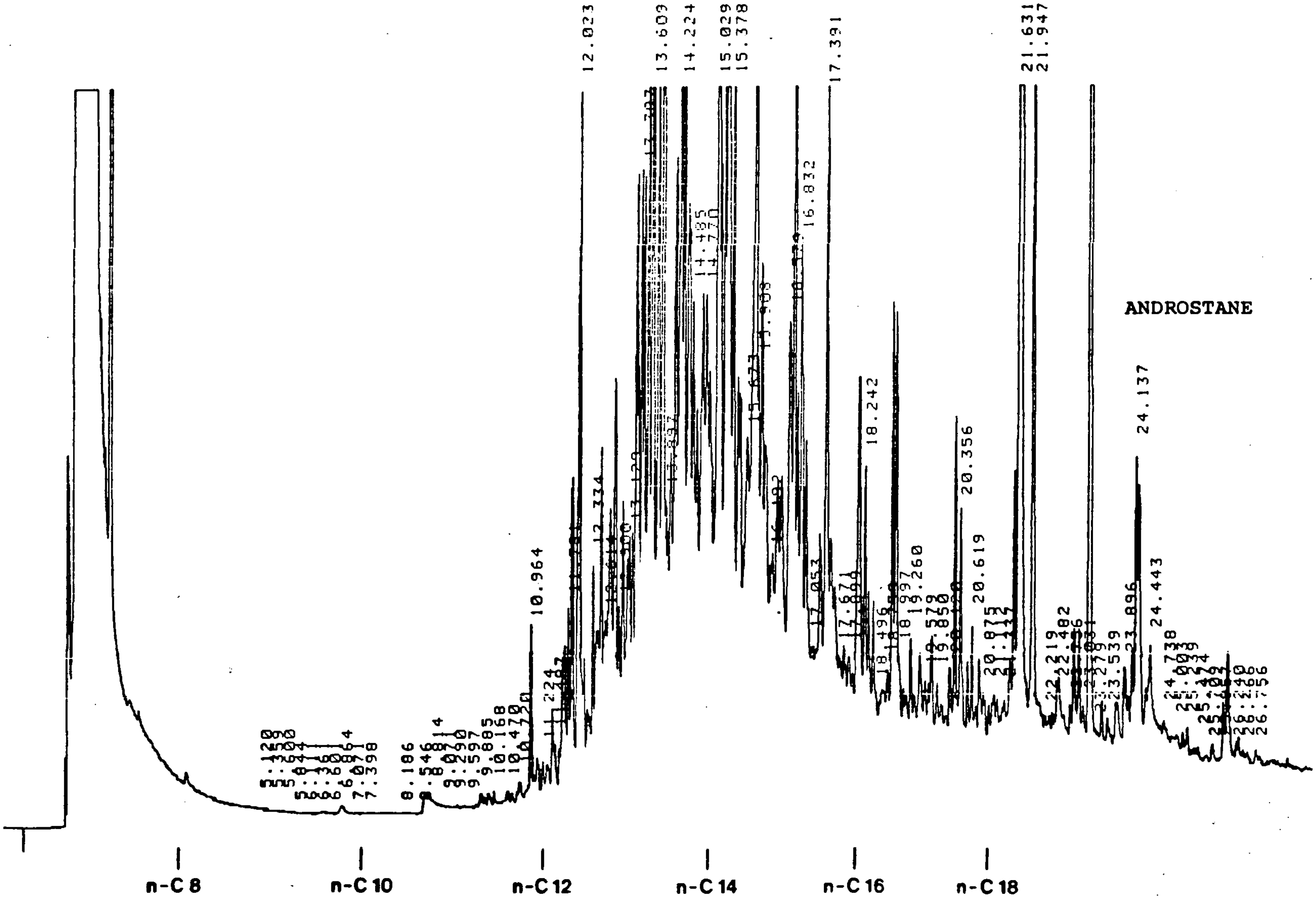


Figure 21. GC trace of the aliphatic hydrocarbons in the top 5 cm of sediment from the West Venture station 200 m northeast of the well-head (Station 23, Grab 2, 0-5 cm depth).

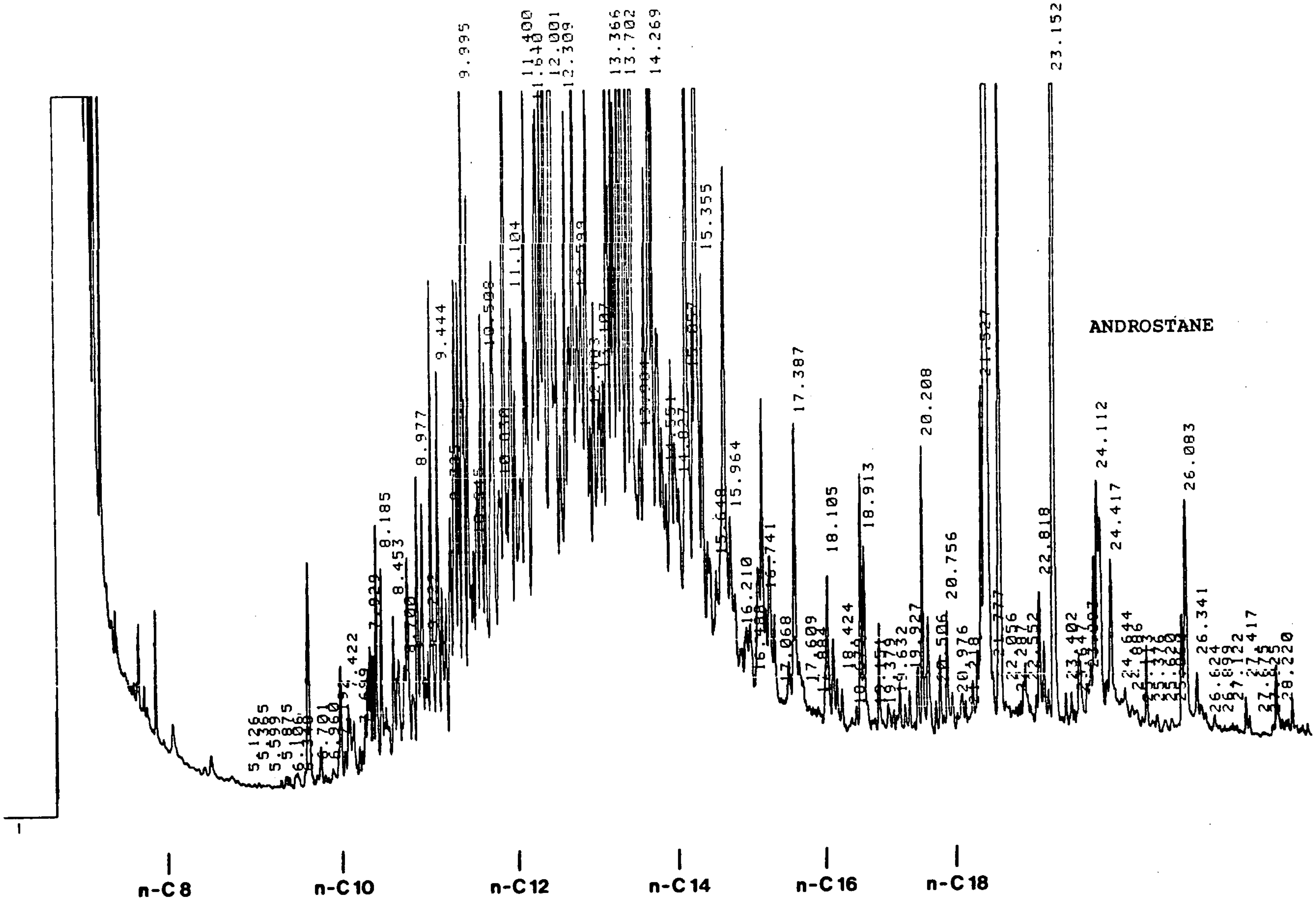


Figure 22. GC trace of the aliphatic hydrocarbons in the sediment from the 5-10 cm depth from the West Venture station 200 m northeast of the well-head (Station 23, Grab 1, 5-10 cm depth).

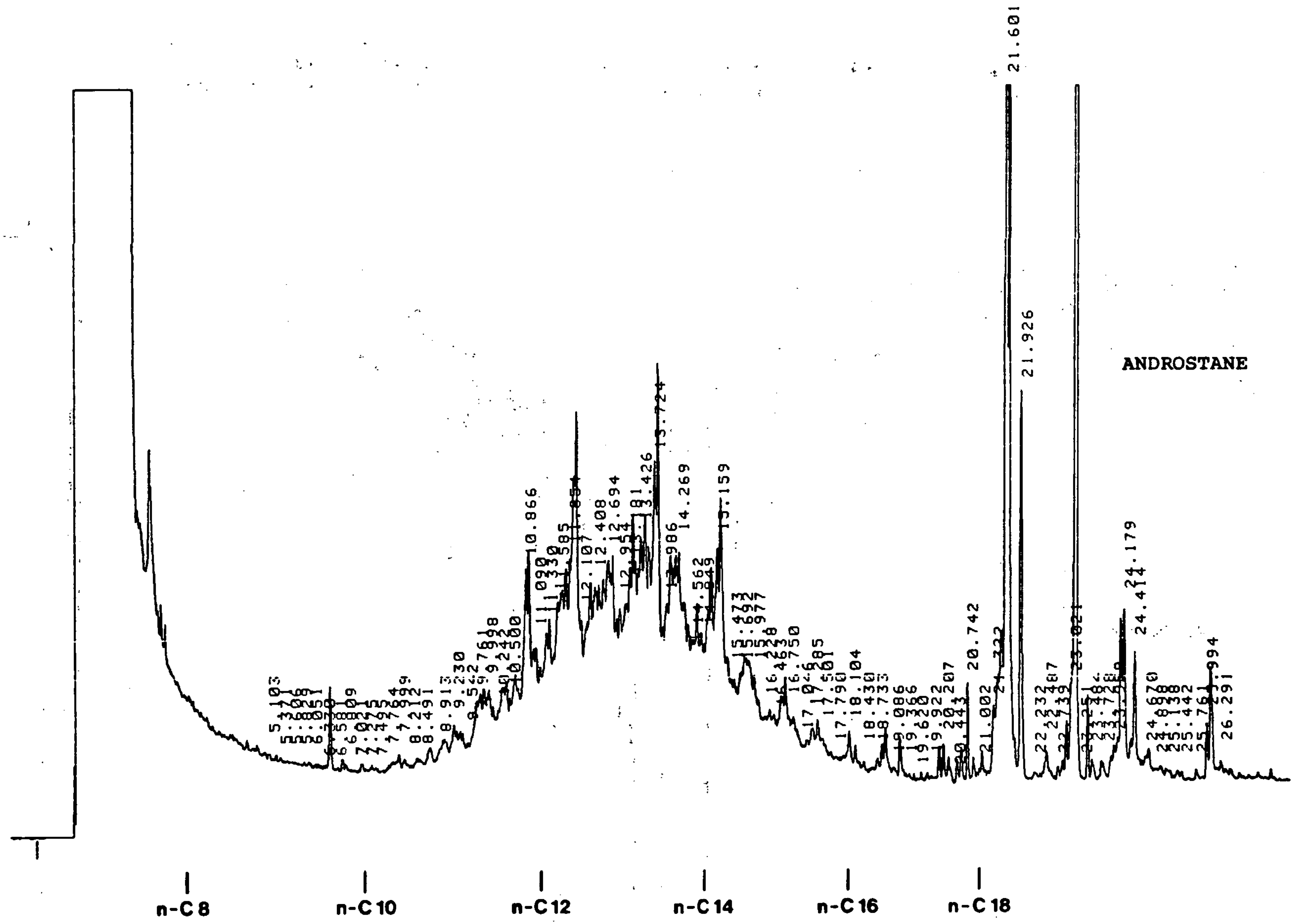


Figure 23. GC trace of the aliphatic hydrocarbons in the sediment from the West Venture station 200 m southwest of the well-head (Station 11, Grab 1, 0-5 cm depth).

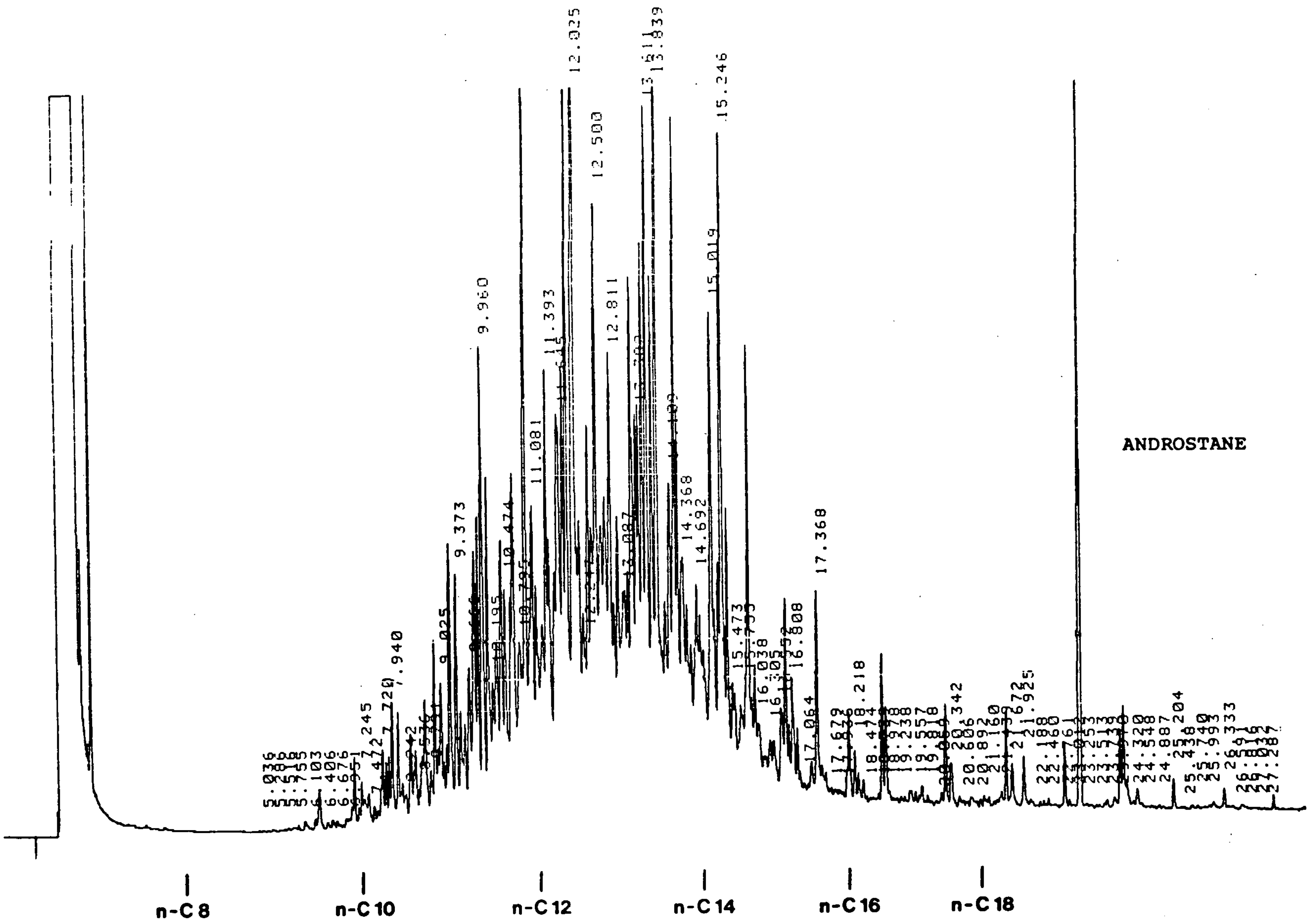


Figure 24. GC trace of the aliphatic hydrocarbons in the sediment collected by divers in February 1985 at the West Venture well-head (Station 1, Sample 1).

there will be considerable wash out of the hydrocarbons commencing with the more volatile (and presumably more water soluble) fractions.

One of the other samples collected at the West Venture well-head by divers in February 1985 showed an additional UCM hump, centred at about n-C19, likely because of the input of hydrocarbons from a different source than the Conoco oil. This sample was the only one collected at either the West Venture or South Des Barres sites that showed a double hump.

All of the samples from South Des Barres that contained hydrocarbon concentrations greater than about an order of magnitude above background showed a GC trace essentially the same as the one shown in Figure 25. Relative to Conoco oil, only hydrocarbons from the range of n-C8 to n-C9 or n-C10 are missing from these samples. None of the South Des Barres post-drilling samples showed the extreme weathering exhibited by the West Venture samples (as shown, for example, in Figure 23). However, one of the "pre-discharge" samples collected from the station 200 m east of the well site two days after the discharge of oiled cuttings began, did show a similar pattern of hydrocarbon loss.

The detailed GC examination performed by Battelle on the post-drilling South Des Barres 200-m samples, and on the 800- and 1,500-m samples collected east of the well site, confirmed the lack of weathering. However, some weathering did occur (as indicated by an increase in the relative abundance of the isoprenoid alkanes) in samples collected 200 m north and northwest of the well site. This result is consistent with the low hydrocarbon concentrations observed at these sites.

When high concentrations of hydrocarbons were present in the samples, the GC fused-silica column would become overloaded and there would be a marked decrease in the resolution of the resolved aliphatics fraction (Figure 26). Note also that in these cases the androstane internal standard would often be below the limit of reliable detection (as it is in Figure 26) and therefore quantitation was performed by the external standard peak-area method.

The aliphatic hydrocarbon background for the South Des Barres area is shown for one of the pre-discharge samples collected from the bottom 5 cm of a sample taken at the well site (Figure 27). Note the lack of interfering peaks in the n-C10 to n-C16 range. The top 5 cm of this sample clearly showed the presence of Conoco oil. The West Venture background samples showed a much simpler pattern, likely the result of a lack of fines in the sandy sediments from the area.

A frequently observed GC trace for the aromatic hydrocarbon fraction is shown in Figure 28. The aromatic fraction was quite often characterized by narrow clump of peaks between n-C11 and n-C12. However, for the highly concentrated hydrocarbon samples, the trace shown in Figure 29 was usually observed. This change was initially attributed to overload of the Sephadex gel column, with resulting trailing of some of the aliphatic fraction into the aromatic fraction. However, a comparison of Figure 29 with the GC trace of the aromatic fraction of a sample analysed by Battelle after rechromatography (see Figure 34), suggests that this is more likely the result of a change in the composition of the aromatic fraction.

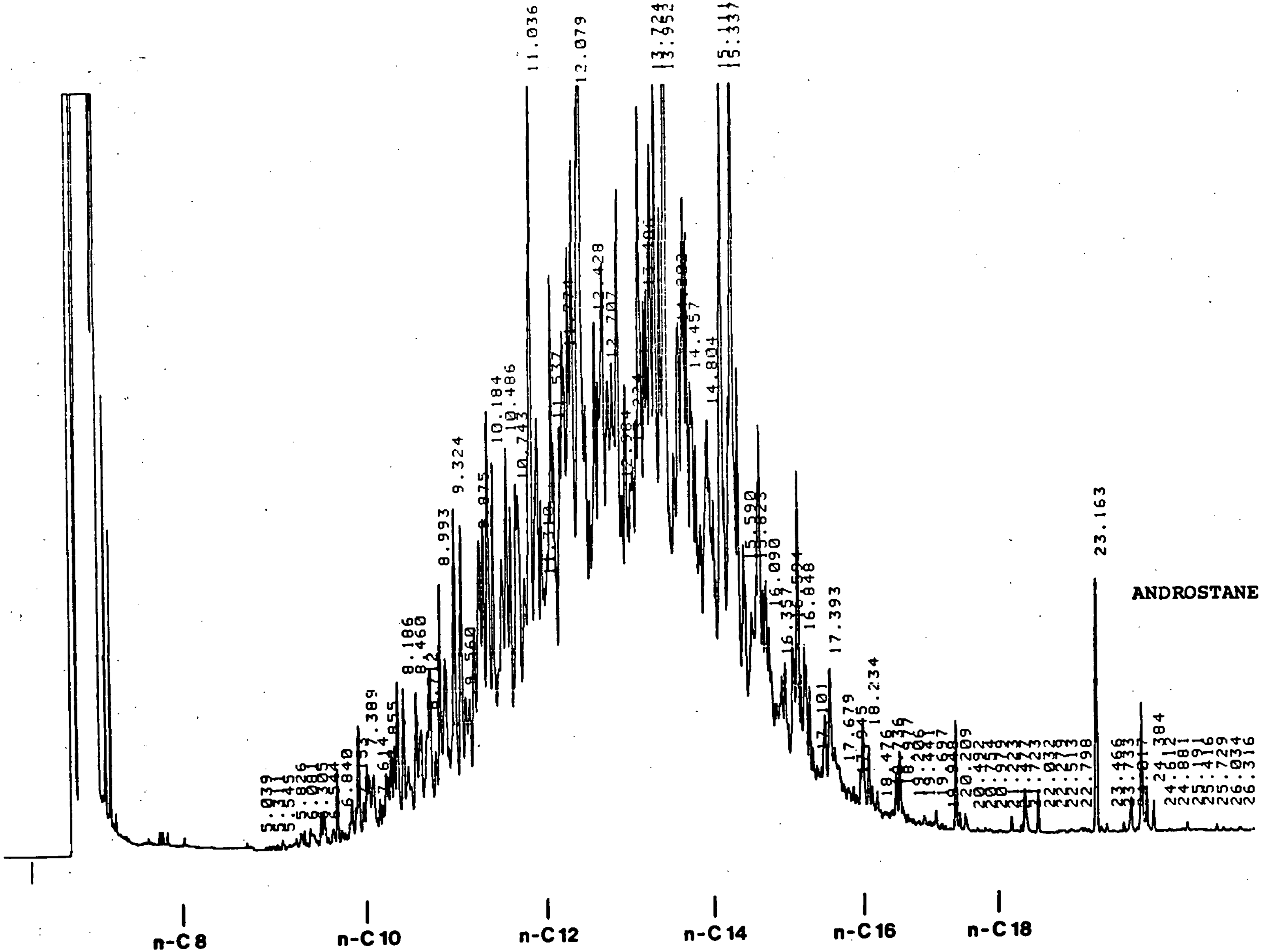


Figure 25. GC trace of the aliphatic hydrocarbons in the sediment from the South Des Barres station 200 m south east of the well-head. (Station 15, Grab 2, 0-5 cm depth).

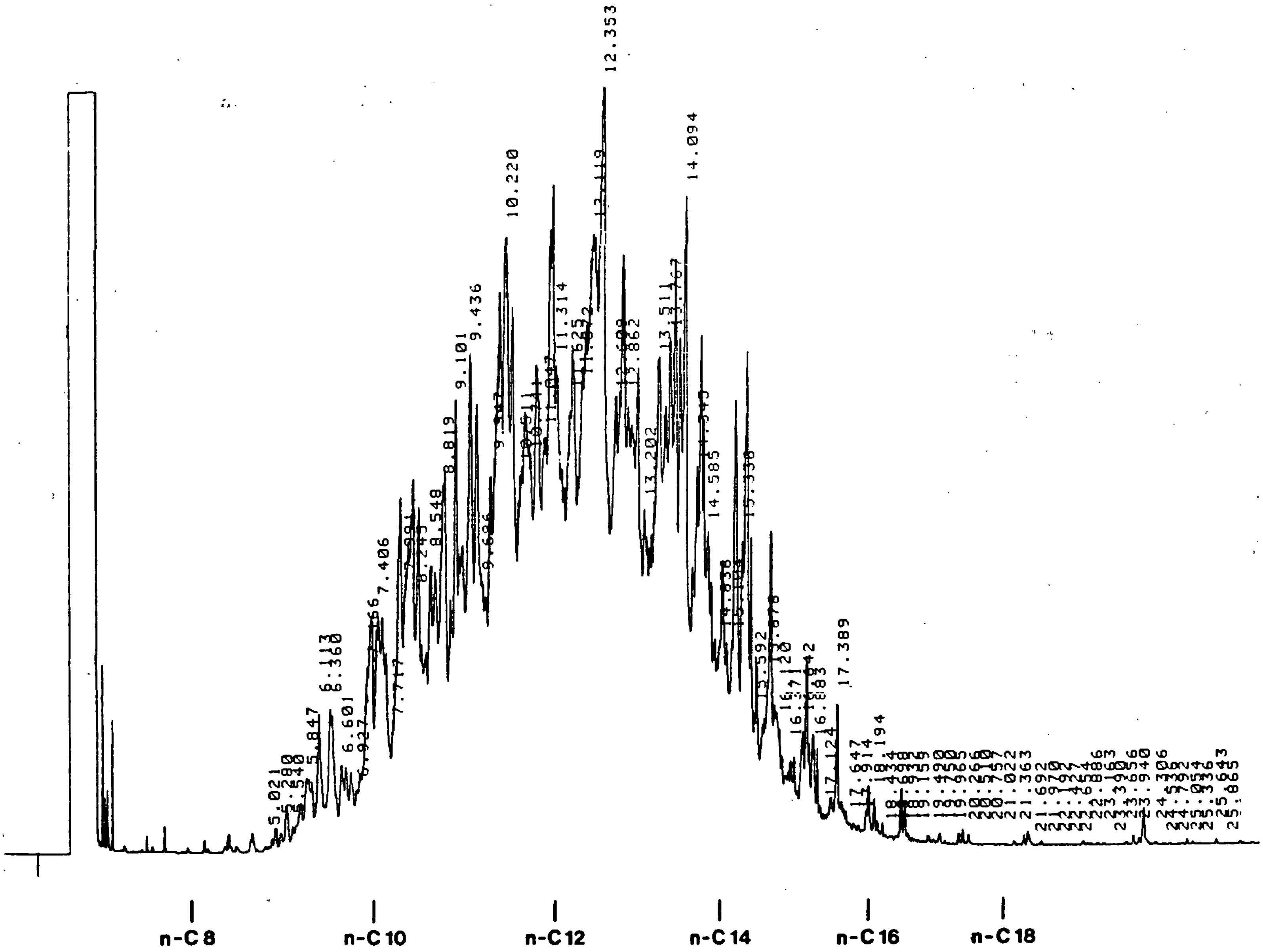


Figure 26. GC trace of the aliphatic hydrocarbons in the sediment from the South Des Barres well-head. (Station 1, Grab 4, Subsample 2, 0-5 cm depth).

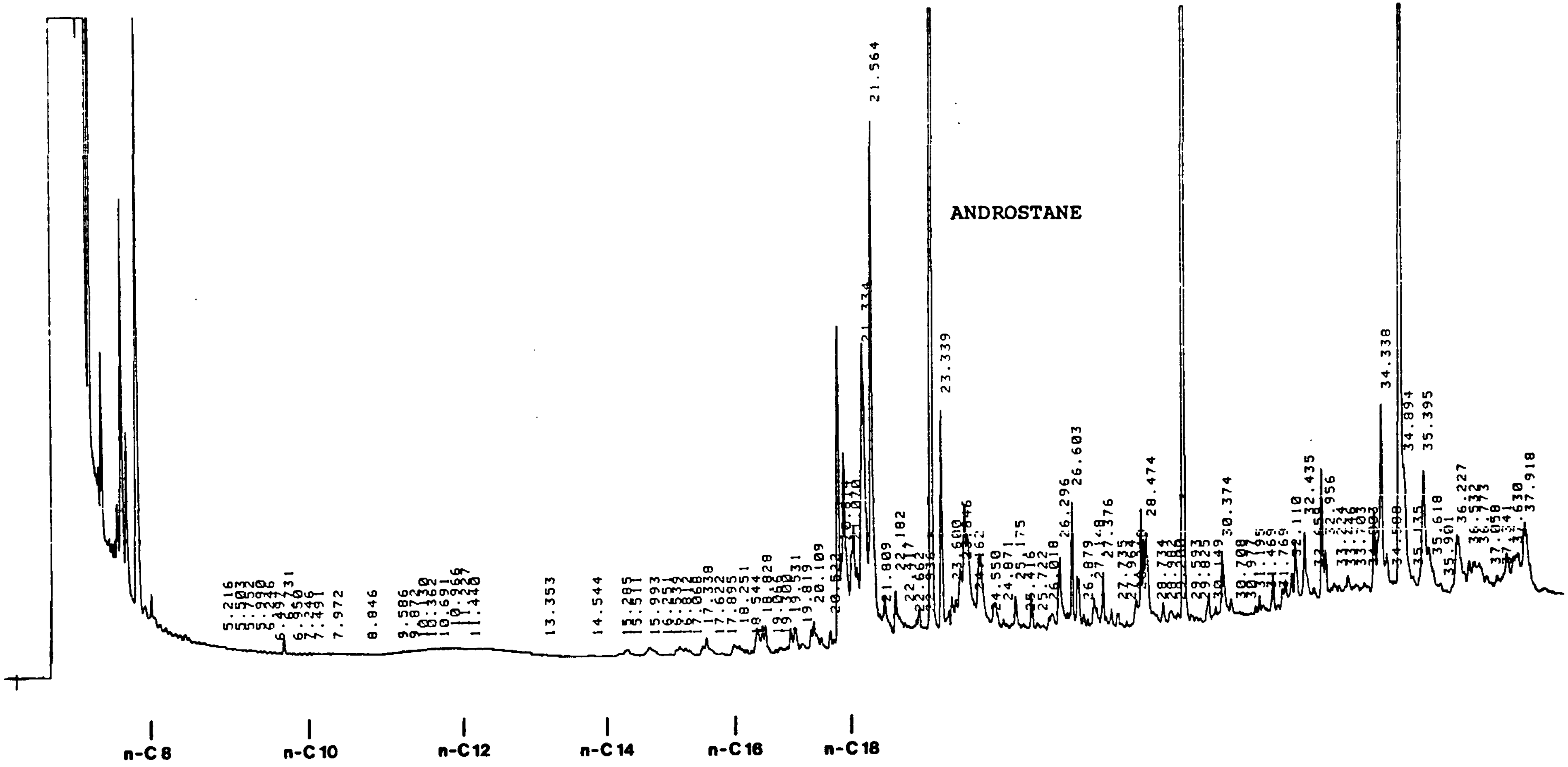


Figure 27. GC trace of the aliphatic hydrocarbons in the sediment from the 5-10 cm depth from the pre-discharge South Des Barres station at the well site (Pre-discharge Station 1, Grab 5, 5-10 cm depth).

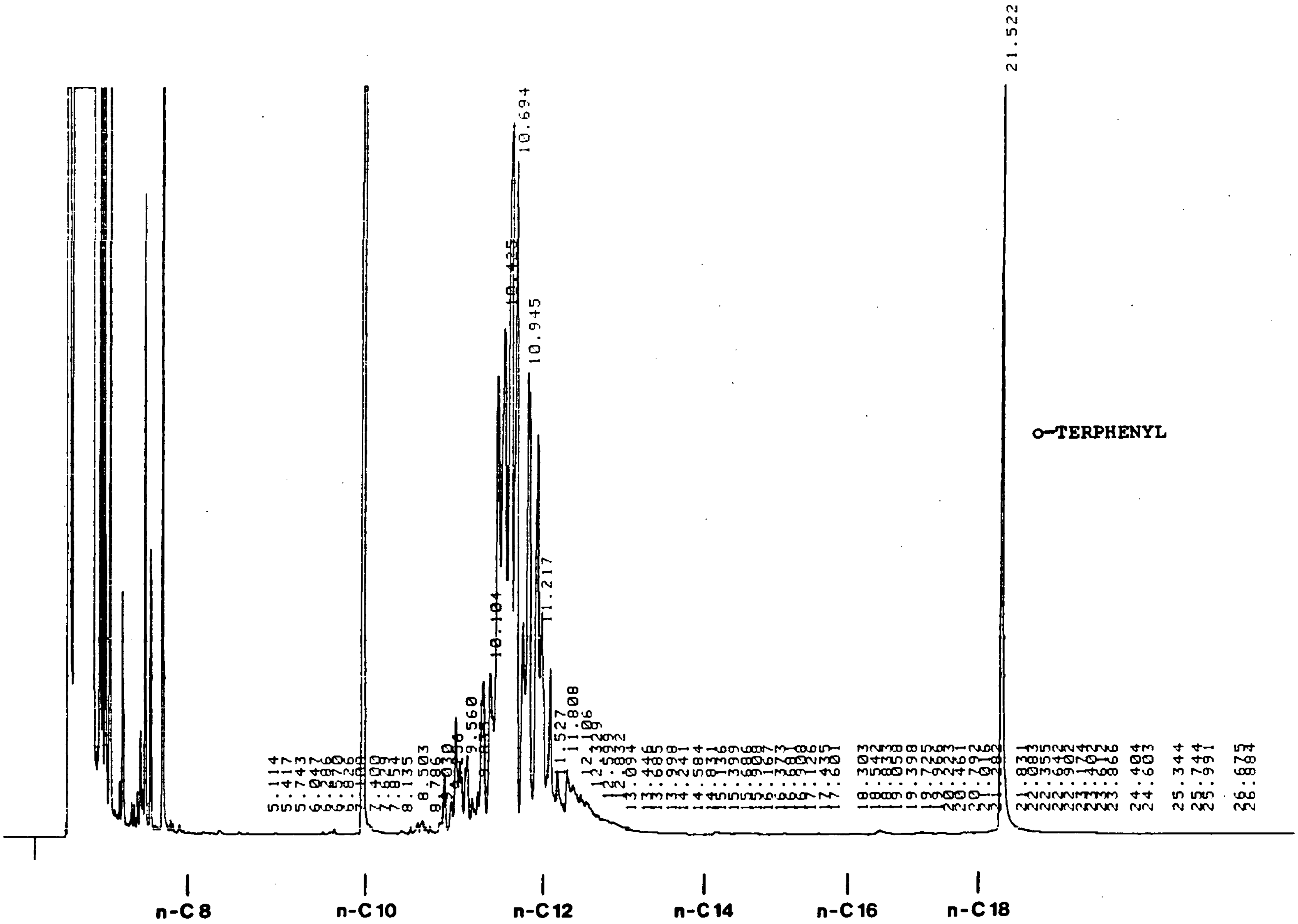


Figure 28. GC trace of the aromatic hydrocarbons in the sediment from the pre-discharge South Des Barres station 200 m east of the well site (Pre-discharge Station 2, Grab 3, 0-5 cm depth).

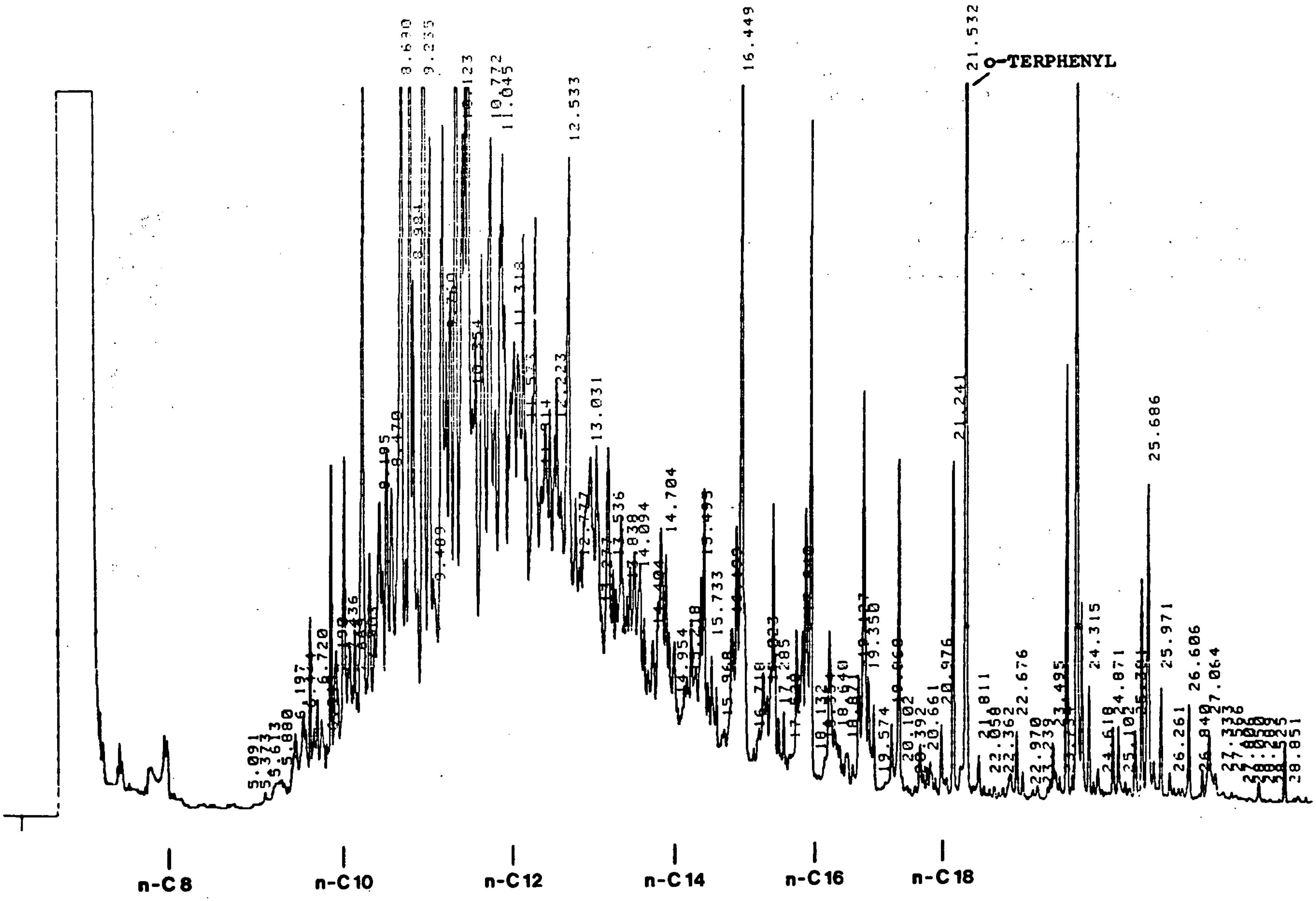


Figure 29. GC trace of the aromatic hydrocarbons in the sediment from the South Des Barres station 200 m south of the well site (Station 5, Grab 1, 0-5 cm depth).

RESULTS OF THE ADDITIONAL ALIPHATIC AND PAH ANALYSES

Aliphatic hydrocarbon data were reported by Battelle as resolved, unresolved, and total aliphatics and major peaks were assigned using GC/FID comparisons to known standards. In the cases where androstane could be detected (i.e., an external standard was not used by Battelle), excellent agreement was obtained between the Dobrocky Seatech Ltd. results and the Battelle results (Brown et al. 1986). For the 14 samples involved, the two sets of results were highly correlated ($r= 0.94$) and the correlation was significant ($p <0.001$). However, for the 14 samples where an external standard had been added by Battelle, good agreement was obtained for only one sample. The correlation obtained for the latter two sets of results was poor ($r = -0.17$) and was not significant ($p >0.50$). Because of these discrepancies, detailed Battelle aliphatic hydrocarbon concentrations have not been included.

Figures 30 through 32 present representative gas chromatograms of, respectively, the aliphatic hydrocarbon fractions of the Conoco oil, and of two South Des Barres samples collected 200 m from the well site. Figure 31 shows a sample from an area of low-sediment oil concentration and Figure 32 a sample from an area of high-sediment oil concentration. The aliphatic hydrocarbons comprise more then 90% of the Conoco oil (928 µg/g oil) with nearly identical resolved and unresolved concentrations. Alkanes n-C11 through n-C15 were the predominant resolved aliphatic components. Figures 33 and 34 represent GC/MS reconstructed ion chromatograms (RICs) of the aromatic hydrocarbon fractions from the two 200-m South Des Barres samples the aliphatic fractions of which are shown in Figures 31 and 32.

The concentrations of PAHs measured in the Conoco oil and sediment extracts are presented in Table 17. The PAH concentrations represent the most common two- to five-ring aromatics with selected alkyl homologues. Note that the PAH sums presented in Table 17 refer only to the total of the PAH components listed and not to the total of all unsaturated compounds in the f_2 fraction. This means that the totals are not directly comparable to the total aromatics results presented in Table 13 and Appendix 2. The PAH concentrations of the components measured are highest in the South Des Barres and West Venture cuttings and well-head samples, (see Table 17). The remainder of the stations exhibit considerably lower concentrations of PAH.

The Battelle quality control analyses results show measurable quantities of aliphatic and aromatic hydrocarbons in blanks (1.13 µg and 62.04 ng, respectively); however, the concentrations of these analytes did not contribute significantly to the levels found in the actual samples.

Recoveries of individual aliphatic hydrocarbons (n-C10 to n-C30) in fortified procedural blanks ranged from 85% to 102%, which is considered to be well within the acceptable range. Recoveries for individual PAH in blank spikes ranged from 86% to 120%, which is also considered to be acceptable. One exception was the recovery of benzo(a)pyrene, which was only 58%. This value is below the acceptable range and suggests that the benzo(a)pyrene values may be underestimated relative to the true values.

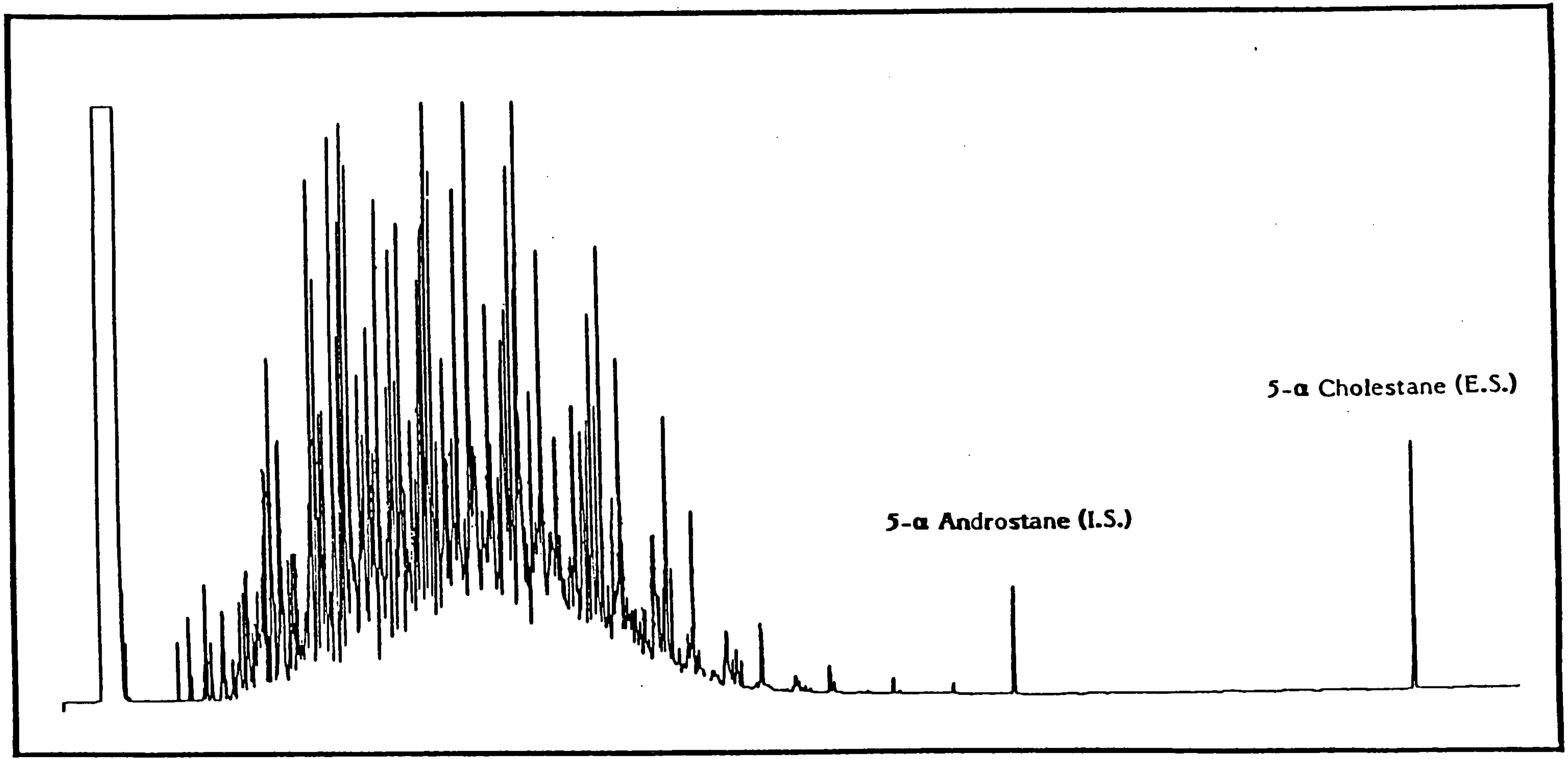


Figure 30. Gas chromatogram (GC/FID) of the *f*1 (aliphatic) fraction of Conoco oil.

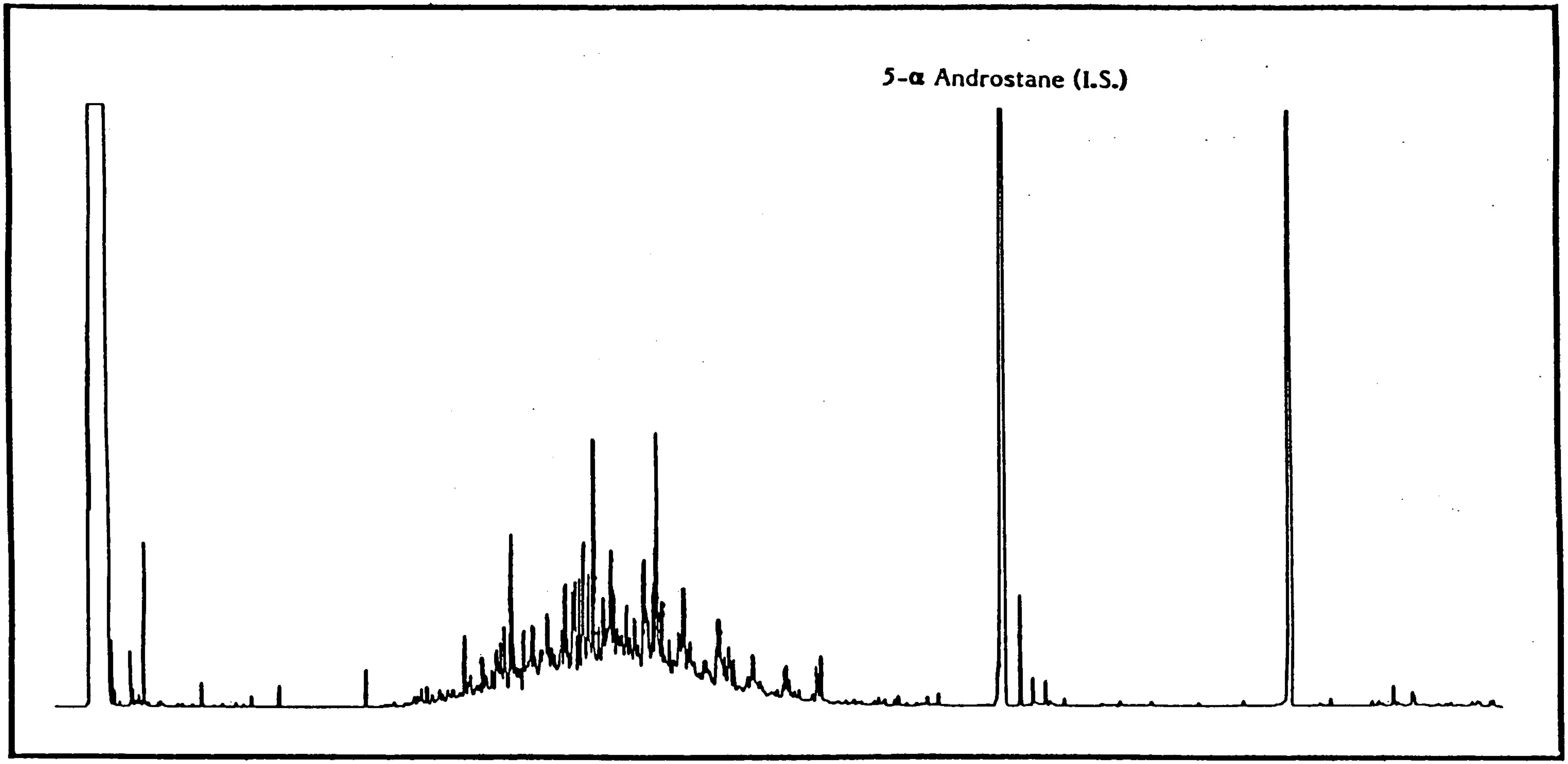


Figure 31. Gas chromatogram (GC/FID) of the f1 (aliphatic) fraction from the South Des Barres station 200 m north of the well-head (Station 11, Grab 2).

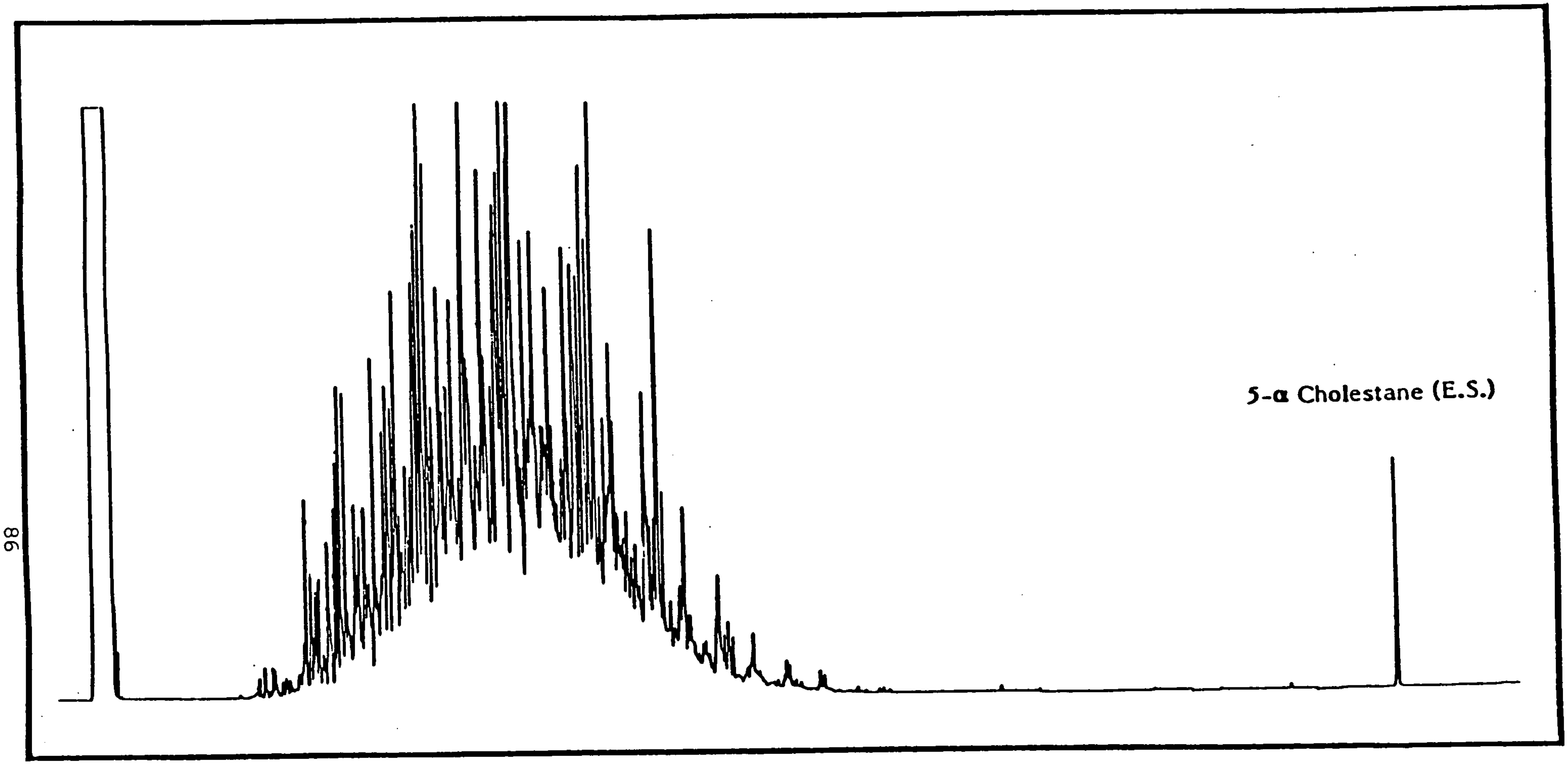


Figure 32. Gas chromatogram (GC/FID) of the f1 (aliphatic) fraction from the South Des Barres station 200 m east of the well-head (Station 2, Grab 1, 5-10 cm depth).

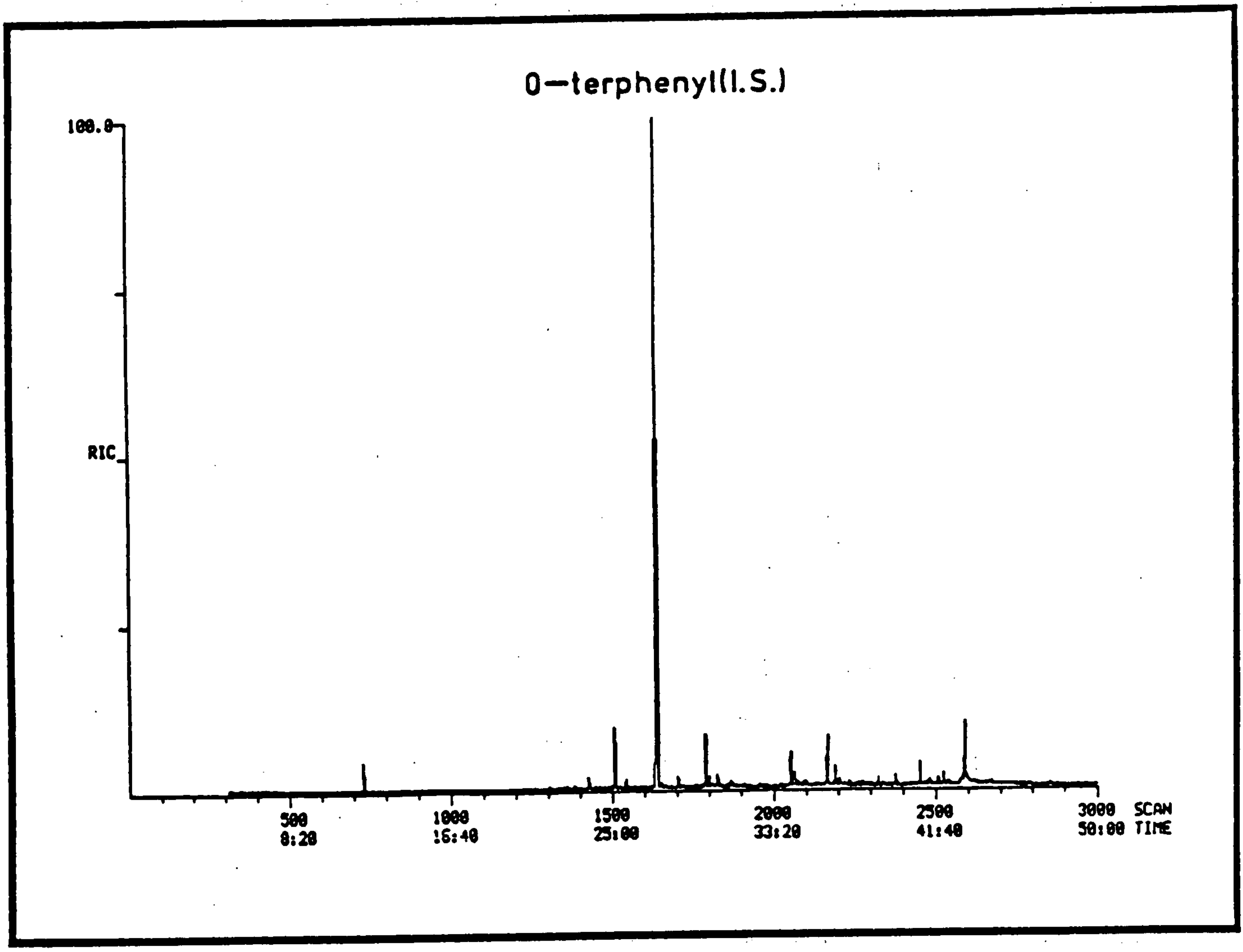


Figure 33. Reconstructed ion chromatogram (RIC) of the $\underline{f2}$ (PAH) fraction from the South Des Barres station 200m north of the well-head (Station 11, Grab 2).

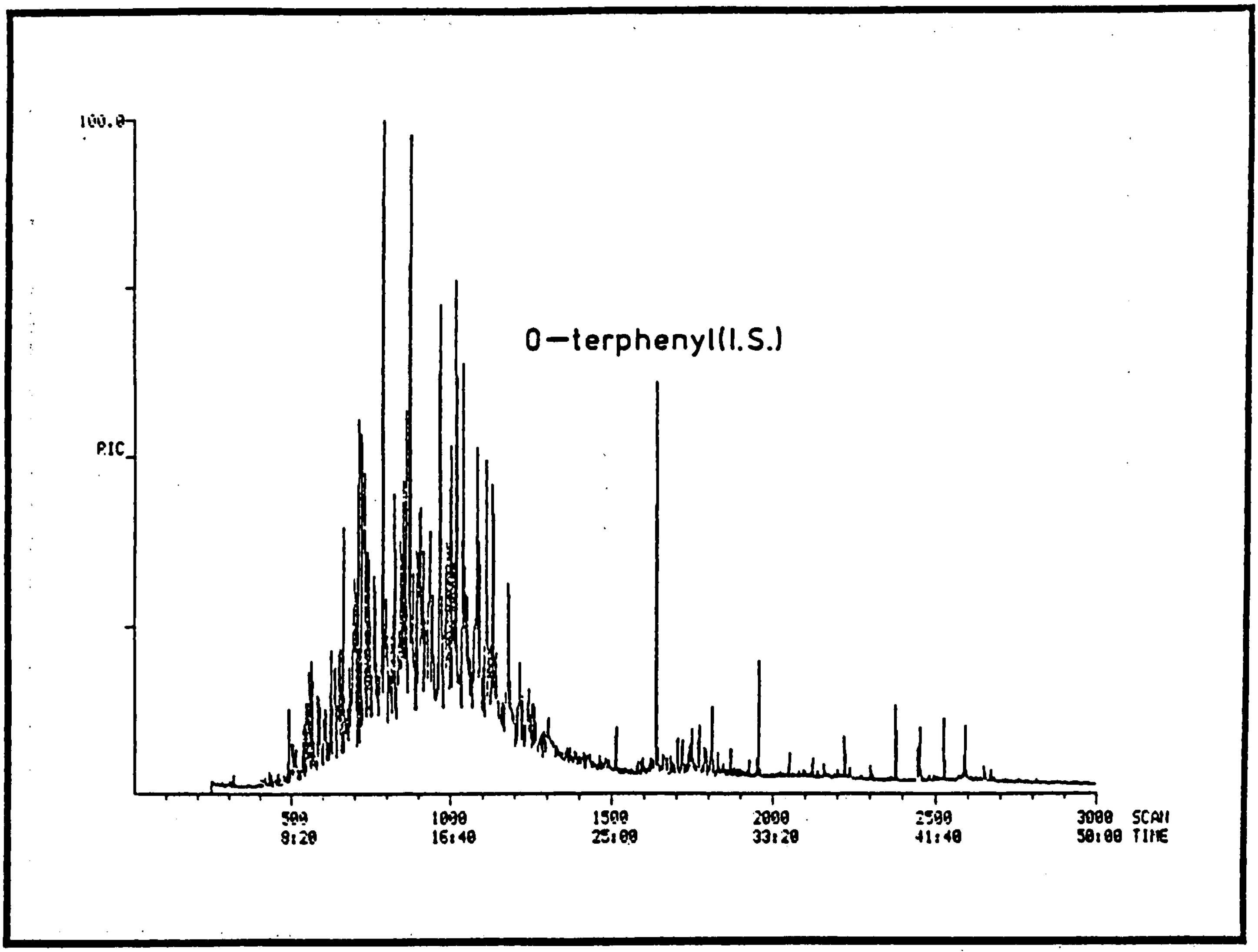


Figure 34. Reconstructed ion chromatograom (RIC) of the f2 (PAH) fraction from the South Des Barres station 200 m east of the well-head (Station 2, Grab 1, 5-10 cm depth).

TABLE 17

Detailed PAH data for Conoco oil and the sediment extracts.

		Sample ng/g dry weight o-terphenyl									
Location		SDB Cuttings		SDB Wellhead				SDB 200 m			
Station	Conoco Oil[a]	SDB	SDB	S1	S1	S1	S1	S2	S2	S5	S8
Grab		1	41	3	3	3	4	1	1	1	2
Subsample				Surface 1	Surface 2	Bottom	Surface 1	Surface	Bottom		
Replicate			a				a				
Compound											
Naphthalene	2	152	3300	1280	2920	760	952	30.5	21.7	1.66	0.28
C_1-N	6	1560	12000	5030	15300	7480	5250	453	431	21.5	1.34
C_2-N	3	2280	12800	6360	25300	13500	6940	1330	1120	75.2	3.47
C_3-N	ND	1640	8760	4970	18800	13700	4810	1370	1110	120	12.0
C_4-N	ND	300	2320	1620	4230	4430	1970	554	268	37.1	4.38
Biphenyl	20	237	1310	522	1680	965	600	105	70.8	3.87	0.25
Fluorene	5	264	830	383	1510	1000	565	17.4	0.3	1.07	0.28
C_1-F	ND	425	1270	604	2480	2000	969	118	12.6	4.72	1.45
C_2-F	ND	316	1150	509	2300	2260	813	99.9	26.6	10.5	3.82
C_3-F	ND	74.4	597	314	1450	1070	274	97.8	ND	43.6	31.9
Phenanthrene	21	674	1790	791	2990	3110	1400	434	330	31.2	2.76
C_1-P	12	448	1320	649	2500	3380	1290	540	366	52.5	6.27
C_2-P	ND	222	6500	299	975	1340	630	279	216	41.6	7.62
C_3-P	ND	57.9	250	130	475	330	117	79.8	36.0	8.03	3.23
C_4-P	ND	0.73	ND	ND	ND	ND	ND	ND	ND	0.67	1.18
Dibenzothiophene	8	130	685	305	1250	1170	404	125	19.2	8.17	0.60
C_1-DBT	ND	86.7	720	446	1280	1380	742	193	139	22.9	3.31
C_2-DBT	ND	154	686	329	1220	1390	467	213	150	29.2	6.26
C_3-DBT	ND	85.6	283	158	723	583	167	75.6	50.4	11.4	4.29
Fluoranthene	20	78.1	178	98.7	250	343	176	74.7	45.4	7.22	2.95
Pyrene	25	42.3	215	121	461	468	174	70.3	42.3	7.40	2.77
Benz(a)anthracene	46	7.60	92.2	16	72.5	138	30.0	9.5	45.0	2.09	1.19
Chrysene	70	13.2	110	46.8	181	238	98.6	34.1	51.5	6.14	2.10
Benzofluoranthene	ND	0.29	49.0	19.1	111	84.0	41.5	20.2	ND	4.36	1.60
Benzo(a)pyrene	ND	ND	40.9	16.9	85.8	94.2	30.1	11.8	61.9	1.48	ND
Benzo(e)pyrene	186	22.2	31.3	10.8	47.5	44.5	10.7	5.40	0.81	3.26	0.29
Perylene	207	208	31.8	19.9	40.7	10.1	21.4	7.75	70.0	4.58	0.09
PAH Sum[b]	631	9480	57300	25100	88630	61270	28940	6350	4690	562	106

Table 17 (continued)

Location	SAMPLE ng/g dry weight o-terphenyl SDB 200 m							800 m	1500 m	Control
Station	S11	S15	S15	S18	S18	S21	S24	S3	S4	S14
Grab	2	3	3	2	2	2	1	2	1+2	3
Subsample		Surface	Bottom	Surface	Bottom					Surface2
Replicate							a			b
Compound										
Naphthalene	0.21	0.56	5.86	0.60	0.64	0.54	0.24	0.82	0.53	0.10
C_1-N	0.21	4.30	21.8	8.63	3.09	0.52	0.55	0.78	0.79	0.07
C_2-N	0.34	0.82	29.5	31.4	8.37	0.26	3.25	1.07	1.41	0.10
C_3-N	0.47	24.5	27.7	44.7	12.9	0.04	6.44	3.11	1.46	0.07
C_4-N	0.11	6.49	1.92	10.4	3.99	ND	1.50	1.86	0.17	ND
Biphenyl	0.08	1.18	0.98	1.35	0.50	0.12	0.13	0.35	0.17	0.02
Fluorene	0.19	0.90	2.00	2.14	0.56	0.08	0.46	0.56	0.21	0.01
C_1-F	0.16	4.03	3.78	5.10	2.21	0.14	2.45	2.02	0.27	0.04
C_2-F	0.26	5.81	3.84	8.03	3.41	0.12	4.19	5.84	0.38	ND
C_3-F	0.09	42.6	2.88	72.4	2.95	1.52	14.2	4.42	ND	ND
Phenanthrene	0.84	13.6	10.8	15.1	4.76	1.26	7.42	5.77	0.59	0.12
C_1-P	0.80	21.6	12.6	24.6	9.43	0.94	12.9	10.4	1.28	0.09
C_2-P	0.47	14.3	5.83	19.0	6.84	0.80	9.18	12.1	0.87	0.02
C_3-P	0.18	1.83	0.54	3.64	2.99	0.06	2.34	3.08	0.17	ND
C_4-P	ND	0.02	0.23	0.83	ND	ND	0.42	1.08	0.03	ND
Dibenzothiophene	0.13	2.61	1.11	3.87	0.72	0.10	1.08	0.86	0.09	0.01
C_1-DBT	0.17	3.69	1.42	4.77	2.79	0.10	1.85	1.55	0.14	ND
C_2-DBT	0.17	9.88	0.60	3.68	3.83	0.06	4.04	6.98	0.07	ND
C_3-DBT	0.05	2.09	0.49	2.23	1.64	ND	0.60	1.73	0.04	ND
Fluoranthene	0.86	3.43	3.24	5.45	1.71	0.10	1.96	9.07	0.53	0.19
Pyrene	0.66	4.38	3.03	4.52	0.62	ND	2.27	5.47	0.48	0.12
Benz(a)anthracene	0.40	0.24	0.44	0.75	0.30	0.22	0.79	2.83	0.90	0.06
Chrysene	0.39	2.42	1.58	2.87	0.44	1.46	2.41	6.49	0.61	0.15
Benzofluoranthene	ND	1.56	1.63	3.52	0.04	4.79	3.91	17.7	ND	0.38
Benzo(a)pyrene	0.03	0.31	0.57	1.27	0.04	1.38	1.21	3.85	ND	0.10
Benzo(e)pyrene	ND	0.31	0.18	0.56	0.08	0.78	0.93	2.99	1.52	0.11
Perylene	0.50	0.42	0.10	1.27	0.34	0.82	1.55	1.78	1.60	0.12
PAH Sum[b]	7.80	174	145	283	75.2	16.3	88.3	115	14.3	1.88

Table 17 (continued)

			SAMPLE ng/g dry weight o-terphenyl					
Location	SDB	WV	WV Well head			WV 200 m		
	Predrilling	Cuttings	Nov/84	Nov/84	Feb/85			
station	S1	WV	M1	M1	M1	M11	M23	M23
Grab	5	1			2	1	2	2
Subsample	Surface		0-3 cm	3-6 cm			Surface	Bottom
Replicate					a			
Compound								
Naphthalene	0.17	42.3	18600	11800	0.91	0.14	0.59	0.58
C_1-N	0.39	243	75300	47900	1.10	0.09	7.91	5.78
C_2-N	0.44	296	81500	53100	0.47	0.68	11.1	12.1
C_3-N	0.71	265	45400	37800	0.42	1.21	8.29	14.5
C_4-N	ND	31.7	7560	4020	ND	0.96	4.27	6.47
Biphenyl	0.13	26.3	10600	6490	0.45	0.05	1.46	1.00
Fluorene	0.295	46.7	483	2171	0.16	0.04	1.13	0.94
C_1-F	0.67	55.7	704	2990	ND	0.17	3.68	3.43
C_2-F	0.67	32.5	3440	4660	ND	0.47	4.77	4.20
C_3-F	0.13	18.0	3343	3400	ND	0.49	3.81	2.81
Phenanthrene	1.41	41.4	6000	4100	0.39	0.18	2.84	2.71
C_1-P	2.15	77.0	7630	5390	0.20	0.53	5.38	4.05
C_2-P	1.05	51.3	5610	3850	0.06	0.50	4.34	2.95
C_3-P	0.19	12.5	1670	1550	ND	0.31	1.39	1.23
C_4-P	ND	ND	47.7	10.7	ND	0.03	0.22	0.09
Dibenzothiophene	0.13	16.8	1490	1070	0.04	0.04	0.72	0.70
C_1-DBT	0.21	28.1	4090	2670	0.10	1.51	3.80	3.41
C_2-DBT	0.08	4.99	5870	3910	0.04	0.51	4.15	2.84
C_3-DBT	0.04	7.18	704	395	ND	0.18	1.84	1.53
Fluoranthene	1.21	9.42	173	138	0.15	0.16	0.19	0.22
Pyrene	0.79	11.9	316	284	0.04	0.23	0.31	0.37
Benz(a)anthracene	0.32	3.03	12.7	21.3	ND	0.06	0.05	ND
Chrysene	0.66	2.02	81.5	47.9	ND	0.09	0.11	0.15
Benzofluoranthene	2.25	6.27	5.94	9.18	0.08	ND	0.04	0.12
Benzo(a)pyrene	0.50	ND	13.3	9.48	ND	ND	0.05	ND
Benzo(e)pyrene	0.48	7.48	4.90	3.29	0.10	0.18	ND	0.04
Perylene	0.66	40.9	14.3	31.4	ND	0.25	0.26	0.04
PAH Sum[b]	15.7	1380	280700	197700	4.76	9.06	72.7	72.2

a Conoco oil in ng/g oil

b PAH sum = sum components listed

SDB South Des Barres 0-76

WV West Venture C-62

RESULTS OF THE DETAILED ANALYSIS OF THE PAH FRACTION OF SELECTED SAMPLES

The concentrations of PAHs measured by Battelle in the Conoco oil and sediment extracts are summarized along with key PAH ratios in Table 18. The totals by ring number and the PAH ratios are defined. The fossil fuel pollution index (FFPI) is based on the general observation that pyrogenic or combustion-derived PAH assemblages are relatively more enriched in the three- to five-ringed PAH compounds and that fossil fuels are highly enriched in two- to three-ringed PAH and polynuclear organo-sulphur compounds (e.g., dibenzothiophene and its alkyl homologues). The ratio is designed to determine the approximate percentage of fossil fuel to total PAH (Boehm et al. 1985; Boehm and Farrington 1984). The ratio is defined as:

$$\text{FFPI} = \frac{N + P + F + DBT}{\text{Total PAH}} \times 100$$

$$= 100 \text{ for fossil PAH (oil, coal)}$$

$$= 0 \text{ for combustion PAH}$$

where N, P, F, and DPT are the naphthalenes, phenanthrenes, fluorenes, and dibenzothiophenes respectively, and Total PAH is the sum of the individual PAH components measured.

As can be seen from Table 18, the PAH concentrations of the various ring sizes and of the sums of the components measured are highest in the South Des Barres and West Venture cuttings and well-head samples. The remainder of the stations exhibit considerably lower concentrations of PAH.

The correlation between the total aliphatic hydrocarbon concentrations (see Appendix 2) and the sum of the PAH components (see Table 18) for each sample, was low and not highly significant ($r = 0.34$, $p < 0.10$), which indicates different sources for the two parameters. In addition, the Conoco oil contains relatively low levels of PAH (0.631 µg/mg oil) and it is unlikely that the Conoco oil contributed significantly to the PAH concentrations observed in the sediments. This assertion is based on the relative concentrations of the PAH fraction in both the oil and the sediment extracts (see Table 18), and on the observation that the most abundant PAH analytes in the base oil were benzo(e)pyrene and perylene, which occur only as minor components in the PAH distributions of all sediment sample extracts (see Table 17).

As with the aliphatic hydrocarbons, the aromatic hydrocarbons were relatively unweathered, judging from the abundance of two-ringed PAH (naphthalene and biphenyl), which would preferentially be weathered as a result of physical/chemical and, to a lesser degree, biodegradative processes over the three- to five-ringed PAH. In particular, the two West Venture cuttings pile core samples (Station M1, depths 0-3 cm and 3-6 cm), one of the South Des Barres cuttings samples (SDB 41a), and all of the South Des Barres well-head samples, showed high concentrations of naphthalene and its alkyl homologues (see Table 17). These samples, along with the other South Des Barres cuttings sample, and the two samples from 200 m east of the

TABLE 18

Compilation of the total amounts of polynuclear aromatic hydrocarbons by ring number and of key ratios of these aromatic hydrocarbons for each station studied.

		Sample							
Location		SDB cuttings		SDB well head				SDB 200 m	
Direction from Wellhead								E	E
Station	Conoco Oil	SDB	SDB	S1	S1	S1	S1	S2	S2
Grab		1	41	3	3	3	4	1	1
Subsample				Surface 1	Surface 2	Bottom	Surface 1	Surface	Bottom
Replicate			a				a		
				PAH concentration in ng/g dry weight o-terphenyl					
Totals by ring number[1]									
2 RING	31	6169	40490	19782	68230	40835	20522	3843	3022
3 RING	46	2938	16081	4917	19153	19013	7838	2273	1346
4 RING	161	141	595	283	964	1187	479	189	184
5 RING	393	230	153	67	285	233	104	45	133
PAH Sum	631	9479	57319	25048	88630	61270	28942	6350	4685
				PAH ratio					
Ratio[2]									
N/P	0.33	4.23	3.97	10.3	9.59	4.89	5.80	2.80	3.11
P/D	4.13	3.07	4.15	1.51	1.55	1.80	1.93	2.20	2.64
MP/P	0.57	0.42	4.51	1.36	1.32	1.62	1.46	2.07	1.87
Be/Ba	ND	ND	0.77	0.64	0.55	0.47	0.35	0.46	0.01
FFPI(%)	9	93	96	97	97	96	98	95	92

Table 18 (continued)

	Sample									
Location	SDB 200									800 m
Direction from well head	S	W	N	SE	SE	SW	SW	NW	NE	E
Station	S5	S8	S11	S15	S15	S18	S18	S21	S24	S3
Grab	1	2	2	3	3	2	2	2	1	2
Subsample				Surface	Bottom	Surface	Bottom			
Replicate								a		
	PAH concentration in ng/g dry weight o-terphenyl									
Totals by ring number[1]										
2 RING	259	22	1.4	37.9	87.8	97.1	29.5	1.5	12.1	8.0
3 RING	266	73	3.5	123	46.1	165	42.1	5.2	61.1	56.4
4 RING	23	9.0	2.3	10.5	8.3	13.6	3.1	1.8	7.4	23.9
5 RING	14	2.0	0.5	2.6	2.5	6.6	0.5	7.8	7.6	26.3
PAH sum	562	106	7.8	174	145	283	75.2	16.3	88.3	115
	PAH ratio									
Ratio[2]										
N/P	1.91	1.02	0.59	0.71	2.89	1.52	1.21	0.44	0.37	0.24
P/D	1.87	1.46	4.40	2.81	8.29	4.34	2.67	11.8	4.26	2.92
MP/P	3.29	6.63	1.73	2.77	1.78	3.18	4.05	1.42	3.35	4.62
Be/Ba	2.20	ND	ND	1.00	0.32	0.44	2.00	0.57	0.77	0.78
FFPI(%)	93	90	63	92	92	92	95	40	83	56

Table 18 (continued)

	Sample									
			SDB	WV	WV Wellhead					
Location	1500 m	Control	Predrilling	Cuttings	Nov 84	Nov 84	Feb 85	WV 200 m		
Direction from well head	E	W						SW	NE	NE
Station	S4	S14	S1	WV	M1	M1	M1	M11	M23	M23
Grab	1+2	3	5	1			2	1	2	2
Subsample		Surface 2	Surface		0-3 cm	3-6 cm			Surface	Bottom
Replicate		b					a			
	PAH concentration in ng/g dry weight o-terphenyl									
Totals by ring number[1]										
2 RING	4.5	0.36	1.8	904	239,000	161,000	3.4	3.1	33.6	40.4
3 RING	4.1	0.29	7.0	392	41,000	36,200	1.0	5.0	38.1	30.9
4 RING	2.5	0.52	3.0	26.4	583	491	0.19	0.54	0.66	0.74
5 RING	3.1	0.71	3.9	54.7	38.4	53.4	0.18	0.43	0.35	0.20
PAH sum	14.3	1.88	15.7	1377	280,700	197,700	4.76	9.06	72.7	72.2
	PAH ratio									
Ratio[2]										
N/P	1.48	1.48	0.36	4.81	10.9	10.4	4.46	1.97	2.27	3.57
P/D	8.65	23.0	10.40	3.19	1.72	1.85	3.61	0.69	1.35	1.30
MP/P	3.98	0.92	2.40	3.40	2.49	2.63	0.67	7.61	3.99	3.07
Be/Ba	ND	1.10	0.96	ND	0.37	0.35	ND	ND	ND	ND
FFPI(%)	59	34	55	92	96	97	83	89	97	97

[1] The totals by ring number are:
2 RING Naphthalenes + Biphenyl
3 RING Fluorenes + Phenanthrenes + Dibenzothiophenes
4 RING Fluoranthene + Pyrene + Benz(a)anthracene + Chrysene
5 RING Benzofluoranthene + Benzo(a)pyrene + Benzo(e)pyrene + Perylene

[2] The PAH ratios are:
N/P Naphthalenes/Phenanthrenes
P/D Phenanthrenes/Dibenzothiophenes
MP/P Methyl (alkyl) Phenanthrenes/Phenanthrene
Be/Ba Benzo(e)pyrene/Benzo(a)pyrene
FFPI Fossil Fuel Pollution Index - see text

South Des Barres well site, all contained naphthalenes in excess of the concentration (2 ppm) expected to restrict many species of benthic organisms (Armstrong et al. 1979).

The relative proportions of the different ring sizes of the PAHs and the ratio of naphthalene plus alkyl homologues to phenanthrene plus alkyl homologues, (N/P ratio) can be used as indicators of the various processes affecting the PAH fraction. In general, for both the South Des Barres cuttings and well-head samples, the PAH concentrations decreased dramatically with increasing ring size and the N/P ratios remained high, reflecting the high proportion of naphthalenes. At a distance of 200 m from the well site, in the directions of major transport of oiled cuttings (east, southeast, and south to stations S2, S15, and S5, respectively; see Figure 16), the relative proportion of the two-ringed PAHs had dropped off indicating a loss of the more water-soluble PAH fraction either during the transport or after deposition. Because the N/P ratio was higher in the subsurface sediments at stations S2 and S15, it is likely that at least some of this loss had occurred after deposition.

At all other South Des Barres 200-m stations the deposition rates, and hence the PAH concentrations in the sediments, were lower. At all of these low PAH stations the relative proportion of the two-ringed PAH also remained low. The lowest N/P ratios were observed at the stations with the lowest cuttings input (Stations S11, S21, and S24 which were 200 m to the north, northwest, and northeast respectively) suggesting that the loss of the two-ringed PAH was accelerated when sediment hydrocarbon concentrations were low. At a distance of 800 m east of the South Des Barres well site, the N/P ratio had fallen to an even lower level, but the concentrations of the other PAH remained relatively high. At a distance of 1,500 m east, PAH concentrations were still well above background but, perhaps coincidentally, the N/P ratio was the same as at the control station.

At the West Venture well site, the total PAH concentrations in the cuttings sample were much lower than in the well-head samples. This discrepancy could be explained by assuming that the cuttings sample came from a rock formation that was relatively low in PAH, and that the source of the PAH in the well-head samples was a different formation (see discussion that follows). In all of these cuttings and well-head samples the proportion of the two-ringed PAH is high as is the N/P ratio. As with the South Des Barres samples, the concentrations of the two-ringed PAH and the total PAH in the 200 m West Venture samples fall off dramatically. However, the N/P ratio remains higher in the West Venture samples than in South Des Barres samples of equivalent PAH concentration. This difference may be because the West Venture samples were collected concurrent with the change to a water-based mud whereas the South Des Barres samples were collected nearly a month after drilling had ceased. This result suggests that the loss of the two-ringed PAH from the sedimented cuttings is relatively rapid.

The dibenzothiophene series has been suggested to be an especially important petroleum indicator (Boehm et al. 1985) and that the ratio of phenanthrene plus alkyl homologues to dibenzothiophene plus alkyl homologues (P/D ratio) could be an indicator of petroleum input, although we are not aware of any specific guidelines as to the use of the ratio. The most pristine samples have the highest P/D ratios (see Table 18) which suggests a low dibenzothiophene and hence petroleum input. However, the P/D ratio is lower in the well-head sediment samples than in the 200-m sediment samples containing substantial amounts of oiled cuttings and a preferential loss of phenanthrenes into the water (relative to dibenzothiophenes) may be complicating the interpretation.

The degree of alkylation within a homologous series of aromatics (e.g., the phenanthrenes) in a given PAH assemblage is dependent on the temperature of formation of the PAH. Thus, high temperature processes (incomplete combustion or pyrolysis) favour less alkylation and low temperature processes (petroleum maturation) favour high degrees of alkylation. The ratio of methyl or alkylphenanthrenes to phenanthrene (MP/P ratio) is one possible indicator of combustion related PAHs. The MP/P ratio is low in most of the pristine samples, perhaps reflecting an atmospheric input of combustion related PAH into the area. However, the ratio does not seem to show any trends for the other samples.

Similarly, a low ratio of benzo(e) to benzo(a)pyrene (Be/Ba ratio) has been used as an indicator of crude oil contamination and of combustion processes. However this ratio shows no discernable trends in the samples analyzed.

The FFPI shows a low level in the Conoco oil (9%) but high percentages in the cuttings samples and in sediments from the well-head and the 200-m stations that were in the directions of predominant cuttings transport (see Figures 9, 11, and 16). The South Des Barres stations that were "predominantly upcurrent" showed much lower FFPI values.

The high levels of PAH in the cuttings and sediment samples can be attributed either to contributions to the drilling mud cuttings from source rock formations, or to petroleum-based additives that may have been during drilling. Pyrogenic PAH compounds (primarily the three- to five-ringed PAH) are present as well. The three mud cuttings samples WV 1, SDB 1, and SDB 41a (each from different hole depths), contain vastly different concentrations of PAH, suggesting contributions of specific rock formations to the PAH levels observed in the sediments surrounding the drilling platforms. The abundance of the phenanthrene and dibenzothiophene homologous series suggests that, in general, source rock or formation-related petrogenic hydrocarbons are likely to account for the observed PAH distributions. By contrast, diesel oil is abundant in naphthalenes and is much less abundant in the phenanthrenes and dibenzothiophenes.

The results of this study suggest that oil-based drilling muds formulated with mineral oils reduced in aromatic hydrocarbons, combine with significant contributions of PAH from the formation hydrocarbons during the actual drilling processes. Future work would have to include long-term post-drilling monitoring to determine the fate of the saturate and aromatic hydrocarbons that were documented in this study.

It is worth reiterating at this point that the aliphatic hydrocarbon fractions (the bulk of the oil on the cuttings) have not shown this dramatic change between the base oil and the sediment samples (see Figures 19 to 26). Even if a substantial input of PAH were added from the drilling formations (as is suggested), the aliphatic input could only have been in the n-C10 to n-C16 boiling range. Hydrocarbons in this range are likely to have the same approximate GC/FID response factors as Conoco oil and the calibration to Conoco ODC oil used for this study would still be valid.

RESULTS OF THE SEDIMENT PARTICLE-SIZE ANALYSIS

The sediment particle-size analysis results for each station at the West Venture and South Des Barres sites were given in the interim report (Yunker et al. 1985). At the West Venture site, all samples consisted of 100% sand. The South Des Barres samples were mostly sand, with some gravel and mud. All but four of the sites had less than 3% mud; an average of 83.7 ± 1.2% mud was observed for the two well-head samples.

Sediment samples from the South Des Barres site that had a mud fraction significantly higher than the mud content of the samples collected 1,500 m from the well site, were analysed further by laser granulometry. The South Des Barres 1,500-m stations (see Figure 3) had a mud content of 1.99 ± 0.81 (n = 8); any sample with a mud content over 2.67% would be above the 95% confidence level for the 1,500-m samples and significantly (alpha(2) = 0.05) different from this background concentration. Sediment samples from stations S1 (0 m), S2, S5 (200 m), and S13 (1,500 m) showed mud fractions greater than this level; for reference purposes the fine fraction for a 200-m station just below the cut off (S21) and from the background station S14 (pre-drilling control), and S10, and S20 (1,500 m) were also determined. The results are given in Appendix 3.

The plots of the particle-size distributions for the South Des Barres well-head samples showed a large fine fraction. The station 200 m east of the well-head (S2) showed increased amounts of fine and coarse material relative to background. All other samples showed substantially the same results indicating that, at least for this study, the sediment-size fraction distribution is a poor indicator of the areal extent of the spread of cuttings.

COMPUTER SIMULATION OF THE CUTTINGS DISPERSION AND FATE

Simulation of cuttings dispersion for both South Des Barres and West Venture resulted in reasonable estimates of mound dimensions, which were within a factor of two of the observed features (horizontal size of 30-60 m and thickness of about 10 cm for South Des Barres; horizontal size of 20-24 m with a thickness of about 30 cm for West Venture). The results for hydrocarbon concentrations in surficial sediments generally agreed for the South Des Barres but overestimated concentrations at West Venture. For West Venture, the probable cause for the lower observed concentrations, compared to the predicted values, was dispersion and dilution of the cuttings in the natural bottom material by extensive reworking of sediments.

At South Des Barres (72 m deep), a mixing layer 5 cm deep was used when modelling the hydrocarbon dispersion, so that comparisons could be made to the field data. Observed hydrocarbon concentrations were generally the same as was predicted (see Figure 9), except near the discharge site where concentrations were underestimated. Part of this underestimation could be explained by the migration of oil upwards in the cuttings pile (the base oil is about 0.23 kg/L less dense than sea-water), thereby producing a higher oil concentration in a surface layer of less than 5 cm. This behaviour has been observed in laboratory experiments (IOE 1985b).

Integrating the observed distribution (for a thickness of 5 cm) it was calculated that approximately 300 m^3 (1,900 bbl) of oil was present in the sediment, which was about twice the hypothetical release accompanying the cuttings. This result could be explained by either uncertainties in the discharge estimates or, more likely, by the hydrocarbons being concentrated in an average depth range of less than 5 cm over the whole area sampled. Better agreement with the model would be obtained if there were either an increase in grain size, or if the mixing depth was decreased to less than 5 cm.

For West Venture, the areas enclosed by the predicted 25 µg/g and the 250 µg/g contours, were substantially larger than those observed (see Figure 11). Note, however, that although the concentrations at a 1,000-m distance from the well site predicted by the model were not observed, the model did correctly predict the major directions of transport of the oiled material. Conoco ODC oil was observed in the GC trace of one sample collected 1,000 m northeast of the well site and in one sample collected 1,000 m southwest of the well site (see Table 14). Measured hydrocarbon concentrations in these two samples (3.9 and 5.6 µg/g respectively) were just above background (see Table 12).

Integrating the observed hydrocarbon concentrations for a depth of 10 cm, it was calculated that approximately 4 cm^3 (26 bbl) of oil was present in the surficial sediments, which was only a few per cent of the hypothetical release accompanying the cuttings. As opposed to the South Des Barres site, this calculation was substantially lower than expected. The low observed concentrations could be explained by a deeper mixing depth, by burial of released material by less contaminated sand, or by both, in the highly dynamic sediment environment at West Venture. A further, less likely, possibility could be remobilization of the oiled cuttings back into the water column with subsequent dispersal.

A sensitivity analysis was undertaken for both well sites to identify the consequences of uncertainties in the input data. The results show that the initial bottom-cuttings distribution (without consideration of erosion or burial) was dependent on grain-size distribution (up to two orders of magnitude change in mound thickness for the distributions used) and less dependent on current speed. (Fine particles of less than 125 µm, or phi = 3, have a settling rate of less than 0.01 m/s.) Because of the long settling times expected for these particles in the turbulent waters of Sable Bank, their spread has to be considered as a dispersion problem within the water column and this size fraction could not be included in the model.

For the deeper site (South Des Barres) the principal factors affecting the accuracy of predictions were the quantification of particle-size distribution and total volumetric discharge of cuttings. An effort should be made to monitor these during a drilling period; it is imperative that this be done if some predictive capability is to be developed for assessing the environmental impact for drilling discharges. The particle-size distribution discussed here is not the dimension of each individual component after extensive washing, agitation, and deflocculation. Instead, the distribution should represent the size of particles that form naturally from the cuttings as they are introduced into the water.

For the West Venture site the uncertainties in grain size and volume of discharge were important; however, to these were added the equally important uncertainties in the dispersion process resulting from the transport of both the natural sediments and the oiled cuttings. Present studies of sediment transport on Sable Island Bank, funded by ESRF, may shed more light on this problem.

CONSTRAINTS ON THE ANALYSIS OF HEAVILY OILED SAMPLES

In Table 19 a comparison is made between results expressed on a wet-weight basis and results expressed on a dry-weight basis for the highly oiled cuttings and well-head samples from both well sites. Two conclusions are drawn from these data. First, the coefficient of variation for the analyses is smaller for the wet-weight samples than for the dry-weight sample, and secondly, the wet-weight samples show a closer agreement between the oil concentrations measured for the cuttings samples and the oil concentrations for the well-head samples. Thus, for these highly oiled samples, a significant amount of the variation between samples has been introduced by the drying process.

On comparing the results of oil concentrations obtained from the analysis of cuttings using the extraction and external standard peak-area calibration procedures and those from cuttings measured by the operators using the retort (heating) method, an apparent bias is found, in which the latter were consistently higher. The oil contents of West Venture and South Des Barres cuttings reported by the operators on a weekly basis were compiled by Chenard et al. (1985). The South Des Barres results are on a dry-weight basis as are presumably the West Venture results (see Table 19).

A detailed examination of the retort data raises the possibility that there was significant week-to-week variance in the results (possibly because of different analysts). In addition, the retort method is a relatively qualitative procedure which suggests that the oil concentrations should only have been reported to one, or perhaps two, significant figures. However, it is likely that the retort method (which involved heating) is recovering more oil from the cuttings than the ambient temperature solvent extraction method used in this study (IOE 1985a), which would lead to the higher values reported by the operators. Less likely possibilities are that the peak-area calibration method is introducing a low bias for the heavily oiled samples, and/or the GC detector was overloaded by the heavily oil samples, which would also result in lower values. We note that the South Des Barres cuttings were washed with sea-water before discharge and this would help to remove "free" oil and to produce the lower sediment oil concentrations measured in this study (Shell Canada Ltd. 1986).

As the goal of this study was to define precisely the changes in sediment hydrocarbon concentrations in the low parts-per-million range and,

TABLE 19

Comparison of wet weight to dry weight for the highly oiled samples[a]

Samples	Present study			Reported by operators[b]	
	Wet weight (µg/g weight in Conoco	Dry weight oil equivalents)	n	Retort method (µg/g dry weight	n
West Venture cuttings	41,700 ± 19,700	59,400 ± 30,900	3	136,000 ± 48,000	89
West Venture well-head	73,300 ± 5,370	151,000 ± 13,400	4		
West Venture well-head core (0-3 cm)	34,900	45,800	1		
South Des Barres cuttings	36,100 ± 6,990	47,500 ± 3,890	4	118,000 ± 31,000	123
South Des Barres well head	44,500 ± 26,100	88,400 ± 61,200	13		

[a] Results are the mean ± the standard deviation.

[b] Cuttings oil content reported by the operators (Chenard et al. 1985).

hence, to define the areal extent of the spread of the Conoco ODC base oil, these problems with the analysis of the heavily-oiled samples did not affect the overall study results. The consistency observed in the analyses demonstrates that the samples that contained high level of oil were reliably identified. Any apparent bias between different methods of analysis for these heavily oiled samples would have little influence on the overall results or conclusions of this study.

CONCLUSIONS

A sample collection and analysis program has been successfully carried out at two east coast rig sites to monitor the characteristics, behaviour and fate of hydrocarbons introduced to the benthic environment as a result of the use of oil-based drilling muds.

Total aliphatic hydrocarbon levels at West Venture C-62 were observed to drop off to a level 10 times above background at approximately 200 m from the rig site and no predominant direction of spread was apparent. Hydrocarbon concentrations remained below an order of magnitude above background at distances greater than 200 m from the wellhead. At the wellhead Conoco ODC oil aliphatic concentrations dropped from 60,000 times background at the cessation of drilling to 700 times background three months later. The available evidence indicates that the oiled cuttings have been dispersed or possibly buried. Because of the shallow (16 m) depth, this dispersal is most likely due to wave action.

The total aliphatic concentrations measured in the sediments collected around the South Des Barres O-76 site indicate that the primary direction of transport of hydrocarbons was in an easterly, and perhaps to a lesser extent, a southerly direction, and suggest that the oil and cuttings have been dispersed primarily by ocean currents at this deeper (70 m) location. Depending on the direction, the hydrocarbon levels dropped to 10 times above background at distances ranging from 200 to 1,500 plus m from the well-head. Concentrations of over four orders of magnitude above background were confined within a distance of 200 m from the well-head. These higher concentrations and the oceanographic regime suggest that the oil from the cuttings may persist for a longer time in the deep water environment.

Deposits of oiled cuttings can be expected to be highly cohesive because of the oil content and the high amounts of fine particles they can contain. The strength properties of the material can also be expected to change with time as a result of emulsification, biodegradation, and mixing with natural bottom materials. At this point, the susceptibility of the oiled cuttings to erosion has not been quantified, which makes it difficult to assess the durability of the bottom deposits. On Sable Island Bank, however, it is possible that the natural bottom material has a higher mobility than the released material.

When sediment transport is low, relatively little mixing of natural material with the cuttings will occur during the drilling period, resulting in a mound of relatively pure cuttings. The resulting mound will likely be quite durable and may be buried or resuspended only over a long period of time. This is clearly the case for the South Des Barres site. There, at least during the drilling period, waves and currents were of insufficient magnitude to cause substantial sediment transport of the natural bottom material. However, bottom material will likely be mobilized intermittently during winter storms. Climatological data could be used to compute a time scale for obliteration of the cuttings mound; this computation is, however, beyond the scope of the present study.

When sediment transport is relatively high, substantial resuspension and burial of the cuttings during the drilling period can occur as the cuttings are released, with the resulting bottom material being a mixture of cuttings and natural sediments. The effective dilution of the cuttings may also reduce the cohesiveness of the bottom material, increasing the erodability and biodegradability. However, because of the lower hydrocarbon concentrations present after this mixing, this feature may be more difficult to detect.

Based on wave orbital velocity data (see Figure 7) the natural bottom sediment is clearly highly mobile at the West Venture site, with waves during the drilling period being sufficient to cause sediment motion more than 50% of the time. In addition, currents (which are mostly tidal) would further increase the estimate for the proportion of time when sediments are mobile. For the wave orbital velocities shown in Figure 7 and typical current speeds of 0.10 m/s at a 1-m distance from the bottom, the transport rates for the natural sand-sized sediments will vary roughly between 1 m^2/yr and 5,000 m^2/yr, with a typical value of 200 m^2/yr. Using the latter value for Q, a discharge volume of 700 m^3, and a representative horizontal mound dimension of 30 m for the West Venture simulation, we find that the time scale for burial of a coherent mound is about 1.5 months. Because this is shorter than the release period, we should expect extensive mixing and dilution of the cuttings into the sediments even as the drilling is progressing. However, if the cuttings are also resuspended and transported under these conditions, one could expect even greater dilution of the cuttings into the natural sediments.

The effective mixing depth resulting from this sediment motion is not well known but is likely greater than the 10 cm used in the computer simulation (which neglected sediment dynamics) which resulted in the predicted mound dimensions and hydrocarbon concentrations being higher than the observed distributions. For West Venture we can therefore conclude that sediment transport mechanisms play an important role, even in the short-term fate of oiled cuttings. Our limited knowledge of sediment transport itself, complicated by the unquantified properties of the discharged cuttings, limits the extent to which the behaviour of the discharged materials can be predicted, once they settle to the bottom.

Simulation of cuttings dispersion for both South Des Barres O-76 and West Venture C-62 has resulted in reasonable estimates of mound dimensions, which were within a factor of two of the observed features (horizontal size of 30-60 m and thickness of about 10 cm for South Des Barres; horizontal size of 20-24 m with a thickness and about 30 cm for West Venture). The results for surficial sediment hydrocarbon concentrations generally agreed for South Des Barres but overestimated concentrations at West Venture. For West Venture, the probably cause for lower concentrations was dispersion and dilution of the cuttings in the natural bottom material by intensive reworking of the sediments.

The results of sensitivity analyses show that the initial distribution of cuttings on the bottom (without consideration of erosion or burial) is more dependent on grain-size distribution (up to two orders of magnitude change in mound thickness for distributions "b" and "c" in Figure 5) and less dependent on current speed.

For the deeper site (South Des Barres) the principal factors affecting the accuracy of predictions are the quantification of grain-size distribution and total volumetric discharge. An effort should be made to monitor these during a drilling period; it is imperative that this be done if some predictive capability is to be developed for assessing the effects on the environment of drilling discharges. The particle-size distribution discussed here is not the dimension of each individual component after extensive washing, agitation, and deflocculation, but rather represents the size of particles that form naturally from the cuttings as they are introduced into the water.

For the West Venture site, the uncertainties in grain size and volume of discharge are important; however, to these are added the equally important uncertainties in the dispersion process due the transport of both the natural sediments and the oiled cuttings. Present studies of sediment transport on Sable Island Bank, funded by ESRF, may shed more light on this problem.

In general the Battelle data on aliphatic composition and on PAH concentrations supported the conclusions reached about the distributions of hydrocarbons in the sediments and the results of the computer simulation of the cuttings dispersion and fate.

Aliphatic fraction results from both Dobrocky Seatech Ltd. and Battelle, for samples of the South Des Barres 200-m stations north and northeast of the well site (Station S11 and S21), from the pre-drilling South Des Barres well-head (S1) and from the two West Venture surface samples (M11 and M23), all showed low amounts of Conoco ODC oil. The aliphatic hydrocarbon composition of all of these samples showed traces of Conoco base oil with n-C12 to n-C16 being the predominant resolved aliphatics. However, some weathering had occurred in the post-drilling samples, as indicated by the increase in the relative abundance of the isoprenoid alkanes.

There was no evidence in the Battelle data of Conoco oil in the South Des Barres control station sample (S14) and in the West Venture well-head sample collected three months after the use of oil-based muds ceased. Dobrocky Seatech Ltd. results agreed for the former sample but not the latter one. At present there is no explanation for this discrepancy. However, Dobrocky Seatech Ltd. found Conoco oil in all six samples collected and analysed from that site at that time.

The remainder of the saturate fractions of the sample extracts analysed by both Battelle and Dobrocky Seatech Ltd. showed composition distributions that denoted the presence of the Conoco base oil as the major aliphatic component. All of these samples exhibited n-C11 to n-C16 as the predominant resolved alkanes. The oil in these fractions appeared to be relatively unweathered, as indicated by the concentration of resolved aliphatics exceeding the unresolved in every case. However, some biodegradation of the oil had occurred, as shown by the increase in the relative abundances of the branched alkane isoprenoids compared to the base oil. In addition, only a limited degree of preferential degradation of the even carbon number alkane analytes was evident.

The PAH composition of the samples was highly varied and exhibited no apparent correlation to the aromatic composition of Conoco base oil, which had a low aromatic content (0.631 µg/mg oil). The most abundant PAH analytes in the base oil were benzo(e)pyrene and perylene (0.186 µg/mg oil and 0.207 µg/mg oil, respectively), which occur as only minor components in the PAH distributions of all sediment sample extracts.

As with the aliphatic hydrocarbons, the aromatic hydrocarbons were relatively unweathered, judging from the abundance of two-ring PAH (naphthalenes and biphenyl), which would preferentially be weathered as a result of physical, chemical, and to a lesser degree, biodegradative processes, over the three- to five-ringed PAH. In particular, the two West Venture cutting pile core samples (Station M1, depths 0-3 cm and 3-6 cm), one of the South Des Barres cuttings samples (SDB-41a), and all of the South Des Barres well-head samples, showed high concentrations of naphthalene and its alkyl homologues.

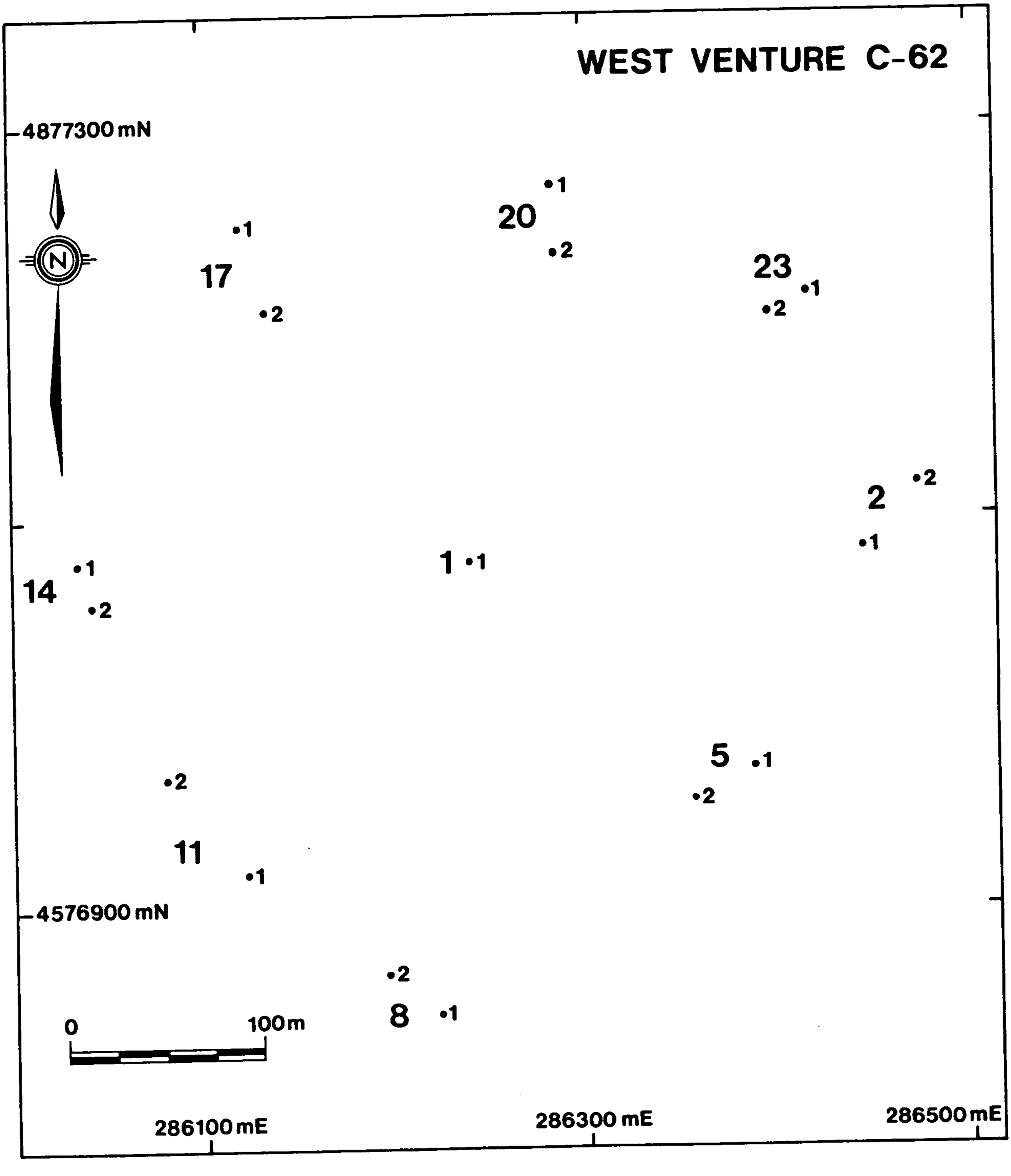
The high levels of PAH in many samples can be attributed either to contributions to the drilling mud cuttings from source rock formations, or to petroleum-based additives that may have been added during drilling. Pyrogenic PAH compounds (primarily the three- to five-ringed PAH) are present as well. The three West Venture and South Des Barres mud cuttings samples WV 1, SDB 1, and SDB 41a (each from different hole depths), contain vastly different concentrations of PAH, suggesting contributions of specific formations to the PAH levels observed in the sediments surrounding the drilling platform. The abundance of the phenanthrene and dibenzothiophene homologous series suggests that, in general, source rock or formation-related petrogenic hydrocarbons are likely to account for the observed PAH distributions. By contrast, diesel oil is high in naphthalenes and much lower in the phenanthrenes and dibenzothiophenes.

The results of this study suggest that oil-based drilling muds formulated with mineral oils reduced in aromatic hydrocarbons, combine with significant contributions of PAH from the formation of hydrocarbons during the actual drilling processes. Future work would have to include long-term post-drilling monitoring to determine the fate of the saturate and aromatic hydrocarbons that were documented in this study.

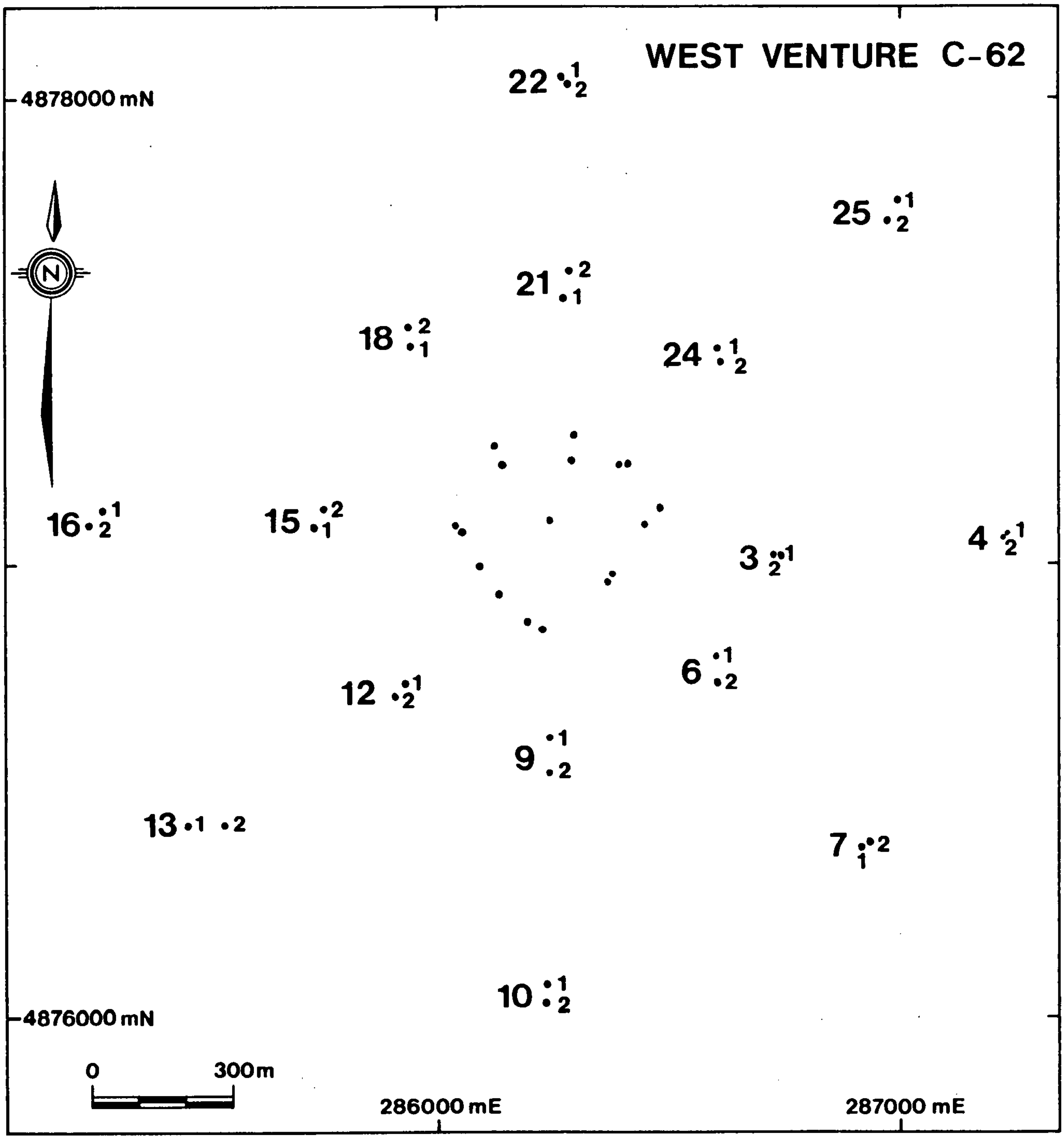
APPENDICES

APPENDIX 1

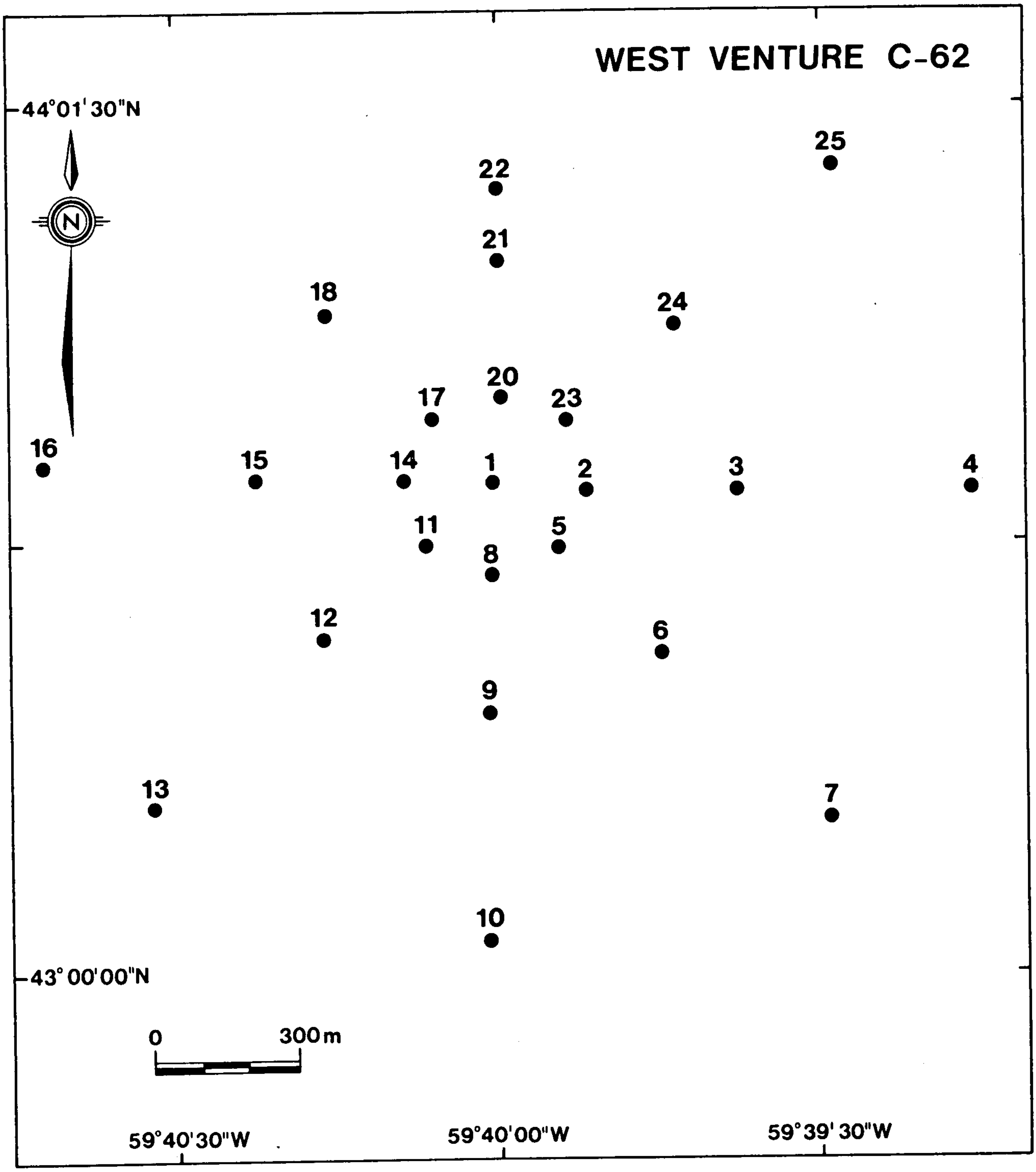
Station Numbers and Grab Positions for all Samples Collected



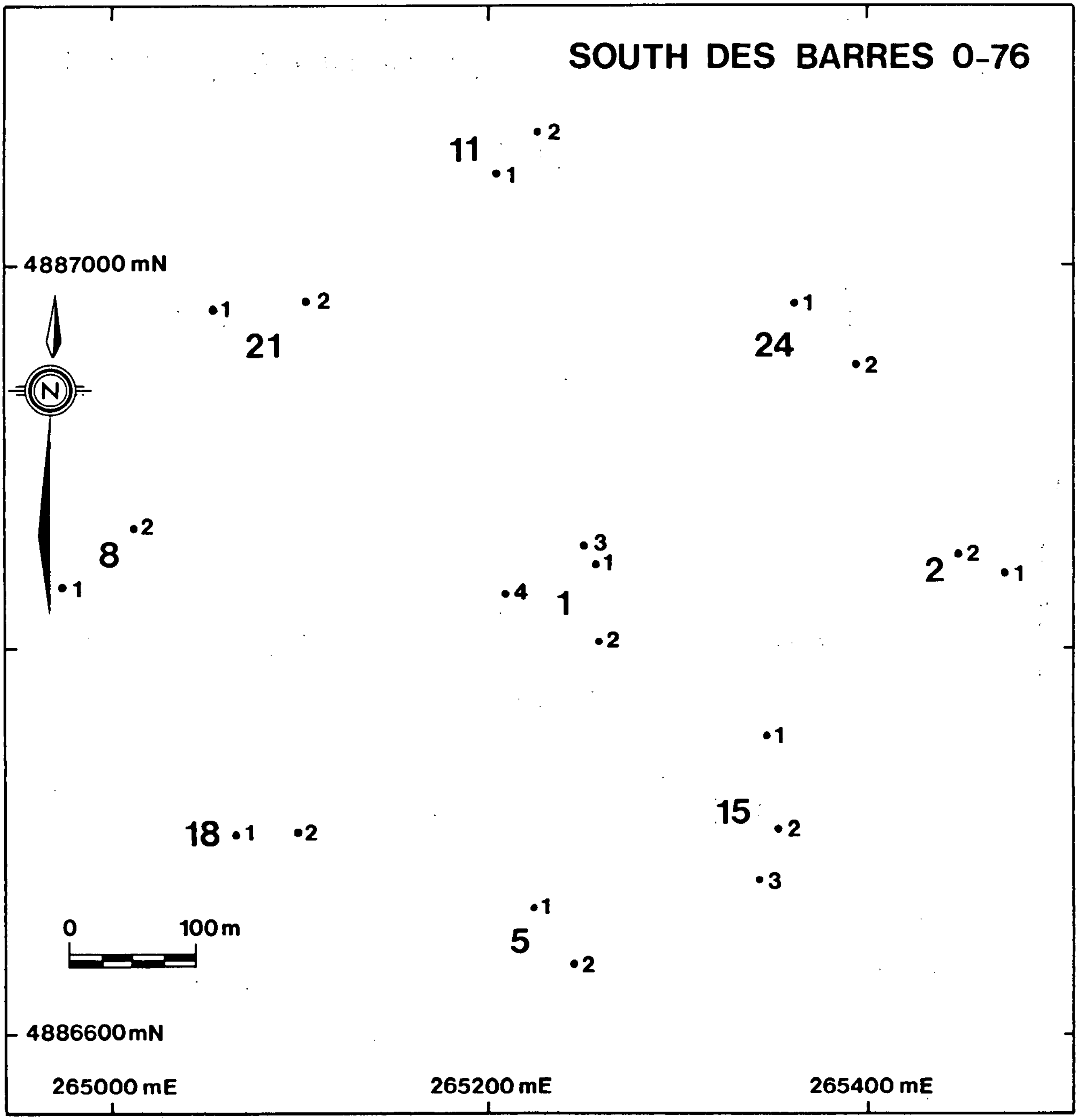
Station and grab positions for the post-discharge of oiled cuttings sampling of the West Venture C-62 site within 200 m of the wellhead.



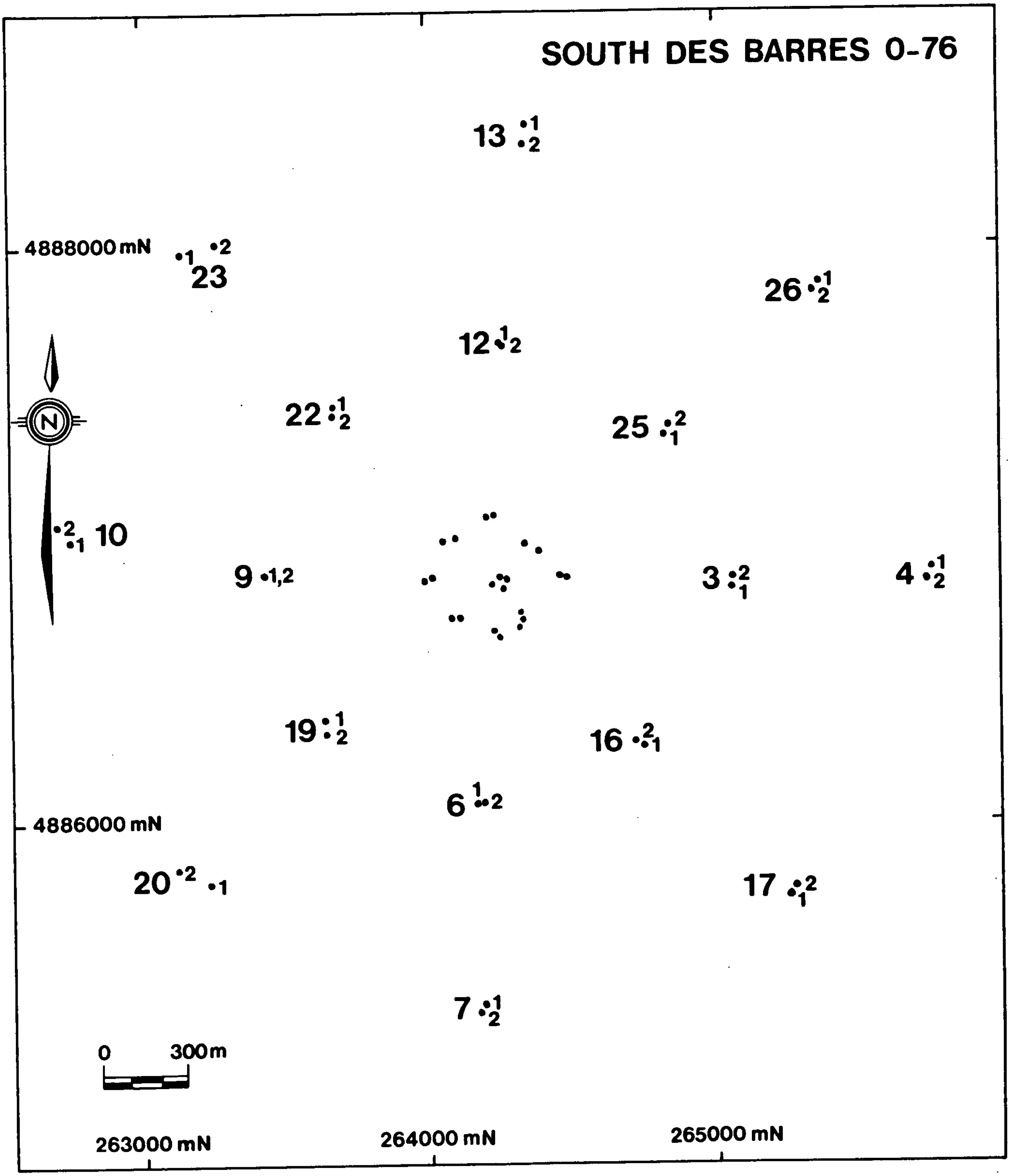
Station and grab positions for the post-discharge of oiled cuttings sampling of the West Venture C-62 site within 1000 m of the wellhead.



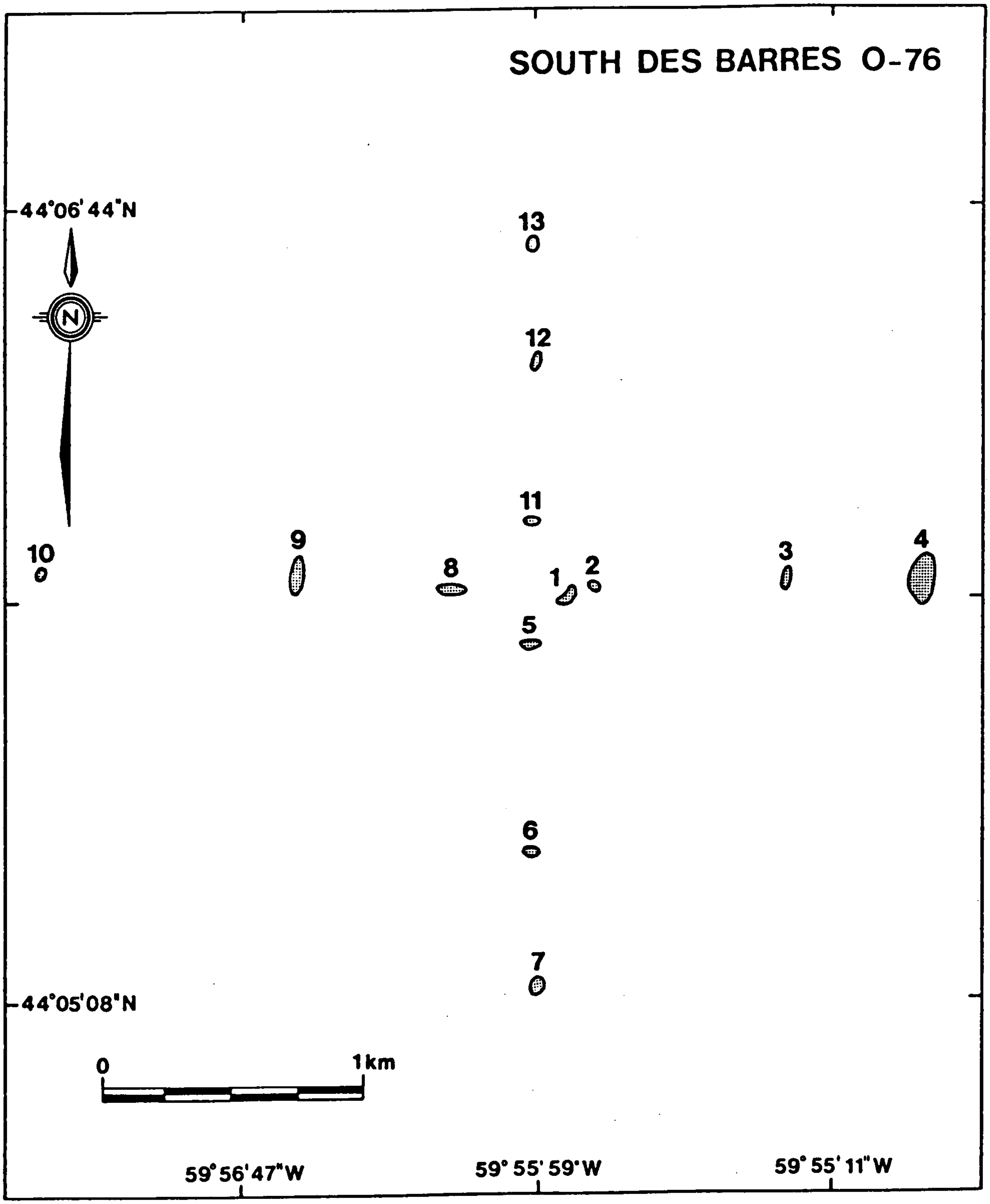
Station positions for the predischarge sampling of the West Venture C-62 site within 1000 m of the wellhead.



Station and grab positions for the post-discharge sampling of the South Des Barres O-76 site within 200 m of the wellhead.



Station and grab positions for the post-discharge sampling of the South Des Barres O-76 site within 1500 m of the wellhead.



Station positions for the predischarge of oiled cuttings sampling of the South Des Barres O-76 site within 1500 m of the wellhead. Grab locations were reported to be within the bounds of the ellipse shown at each station.

Note: the position of the pre-drilling stations is represented either as a large dot or ellipse because of the uncertainty of where the samples were collected, due to the less accurate positioning methods used during those cruises.

APPENDIX 2

Detailed Results of the Hydrocarbon Analyses

Notes on Abbreviations used in Appendix 2:

Stations labelled M1-M26 refer to the Mobil West Venture C-62 stations shown in Figure 2.

Stations labelled S1-S26 refer to the Shell South Des Barres O-76 stations shown in Figure 3.

"Grab" relates to the different grabs taken at each station shown in Appendix 1.

"Field subsamples" from grabs are labelled Surface for the 0-5 cm portion and Bottom for the 5-10 cm portion. When more than one surface sample was taken from a grab the designations Surface 1 and Surface 2 were used. For the core samples, the subsample is specified by using the actual depth range sampled.

"Analytical replicates" were obtained by subsampling a sediment mixture into two portions for analysis, which are designated a and b.

"Batch" denotes the batch, or group of samples, with which the sample was analysed. Reagent blank levels for each batch are given at the end of the aliphatics and aromatics sections.

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
						ug/g dry weight Conoco		
West Venture Cuttings Samples								
WV	1			10	88,390	3,119	85,270	
WV	12,13			10	26,860	3,935	22,930	
WV	41			10	63,070	3,376	59,690	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
West Venture Wellhead Post-Drilling								
Jar Samples taken November 4, 1984 by diver								
M 1	1		a	4a	168,900	18,350	150,600	
M 1	1		b	4a	146,500	17,540	128,900	
M 1	2		a	4a	136,900	14,400	122,500	
M 1	2		b	4a	153,600	14,980	138,600	
Core taken November 4, 1984 by diver								
M 1		0 - 3 cm		9	45,800	1,778	44,020	
M 1		3 - 6 cm		9	29,990	1,203	28,790	
M 1		6 - 10 cm		9	10,740	617.7	10,120	
M 1		10 - 15 cm		9	4,703	463.9	4,239	
Jar Samples taken February 1, 1985 by diver								
M 1	1			9	112.7	41.64	71.09	
M 1	2		a	9	693.4	69.16	624.2	
M 1	2		b	9	641.9	84.78	557.1	
M 1	3		a	9	32.40	20.22	12.18	
M 1	3		b	9	~50	~30	~20	Androstane obscured
M 1	4			9	4320	131.1	4189	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
						ug/g dry weight Conoco		
West Venture 200 m Post-Drilling								
M 2	1	Surface 1	a	1	6.48	3.01	3.47	
M 2	1	Surface 1	b	1	9.21	3.36	5.86	
M 2	2	Surface 1		1	29.23	4.52	24.70	over concentrated
M 5	1	Surface 1		1	5.63	2.58	3.06	
M 5	2	Surface 1		1	13.96	6.20	7.76	
M 8	1+2			1	4.25	2.24	2.00	
M 8	1	Surface		7	2.72	1.92	0.80	
M 8	2	Surface		7	5.14	2.05	3.09	
M11	1+2			1	35.35	8.41	26.94	over concentrated
M11	1			7	10.15	3.01	7.13	
M11	2			7	6.15	5.84	0.31	
M11	2			9	7.06	3.75	3.31	
M14	1+2	Surface 2		1	64.92	26.03	38.89	
M14	1	Surface 1		7	34.02	11.13	22.89	
M14	1	Surface 2		7	4.12	1.80	2.31	
M14	2	Surface 1		7	41.90	16.40	25.49	
M14	2	Surface 2	a	7	36.65	13.03	23.61	
M14	2	Surface 2	b	7	19.70	8.52	11.18	
M17	1+2			1	30.33	8.12	22.21	
M17	1			7	22.90	8.01	14.88	
M17	2			7	4.30	3.21	1.09	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			

West Venture 200 m Post-Drilling (continued)

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
M20	1+2	Surface 2		1	23.99	5.26	18.73	
M20	1	Surface 1		7	20.55	7.76	12.79	
M20	1	Surface 2		7	5.13	4.21	0.92	
M20	1	Bottom		7	6.88	3.72	3.16	
M20	2	Surface 1		7	11.24	5.19	6.05	
M20	2	Surface 2		7	5.86	3.28	2.58	
M20	2	Bottom		7	8.95	4.87	4.08	
M23	1+2	Surface		1	98.43	30.09	68.35	
M23	1	Surface	a	7	9.18	3.84	5.34	
M23	1	Surface	b	7	5.02	1.92	3.10	
M23	1	Bottom		7	21.32	9.03	12.29	
M23	2	Surface		7	19.56	8.74	10.82	
M23	2	Bottom		7	73.28	29.06	44.21	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
West Venture 500 m Post-Drilling								
M 3	1+2	Surface		9	2.57	2.45	0.12	
M 6	1+2			1	11.47	4.68	6.79	
"	"				13.34	4.92	8.42	
M 9	1	Surface 2		1	4.76	4.50	0.26	
M 9	2	Surface 2		1	2.91	1.51	1.39	
M12	1+2	Surface		1	18.34	6.30	12.04	
M15	1			1	10.66	4.05	6.61	
M15	2			1	14.14	5.49	8.64	
M18	1+2	Surface 1		1	10.82	3.80	7.02	
M21	1+2	Surface	a	1	4.85	4.28	0.57	over concentrated
M21	1+2	Surface	b	1	3.98	3.21	0.77	
M24	1+2			1	11.99	4.82	7.17	
West Venture 1000 m Post-Drilling								
M 4	1+3			3	2.80	1.77	1.03	
M 7	1	Surface 1		3	2.82	2.56	0.27	
M 7	2	Surface 2		3	2.34	2.34	<0.05	
M10	1+2	Surface	a	3	1.36	1.32	<0.05	over concentrated
M10	1+2	Surface	b	3	2.33	2.28	0.05	
M13	1+2	Surface		3	3.92	2.81	1.11	
M16	1	Surface 2		3	2.35	2.30	0.05	
	+2	Surface 1						
M22	1+2			3	2.82	2.74	0.07	
M25	1			3	5.58	3.91	1.66	over concentrated
M25	2			3	2.48	2.36	0.13	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
West Venture Control Post-Drilling								
M26	1	Surface 2	a	4	0.53	0.48	0.05	over concentrated
M26	1	Surface 2	b	4	0.95	0.90	0.05	
"		"	"		0.58	0.58	<0.05	
M26	3	Surface 1	a	4	3.04	1.64	1.39	
M26	3	Surface 1	b	4	1.79	1.74	0.05	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
West Venture Wellhead Pre-Drilling								
M 1	2	Surface	a	4	0.48	0.48	<0.05	
"	"		"		0.50	0.49	<0.05	
M 1	2	Surface	b	4	1.31	1.15	0.16	
M 1	3	Surface		4	1.74	1.72	<0.05	
West Venture Pre-Drilling								
M11	1	Surface		4	0.81	0.71	0.10	
M11	3	Surface		4	0.94	0.85	0.09	
M15	1	Surface		4	0.56	0.56	<0.05	
M15	2	Surface	a	4	0.38	0.38	<0.05	
M15	2	Surface	b	4	0.79	0.37	0.42	
M20	1	Surface		4	0.61	0.60	<0.05	
M20	2	Surface		4	0.17	0.17	<0.05	
M22	2	Surface		4	0.93	0.93	<0.05	over concentrated
"	"	"			0.93	0.93	<0.05	
M22	3	Surface		4	0.11	0.09	<0.05	
West Venture Control Pre-Drilling								
M26	1	Surface	a	4	0.99	0.78	0.22	
M26*	1	Surface	b	4	9.80	9.11	0.69	over concentrated
M26	3	Surface	a	4	1.72	1.46	0.26	over concentrated
M26	3	Surface	b	4	1.61	1.59	<0.05	aliphatic fraction over concentrated

* Sample contaminated during collection or storage before receipt by Dobrocky.

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
South Des Barres Cuttings Samples								
SDB	1			10	45,580	5,187	40,390	
SDB	12			10	49,170	3,599	45,570	
SDB	41		a	10	43,360	3,476	39,890	
SDB	41		b	10	51,920	2,595	49,330	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
						ug/g dry weight Conoco		
South Des Barres Wellhead Post-Drilling								
S 1	1	Surface	a	10	91,320	5,112	86,210	
S 1	1	Surface	b	10	85,370	3,927	81,440	
S 1	2	Surface	a	4a	230,600	24,690	205,900	
S 1	2	Surface	b	4a	141,100	14,200	126,900	
S 1	3	Surface 1		10	26,280	989.9	25,290	
S 1	3	Surface 2		10	104,800	5,399	99,440	
S 1	3	Bottom		10	111,700	6,004	105,700	
S 1	4	Surface	a	4a	151,800	14,550	137,300	
S 1	4	Surface	b	4a	26,900	2,210	24,700	
S 1	4	Surface 1	a	10	53,100	2,884	5,021	
S 1	4	Surface 1	b	10	50,940	3,614	47,330	
S 1	4	Surface 2		10	9,107	1,007	8,100	
S 1	4	Bottom		10	66,700	3,126	63,480	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
South Des Barres 200 m Post-Drilling								
S 2	1+2	Surface		2	34,400	1,844	32,560	
S 2	1	Surface		6	16,980	1,257	15,720	
S 2	1	Bottom		6	21,870	535.1	21,340	
S 2	2	Surface	a	6	15,440	483.3	14,960	
S 2	2	Surface	b	6	18,160	662.9	17,720	
S 2	2	Bottom		6	5,464	191.0	5,273	
S 5	1+2			2	2,665	25.12	2,640	portion of sample lost
S 5	1			6	2,094	145.7	1,948	
S 5	2			6	4,355	200.8	4,154	
S 8	1			2	94.37	10.79	83.58	over concentrated
S 8	2			2	425.5	101.1	324.4	over concentrated
S11	1+2			2	78.25	22.59	55.66	over concentrated
S11	1			6	46.02	21.50	24.52	
S11	2			6	16.68	4.57	12.11	
S15	1	Surface		2	11,860	826.4	11,030	
S15	2	Surface		2	624.7	80.13	544.6	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
South Des Barres 200 m Post-Drilling (continued)								
S15	2	Surface		6	1,065	245.3	819.8	
S15	2	Bottom		6	2,348	499.7	1,848	
S15	3	Surface		6	2,685	611.6	2,074	
S15	3	Bottom		6	1,068	258.0	809.2	
S18	1+2	Surface		2	860.5	87.82	772.7	
S18	1	Surface		6	1,844	399.6	1,444	
S18	1	Bottom		6	142.6	43.33	99.24	
S18	2	Surface		6	3,961	440.7	3,520	
S18	2	Bottom		6	1,243	326.9	915.8	
S21	1+2		a	2	72.24	21.54	50.70	over concentrated
S21	1+2		b	2	18.92	6.08	12.84	
S21	1			6	42.76	11.85	30.90	
S21	2			9	8.52	6.35	2.17	
S24	1+2			2	666.1	130.8	535.4	
S24	1		a	6	790.3	186.3	604.0	
S24	1		b	6	1,557	378.7	1,179	
S24	2			6	806.0	222.5	583.5	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
South Des Barres 800 m Post-Drilling								
S 3	1			2	83.66	35.50	48.16	
S 3	2			2	100.3	23.67	76.57	
S 6	1	Surface 1		2	7.60	4.00	3.60	
S 6	2	Surface 1		2	13.12	5.61	7.51	
S 9	1+2			2	11.62	6.21	5.41	
S12	1+2			2	7.46	4.45	3.00	
S16	1+2		a	2	18.32	6.18	12.14	
"	"		"		18.30	6.16	12.14	over concentrated
S16	1+2		b	2	38.67	6.70	31.97	over concentrated
S19	1+2	Surface		2	42.67	14.84	27.83	
S22	1+2	Surface		2	7.19	4.77	2.43	
S25	1			2	40.17	13.07	27.09	over concentrated
South Des Barres 1500 m Post-Drilling								
S 4	1+2			3	63.35	23.21	40.15	
S 7	1+2			3	11.59	5.58	6.01	
S10	1			3	6.65	4.43	2.22	
S10	2			3	8.24	5.98	2.26	
S13	1 +2	Surface 2 Surface 1		3	4.02	2.95	1.07	
S17	1			3	9.89	5.28	4.61	
S17	2			3	10.16	6.56	3.60	
S20	1+2	Surface 1		3	13.71	7.13	6.58	over concentrated
S23	1+2			3	8.26	5.29	2.97	
S26	1 +2	Surface 1 Surface 2	a	3	16.79	6.17	10.62	
S26	1 +2	Surface 1 Surface 2	b	3	9.17	5.64	3.53	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
						ug/g dry weight Conoco		
South Des Barres Control Post-Drilling								
S14	2	Surface 1	a	5	5.40	3.88	1.52	
S14	2	Surface 1	b	5	3.49	2.20	1.29	
S14	3	Surface 2	a	5	1.91	1.54	0.36	
S14	3	Surface 2	b	5	3.93	3.42	0.51	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
South Des Barres Wellhead Pre-Drilling								
S 1	1	Surface		5	32.25	11.48	20.76	
S 1	2	Surface		8	255.4	63.64	191.8	
S 1	3	Surface	a	5	110.6	36.70	73.86	
S 1	3	Surface	b	5	220.2	63.79	156.5	
S 1	4	Surface		8	82.19	32.26	49.93	
S 1	4	Bottom		8	18.65	9.30	9.35	
S 1	5	Surface		8	27.76	9.79	17.97	
S 1	5	Bottom		8	8.52	5.28	3.24	
South Des Barres Pre-Drilling								
S 2	1	Surface		8	11.15	5.53	5.62	
S 2	2	Surface		5	146.2	24.89	121.3	
S 2	3	Surface	a	8	16.46	8.74	7.72	
S 2	3	Surface	b	8	12.78	7.53	5.25	
S 2	3	Bottom		8	10.35	6.47	3.88	
S 2	4	Surface		5	44.86	10.25	34.60	
S 2	5	Surface		8	17.62	9.97	7.65	
S 2	5	Bottom		8	9.05	5.38	3.67	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco			
South Des Barres Pre-Drilling (Continued)								
S 3	4	Surface		8	10.06	8.30	1.76	
S 3	5	Surface		8	10.05	6.02	4.03	
S 5	2	Surface		8	12.68	8.01	4.67	
S 5	2	Bottom		8	7.22	4.71	2.51	
S 5	3	Surface		8	12.37	7.11	5.26	
S 5	4	Surface		5	11.43	6.60	4.83	over concentrated
S 5	5	Surface		5	8.07	4.05	4.02	
S 8	3	Surface		8	8.39	4.31	4.08	
S 8	4	Surface		8	10.90	6.83	4.07	
S 9	4	Surface		5	6.48	5.18	1.30	
S 9	5	Surface	a	5	4.43	3.10	1.33	
S 9	5	Surface	b	5	5.31	3.86	1.45	
S11	1	Surface	a	8	11.58	6.24	5.34	
S11	1	Surface	b	8	6.94	4.31	2.63	
S11	1	Bottom		8	8.12	5.18	2.94	
S11	4	Surface		8	14.18	6.85	7.33	
S13	4	Surface		5	15.35	7.71	7.63	
S13	5	Surface		5	4.20	3.00	1.20	
South Des Barres Control Pre-Drilling								
S14	2	Surface	a	5	3.02	2.54	0.48	
S14	2	Surface	b	5	4.64	3.25	1.38	
S14	3	Surface	a	5	7.80	6.01	1.80	
S14*	3	Surface	b	5	23.81	22.33	1.48	

* Sample contaminated during collection or storage before receipt by Dobrocky.

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aliphatics	Resolved Aliphatics	UCM Aliphatics	Comments
					ug/g dry weight Conoco (assuming 80g of sample used)			
Reagent Blanks								
			a	1	<0.05	<0.05	<0.05	
			b	1	0.73	0.27	0.46	
			a	2	0.13	0.07	0.06	
			b	2	1.05	0.98	0.07	
			a	3	<0.05	<0.05	<0.05	
			b	3	0.15	0.05	0.10	
			a	4	0.79	0.67	0.12	
			b	4	<0.05	<0.05	<0.05	
			a	4a*	<0.05	<0.05	<0.05	over concentrated
			b	4a*	1.59	0.86	0.73	over concentrated
			a	5	0.53	<0.05	0.49	
			b	5	1.70	1.67	<0.05	
			a	6	1.33	1.27	0.05	
			b	6	<0.05	<0.05	<0.05	
			a	7	0.45	0.44	<0.05	
			b	7	2.34	2.34	<0.05	
			a	8	0.24	0.24	<0.05	
			a	9	0.31	0.09	0.22	
			b	9	<0.05	<0.05	<0.05	
			a	10	1.63	0.55	1.08	
			b	10	<0.05	<0.05	<0.05	

* Note that both Aromatics and Aliphatics were included in these reagent blanks.

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
West Venture Cuttings Samples								
WV	1			10	212.9	70.81	142.1	
WV	12,13			10	18.76	7.23	11.53	
WV	41			10	~ 1400	~ 780	~ 630	Terphenyl obscurred

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
West Venture Wellhead Post-Drilling								
Jar Samples taken November 4, 1984 by diver								
M 1	1		a	4a	3,519	1,594	1,926	Contains aliphatics
M 1	1		b	4a	1,436	781.9	654.5	Standard found
M 1	2		a	4a	1,071	631.7	439.8	may not be all
M 1	2		b	4a	1,014	769.5	244.2	terphenyl
Core taken November 4, 1984 by diver								
M 1		0 - 3 cm		9	~70	~37	~32	Terphenyl not found
M 1		3 - 6 cm		9	~310	~96	~210	Terphenyl not found
M 1		6 - 10 cm		9	299.9	119.0	181.0	
M 1		10 - 15 cm		9	73.29	35.20	38.08	
Jar Samples taken February 1, 1985 by diver								
M 1	1			9	0.09	0.03	0.06	
M 1	2		a	9	4.10	2.10	2.00	
M 1	2		b	9	4.03	1.57	2.46	
M 1	3		a	9	0.14	0.14	<0.01	
M 1	3		b	9	0.22	0.03	0.19	
M 1	4			9	~17	~9	~9	Terphenyl obscured

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
						ug/g dry weight o-terphenyl		
West Venture 200 m Post-Drilling								
M 2	1	Surface 1	a	1	0.29	0.12	0.09	
M 2	1	Surface 1	b	1	0.96	0.38	0.57	
M 2	2	Surface 1		1	0.11	0.07	0.05	
M 5	1	Surface 1		1	0.51	0.16	0.35	
M 5	2	Surface 1		1	1.67	0.74	0.94	
M 8	1+2			1	0.07	0.06	0.01	
M 8	1	Surface		7	0.35	0.06	0.29	
M 8	2	Surface		7	0.05	<0.01	0.05	
M11	1+2			1	0.08	0.04	0.04	
M11	1			7	0.18	0.18	<0.01	
M11	2			7	0.14	0.07	0.07	
M14	1+2	Surface 2		1	0.26	0.13	0.13	
M14	1	Surface 1		7	0.03	0.03	<0.01	
M14	1	Surface 2		7	0.03	0.03	<0.01	
M14	2	Surface 1		7	0.06	0.06	<0.01	
M14	2	Surface 2	a	7	0.04	0.04	<0.01	
M14	2	Surface 2	b	7	0.05	0.03	0.02	
M17	1+2			1	2.48	0.92	1.56	Contains aliphatics
M17	1			7	0.06	0.06	<0.01	
M17	2			7	0.30	<0.01	0.29	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
West Venture 200 m Post-Drilling (continued)								
M20	1+2	Surface 2		1	0.11	0.03	0.07	
M20	1	Surface 1		7	0.71	0.71	<0.01	
M20	1	Surface 2		7	0.12	<0.01	0.12	
M20	1	Bottom		7	0.16	0.05	0.11	
M20	2	Surface 1		7	0.03	0.02	0.01	
M20	2	Surface 2		7	<0.01	<0.01	<0.01	
M20	2	Bottom		7	0.64	0.51	0.13	
M23	1+2	Surface		1	2.47	1.19	1.28	
M23	1	Surface	a	7	0.09	0.07	0.03	
M23	1	Surface	b	7	0.76	0.57	0.19	
M23	1	Bottom		7	2.09	0.43	1.66	
M23	2	Surface		7	0.36	0.05	0.31	
M23	2	Bottom		7	0.12	0.03	0.09	
West Venture 500 m Post-Drilling								
M 3	1+2	Surface		9	0.02	0.01	0.01	
M12	1+2	Surface		1	0.10	0.04	0.05	
West Venture Control Post-Drilling								
M26	1	Surface 2	a	4	0.03	0.03	<0.01	
M26	3	Surface 1	a	4	0.32	0.19	0.13	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
West Venture Wellhead Pre-Drilling								
M 1	2	Surface	b	4	0.05	0.04	<0.01	
West Venture Pre-Drilling								
M11	3	Surface		4	0.01	0.01	0.01	
M22	2	Surface		4	0.01	0.01	<0.01	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
South Des Barres Cuttings Samples								
SDB	1			10	1747	594.2	1152	
SDB	12			10	120.2	47.75	72.46	
SDB	41		a	10	333.2	118.5	214.7	
SDB	41		b	10	455.1	233.1	222.0	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
South Des Barres Wellhead Post-Drilling								
S 1	1	Surface	a	10	123.1	18.66	104.5	Contains Aliphatics
S 1	1	Surface	b	10	800.3	240.7	559.7	Contains Aliphatics
S 1	2	Surface	a	4a	2,572	1,310	1,263	
S 1	2	Surface	b	4a	1,209	266.1	942.9	Contains Aliphatics
S 1	3	Surface 1		10	520.1	178.5	341.5	
S 1	3	Surface 2		10	542.9	185.4	357.5	Contains Aliphatics
S 1	3	Bottom		10	1,144	256.5	887.6	Contains Aliphatics
S 1	4	Surface	a	4a	197.5	58.71	138.7	
S 1	4	Surface	b	4a	~260			Terphenyl not found
S 1	4	Surface 1	a	10	786.6	240.2	546.4	Contains Aliphatics
S 1	4	Surface 1	b	10	852.9	246.1	606.8	Contains Aliphatics
S 1	4	Surface 2		10	1,268	414.7	853.3	
S 1	4	Bottom		10	1,193	377.8	815.4	Contains Aliphatics

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
South Des Barres 200 m Post-Drilling								
S 2	1+2	Surface		2	177.8	112.4	65.44	
S 2	1	Surface		6	401.0	90.53	310.5	Contains Aliphatics
S 2	1	Bottom		6	1,666	141.9	1,524	Contains Aliphatics
S 2	2	Surface	a	6	312.5	105.5	207.0	Contains Aliphatics
S 2	2	Surface	b	6	57.71	27.14	30.57	
S 2	2	Bottom		6	7.58	6.75	0.83	
S 5	1+2			2	64.13	21.48	42.65	
S 5	1			6	121.7	37.22	84.43	Contains Aliphatics
S 5	2			6	55.08	18.98	36.10	
S 8	1			2	1.50	0.38	1.18	
S 8	2			2	3.18	0.35	2.83	
S11	1+2			2	2.60	1.31	1.12	
S11	1			6	0.06	0.06	<0.01	
S11	2			6	0.25	0.15	0.10	
S15	1	Surface		2	~14	~5	~9	Terphenyl not found
S15	2	Surface		2	2.21	1.27	0.94	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
South Des Barres 200 m Post-Drilling (continued)								
S15	2	Surface		6	7.43	2.85	4.57	
S15	2	Bottom		6	5.08	1.73	3.35	
S15	3	Surface		6	39.18	11.02	28.16	Contains Aliphatics
S15	3	Bottom		6	1.58	0.41	1.18	
S18	1+2	Surface		2	12.76	3.64	9.12	
S18	1	Surface		6	2.66	0.31	2.35	
S18	1	Bottom		6	2.96	2.05	0.91	
S18	2	Surface		6	84.84	26.80	58.04	Contains Aliphatics
S18	2	Bottom		6	9.04	4.09	4.95	
S21	1+2		a	2	0.08	0.04	0.03	
S21	1+2		b	2	0.86	0.86	<0.01	
S21	1			6	0.32	0.14	0.18	
S21	2			9	0.19	0.17	0.02	
S24	1+2			2	1.41	0.85	0.56	
S24	1		a	6	1.68	0.63	1.05	
S24	1		b	6	0.72	0.27	0.44	
S24	2			6	6.60	1.26	5.34	
South Des Barres 800 m Post-Drilling								
S 3	1			2	0.05	0.03	0.02	
South Des Barres Control Post-Drilling								
S14	2	Surface 1	a	5	0.37	0.37	<0.01	
S14	3	Surface 2	a	5	0.21	0.18	0.03	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
South Des Barres Wellhead Pre-Drilling								
S 1	1	Surface		5	4.61	2.01	2.60	
S 1	2	Surface		8	32.89	13.38	19.51	
S 1	3	Surface	a	5	7.89	2.10	5.79	
S 1	3	Surface	b	5	3.88	1.49	2.39	
S 1	4	Surface		8	2.72	1.13	1.59	
S 1	4	Bottom		8	9.21	3.79	5.42	
S 1	5	Surface		8	12.43	6.18	6.25	
S 1	5	Bottom		8	1.02	0.03	0.99	
South Des Barres Pre-Drilling								
S 2	1	Surface		8	1.26	1.26	<0.01	
S 2	2	Surface		5	7.15	1.34	5.81	
S 2	3	Surface	a	8	6.93	2.15	4.78	
S 2	3	Surface	b	8	3.90	0.52	3.38	
S 2	3	Bottom		8	11.87	5.28	6.59	
S 2	4	Surface		5	4.24	0.71	3.53	
S 2	5	Surface		8	5.20	2.03	3.17	
S 2	5	Bottom		8	12.55	5.43	7.12	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl			
South Des Barres Pre-Drilling (Continued)								
S 3	4	Surface		8	21.91	7.90	14.01	
S 5	2	Surface		8	0.56	0.06	0.50	
S 5	2	Bottom		8	0.24	0.01	0.23	
S 5	3	Surface		8	10.17	4.67	5.50	
S 5	5	Surface		5	10.24	3.36	6.88	
S 8	3	Surface		8	0.05	0.05	<0.01	
S 8	4	Surface		8	0.05	0.01	0.04	
S11	1	Surface	a	8	0.07	0.01	0.06	
S11	1	Surface	b	8	2.39	1.93	0.46	
S11	1	Bottom		8	0.27	0.27	<0.01	
S11	4	Surface		8	8.66	0.14	8.52	

Station	Grab	Field Subsample	Analytical Replicate	Batch	Total Aromatics	Resolved Aromatics	UCM Aromatics	Comments
					ug/g dry weight o-terphenyl (assuming 80 g of sample used)			
Reagent Blanks								
			b	1	0.02	0.02	<0.01	
			a	2	0.03	0.02	0.01	
			b	2	0.06	0.04	0.02	
			a	4	0.19	0.17	0.01	
			b	4	0.02	0.09	0.01	
			a	5	0.01	0.01	<0.01	
			b	5	0.04	0.04	<0.01	
			a	6	<0.01	<0.01	<0.01	
			b	6	<0.01	<0.01	<0.01	
			a	7	<0.01	<0.01	<0.01	
			b	7	0.19	0.08	0.11	
			a	8	<0.01	<0.01	<0.01	
			b	8	0.11	0.05	0.06	
			a	9	<0.01	<0.01	<0.01	
			b	9	<0.01	<0.01	<0.01	
			a	10	<0.01	<0.01	<0.01	
			b	10	<0.01	<0.01	<0.01	

APPENDIX 3

Sediment Particle- Size Analyses Results

SHELL, SOUTH DES BARRES, 1984

SAMPLE ID S1-2

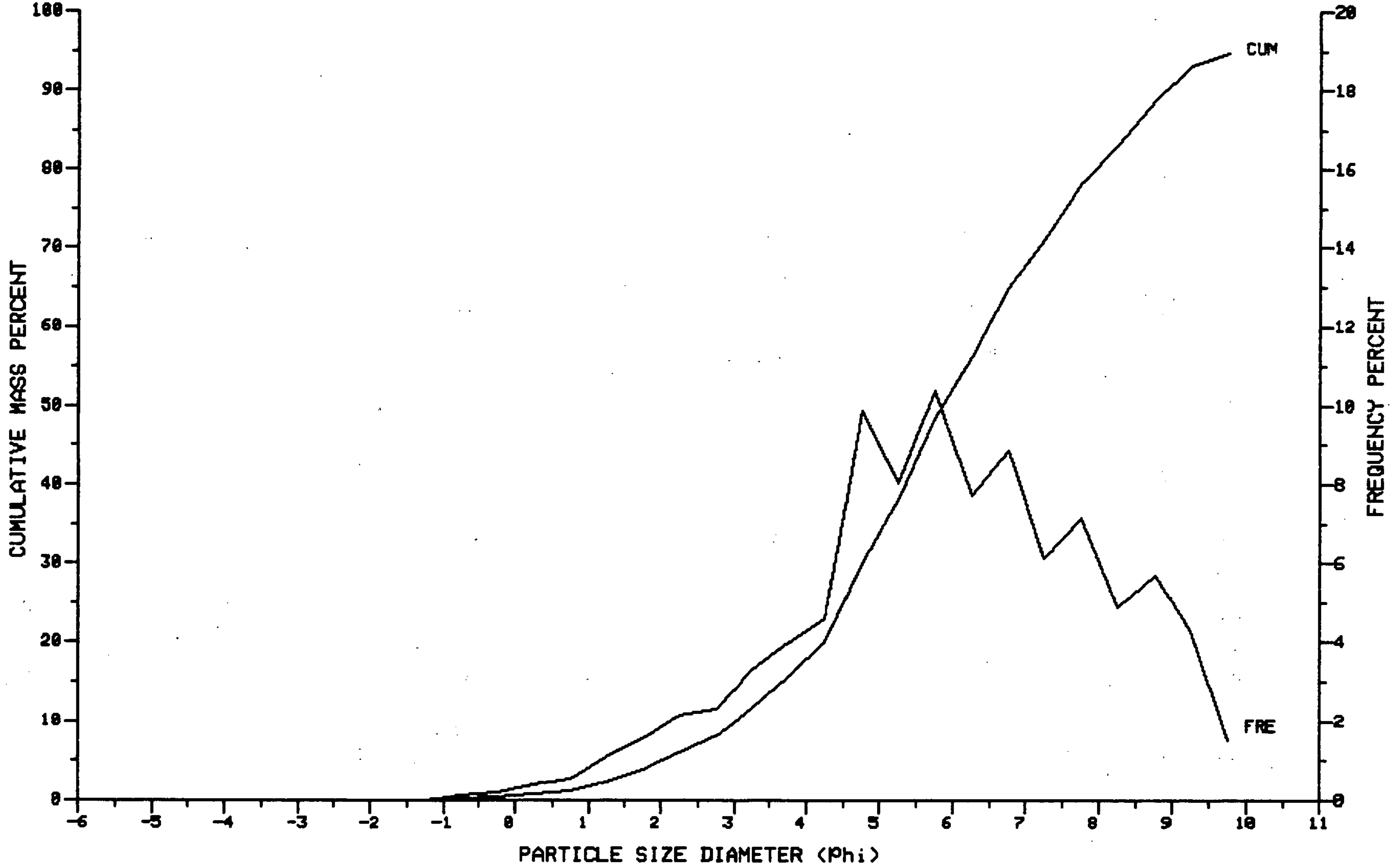
TOTAL GRAVEL+SAND+MUD WEIGHT 84.30 grams
SAND SUB-SAMPLE SPLIT WEIGHT 83.80 grams

SIZE FRACTION mm	phi	WEIGHT IN GRAMS uncor.	cor.	WEIGHT PERCENT cor.	cumm.	COARSE SHELL (grams)	MACRO-ORGANICS (grams)
32.0	-5.00	0.00	0.00	0.00	0.00		
22.6	-4.50	0.00	0.00	0.00	0.00		
16.0	-4.00	0.00	0.00	0.00	0.00		
11.3	-3.50	0.00	0.00	0.00	0.00		
8.00	-3.00	0.00	0.00	0.00	0.00		
5.66	-2.50	0.00	0.00	0.00	0.00		
4.00	-2.00	0.00	0.00	0.00	0.00		
2.83	-1.50	0.00	0.00	0.00	0.00		
2.00	-1.00	0.00	0.00	0.00	0.00		
TOTAL GRAVEL			0.00	0.00	0.00		
1.41	-0.50	0.09	0.09	0.11	0.11		
1.00	0.00	0.17	0.17	0.20	0.31		
0.71	0.50	0.31	0.31	0.37	0.68		
0.50	1.00	0.44	0.44	0.52	1.20		
0.35	1.50	0.92	0.92	1.09	2.29		
0.25	2.00	1.30	1.30	1.54	3.83		
0.177	2.50	1.79	1.79	2.12	5.95		
0.125	3.00	1.92	1.92	2.28	8.23		
0.088	3.50	2.76	2.76	3.27	11.51		
0.0625	4.00	3.36	3.36	3.99	15.49		
TOTAL SAND			13.06	15.49	15.49		
0.0480	4.40	3.21	3.87	4.59	20.08		
0.0320	5.00	6.91	8.34	9.89	29.97		
0.0240	5.40	5.63	6.79	8.05	38.02		
0.0160	6.00	7.27	8.77	10.40	48.42		
0.0120	6.40	5.41	6.53	7.75	56.17		
0.0080	7.00	6.20	7.48	8.87	65.03		
0.0060	7.40	4.27	5.16	6.12	71.15		
0.0040	8.00	4.99	6.02	7.14	78.29		
0.0030	8.40	3.42	4.12	4.89	83.18		
0.0020	9.00	3.99	4.81	5.71	88.89		
0.0015	9.40	2.99	3.61	4.28	93.17		
0.0010	10.00	1.07	1.29	1.53	94.70		
<0.0010		3.70	4.47	5.30	100.00		
TOTAL MUD			71.24	84.51	100.00		

TABLE OF SEDIMENT STATISTICS

STATISTIC	MOMENT	INMAN	FOLK-WARD
Mean	5.938	5.793	5.762
Deviation	2.046	2.086	2.090
Skewness	-0.350	0.045	-0.018
Kurtosis	0.000	0.657	1.009
Median		5.699	
Skewness2		-0.134	
Percent Gravel	0.00		
Percent Sand	15.49		
Percent Mud	84.51		

SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S1-2



SHELL, SOUTH DES BARRES, 1984

SAMPLE ID S1-3

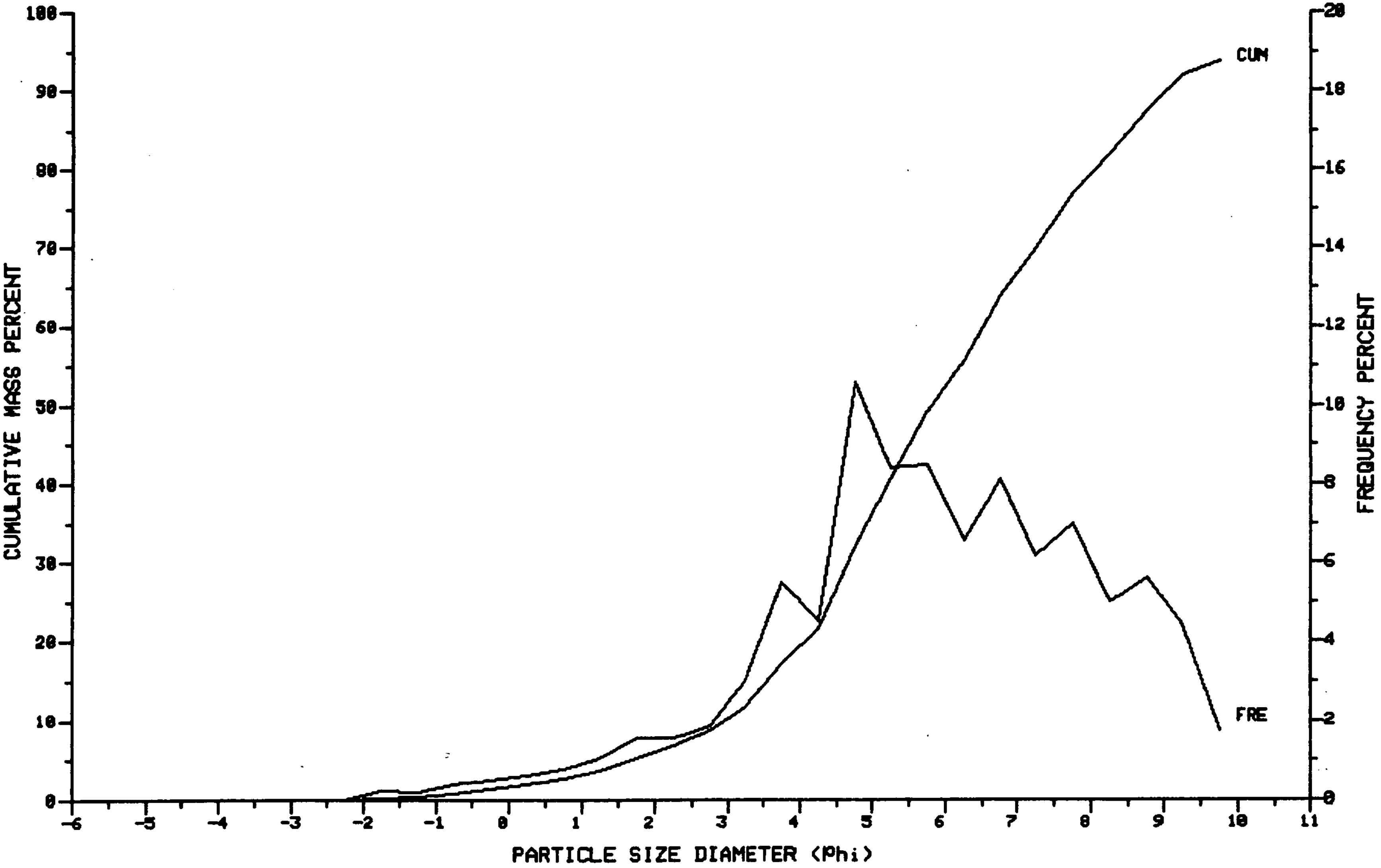
TOTAL GRAVEL+SAND+MUD WEIGHT 93.52 grams
SAND SUB-SAMPLE SPLIT WEIGHT 93.14 grams

SIZE FRACTION		WEIGHT IN GRAMS		WEIGHT PERCENT		COARSE SHELL	MACRO-ORGANICS
mm	phi	uncor.	cor.	cor.	cumm.	(grams)	(grams)
32.0	-5.00	0.00	0.00	0.00	0.00		
22.6	-4.50	0.00	0.00	0.00	0.00		
16.0	-4.00	0.00	0.00	0.00	0.00		
11.3	-3.50	0.00	0.00	0.00	0.00		
8.00	-3.00	0.00	0.00	0.00	0.00		
5.66	-2.50	0.00	0.00	0.00	0.00		
4.00	-2.00	0.00	0.00	0.00	0.00		
2.83	-1.50	0.20	0.20	0.21	0.21		
2.00	-1.00	0.18	0.18	0.19	0.41		
TOTAL GRAVEL			0.38	0.41	0.41		
1.41	-0.50	0.35	0.35	0.38	0.78		
1.00	0.00	0.46	0.46	0.50	1.28		
0.71	0.50	0.57	0.57	0.61	1.89		
0.50	1.00	0.71	0.72	0.77	2.66		
0.35	1.50	0.98	0.99	1.06	3.71		
0.25	2.00	1.44	1.45	1.55	5.27		
0.177	2.50	1.43	1.44	1.54	6.81		
0.125	3.00	1.72	1.73	1.85	8.66		
0.088	3.50	2.80	2.82	3.02	11.68		
0.0625	4.00	5.10	5.14	5.50	17.17		
TOTAL SAND			15.68	16.77	17.17		
0.0480	4.40	3.80	4.22	4.51	21.69		
0.0320	5.00	8.91	9.91	10.60	32.28		
0.0240	5.40	7.05	7.84	8.38	40.67		
0.0160	6.00	7.13	7.93	8.48	49.14		
0.0120	6.40	5.50	6.12	6.54	55.68		
0.0080	7.00	6.82	7.58	8.11	63.79		
0.0060	7.40	5.19	5.77	6.17	69.96		
0.0040	8.00	5.89	6.55	7.00	76.97		
0.0030	8.40	4.18	4.65	4.98	81.94		
0.0020	9.00	4.73	5.26	5.62	87.56		
0.0015	9.40	3.72	4.14	4.42	91.98		
0.0010	10.00	1.47	1.64	1.75	93.73		
<0.0010		5.27	5.86	6.27	100.00		
TOTAL MUD			77.46	82.83	100.00		

TABLE OF SEDIMENT STATISTICS

STATISTIC	MOMENT	INMAN	FOLK-WARD
Mean	5.844	5.740	5.699
Deviation	2.198	2.188	2.208
Skewness	-0.508	0.057	-0.023
Kurtosis	0.000	0.681	1.025
Median		5.616	
Skewness2		-0.171	
Percent Gravel	0.41		
Percent Sand	16.77		
Percent Mud	82.83		

SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S1-3



SHELL, SOUTH DES BARRES, 1984

SAMPLE ID S2-1

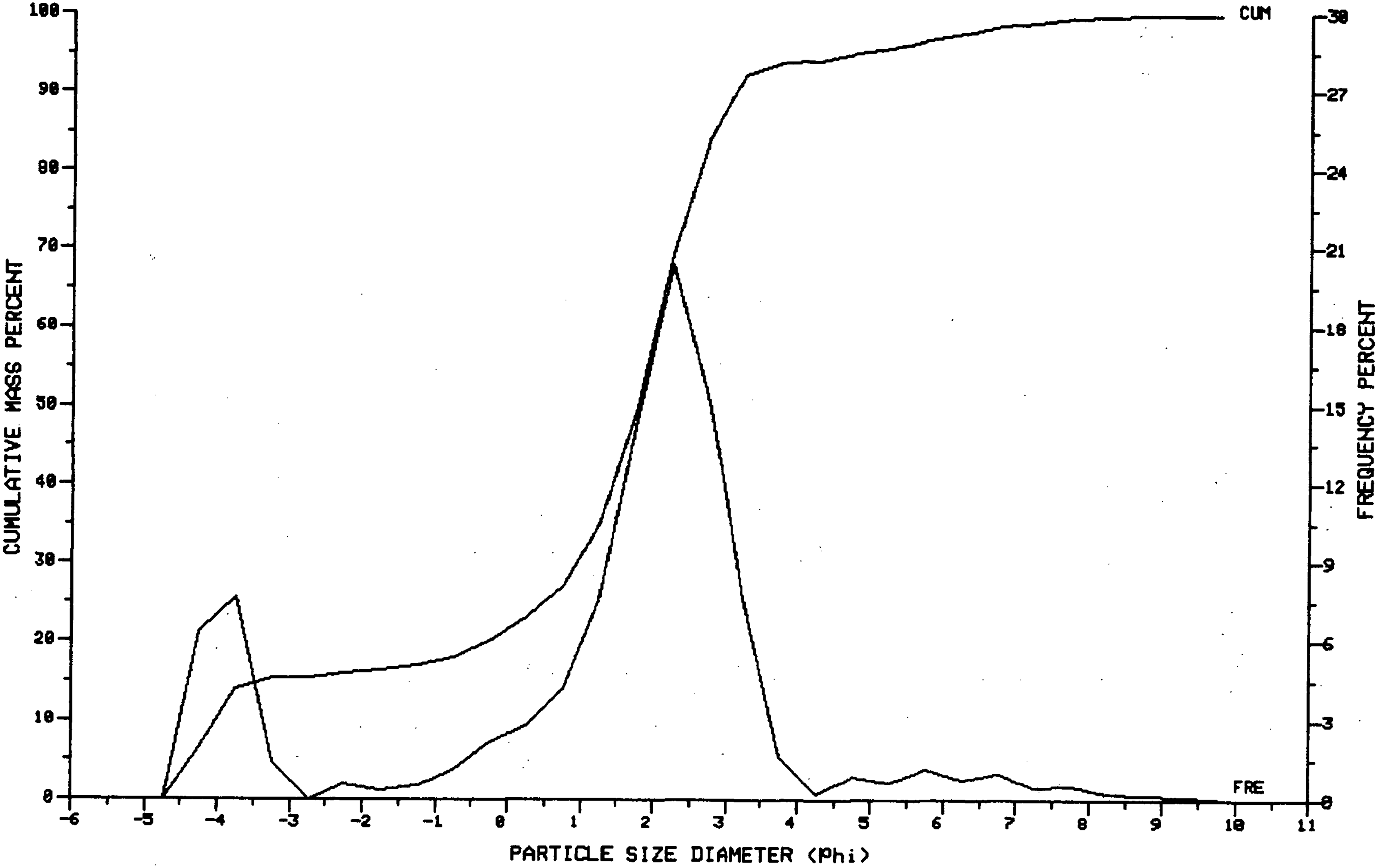
TOTAL GRAVEL+SAND+MUD WEIGHT 154.90 grams
SAND SUB-SAMPLE SPLIT WEIGHT 30.00 grams

SIZE FRACTION		WEIGHT IN GRAMS		WEIGHT PERCENT		COARSE SHELL	MACRO-ORGANICS
mm	phi	uncor.	cor.	cor.	cumm.	(grams)	(grams)
32.0	-5.00	0.00	0.00	0.00	0.00		
22.6	-4.50	0.00	0.00	0.00	0.00		
16.0	-4.00	9.88	9.88	6.38	6.38		
11.3	-3.50	11.88	11.88	7.67	14.05		
8.00	-3.00	2.17	2.17	1.40	15.45		
5.66	-2.50	0.00	0.00	0.00	15.45		
4.00	-2.00	0.89	0.89	0.57	16.02		
2.83	-1.50	0.55	0.55	0.36	16.38		
2.00	-1.00	0.82	0.82	0.53	16.91		
TOTAL GRAVEL			26.19	16.91	16.91		
1.41	-0.50	0.43	1.71	1.11	18.01		
1.00	0.00	0.83	3.31	2.13	20.15		
0.71	0.50	1.09	4.34	2.80	22.95		
0.50	1.00	1.63	6.49	4.19	27.14		
0.35	1.50	2.94	11.71	7.56	34.70		
0.25	2.00	5.52	21.99	14.20	48.90		
0.177	2.50	7.93	31.59	20.39	69.29		
0.125	3.00	5.89	23.46	15.15	84.44		
0.088	3.50	2.97	11.83	7.64	92.08		
0.0625	4.00	0.63	2.51	1.62	93.70		
TOTAL SAND			118.95	76.79	93.70		
0.0480	4.40	0.35	0.38	0.24	93.94		
0.0320	5.00	1.29	1.38	0.89	94.83		
0.0240	5.40	0.91	0.97	0.63	95.46		
0.0160	6.00	1.64	1.76	1.13	96.60		
0.0120	6.40	1.11	1.19	0.77	97.37		
0.0080	7.00	1.42	1.53	0.99	98.35		
0.0060	7.40	0.68	0.73	0.47	98.82		
0.0040	8.00	0.70	0.75	0.49	99.31		
0.0030	8.40	0.29	0.31	0.20	99.51		
0.0020	9.00	0.27	0.29	0.19	99.70		
0.0015	9.40	0.16	0.17	0.11	99.81		
0.0010	10.00	0.06	0.06	0.04	99.85		
<0.0010		0.21	0.23	0.15	100.00		
TOTAL MUD			9.76	6.30	100.00		

TABLE OF SEDIMENT STATISTICS

STATISTIC	MOMENT	INMAN	FOLK-WARD
Mean	1.309	0.220	0.739
Deviation	2.650	2.511	2.639
Skewness	-0.678	-0.619	-0.482
Kurtosis	0.000	0.818	1.924
Median		1.775	
Skewness2		-0.625	
Percent Gravel	16.91		
Percent Sand	76.79		
Percent Mud	6.30		

SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S2-1



SHELL, SOUTH DES BARRES, 1984

SAMPLE ID S5-1

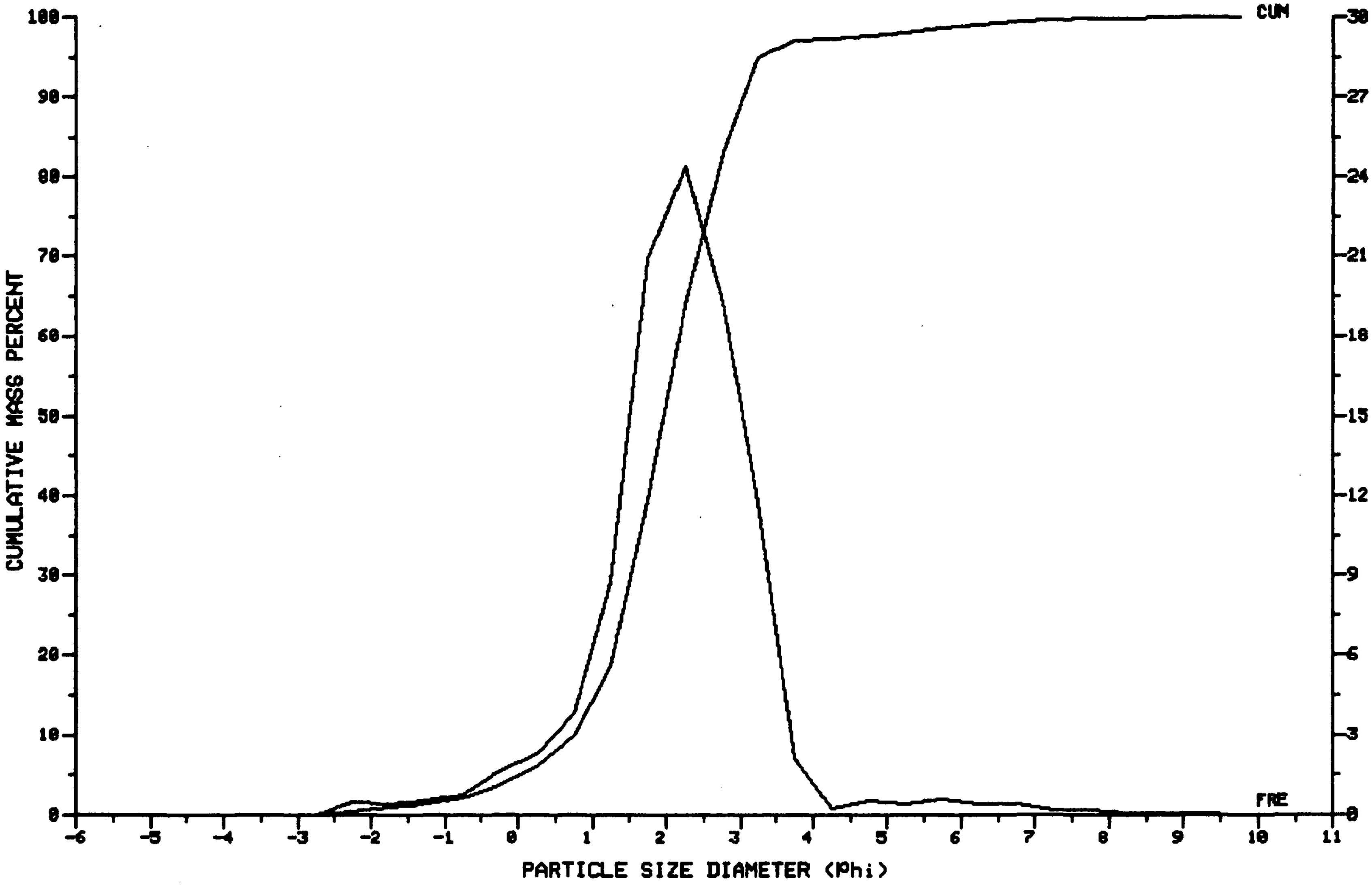
TOTAL GRAVEL+SAND+MUD WEIGHT 111.80 grams
SAND SUB-SAMPLE SPLIT WEIGHT 30.25 grams

SIZE FRACTION		WEIGHT IN GRAMS		WEIGHT PERCENT		COARSE SHELL	MACRO-ORGANICS
mm	phi	uncor.	cor.	cor.	cumm.	(grams)	(grams)
32.0	-5.00	0.00	0.00	0.00	0.00		
22.6	-4.50	0.00	0.00	0.00	0.00		
16.0	-4.00	0.00	0.00	0.00	0.00		
11.3	-3.50	0.00	0.00	0.00	0.00		
8.00	-3.00	0.00	0.00	0.00	0.00		
5.66	-2.50	0.00	0.00	0.00	0.00		
4.00	-2.00	0.49	0.49	0.44	0.44		
2.83	-1.50	0.46	0.46	0.41	0.85		
2.00	-1.00	0.59	0.59	0.53	1.38		
TOTAL GRAVEL			1.54	1.38	1.38		
1.41	-0.50	0.23	0.83	0.74	2.12		
1.00	0.00	0.51	1.83	1.64	3.76		
0.71	0.50	0.71	2.55	2.28	6.04		
0.50	1.00	1.18	4.24	3.79	9.83		
0.35	1.50	2.71	9.74	8.71	18.54		
0.25	2.00	6.50	23.35	20.89	39.42		
0.177	2.50	7.59	27.27	24.39	63.81		
0.125	3.00	5.99	21.52	19.25	83.06		
0.088	3.50	3.67	13.18	11.79	94.85		
0.0625	4.00	0.66	2.37	2.12	96.98		
TOTAL SAND			106.88	95.60	96.98		
0.0480	4.40	0.20	0.22	0.19	97.17		
0.0320	5.00	0.52	0.57	0.51	97.68		
0.0240	5.40	0.38	0.42	0.37	98.05		
0.0160	6.00	0.58	0.64	0.57	98.63		
0.0120	6.40	0.38	0.42	0.38	99.01		
0.0080	7.00	0.43	0.47	0.42	99.43		
0.0060	7.40	0.19	0.21	0.19	99.62		
0.0040	8.00	0.17	0.19	0.17	99.79		
0.0030	8.40	0.07	0.07	0.07	99.86		
0.0020	9.00	0.06	0.06	0.06	99.91		
0.0015	9.40	0.03	0.04	0.03	99.95		
0.0010	10.00	0.01	0.01	0.01	99.96		
<0.0010		0.04	0.05	0.04	100.00		
TOTAL MUD			3.38	3.02	100.00		

TABLE OF SEDIMENT STATISTICS

STATISTIC	MOMENT	INMAN	FOLK-WARD
Mean	2.196	1.946	1.953
Deviation	1.172	0.842	0.914
Skewness	0.444	-0.024	-0.110
Kurtosis	0.000	0.931	1.174
Median		1.966	
Skewness2		-0.378	
Percent Gravel	1.38		
Percent Sand	95.60		
Percent Mud	3.02		

SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S5-1



SHELL, SOUTH DES BARRES, 1984

SAMPLE ID S21-1

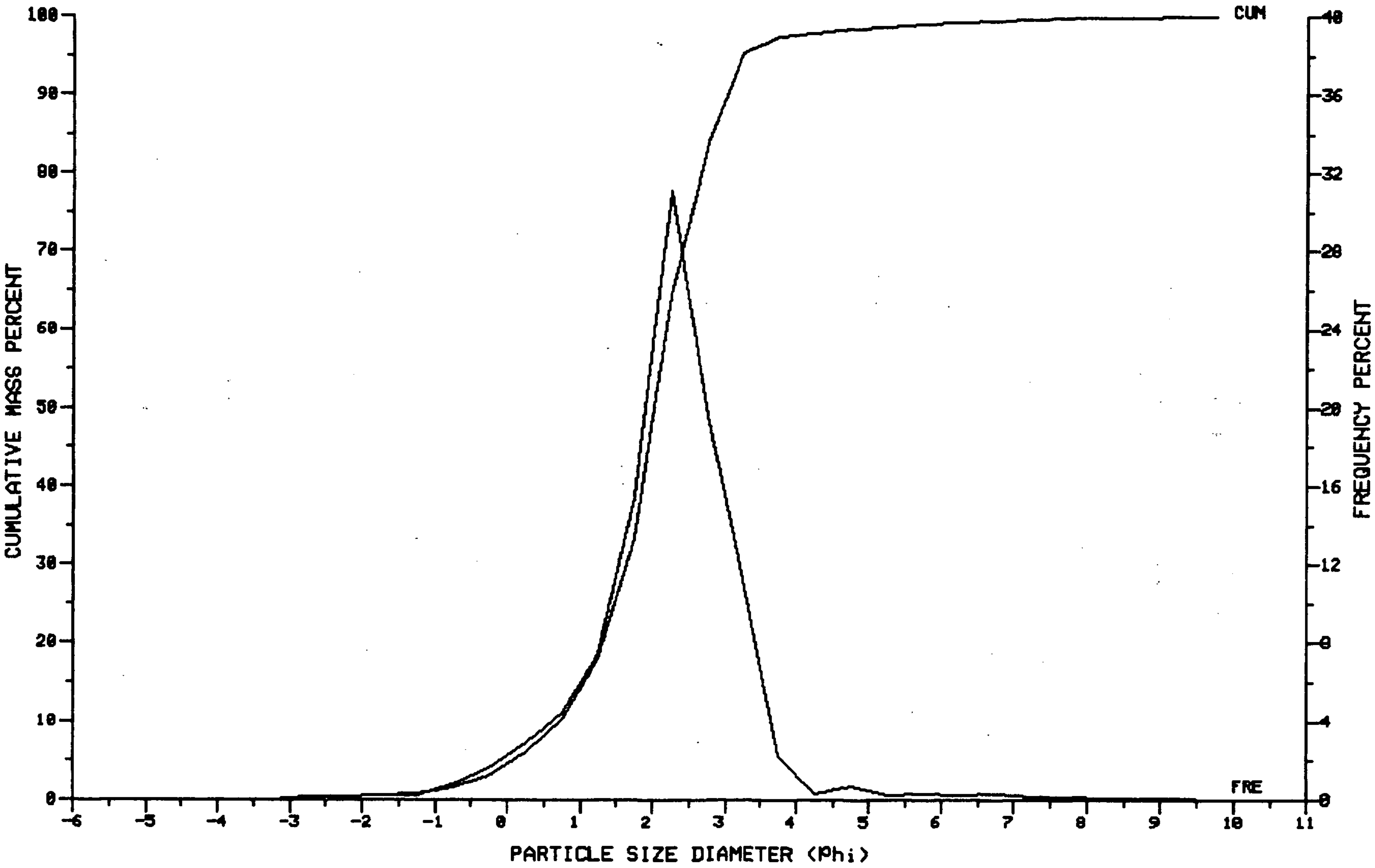
TOTAL GRAVEL+SAND+MUD WEIGHT 190.11 grams
SAND SUB-SAMPLE SPLIT WEIGHT 21.77 grams

SIZE FRACTION		WEIGHT IN GRAMS		WEIGHT PERCENT		COARSE SHELL (grams)	MACRO-ORGANICS (grams)
mm	phi	uncor.	cor.	cor.	cumm.		
32.0	-5.00	0.00	0.00	0.00	0.00		
22.6	-4.50	0.00	0.00	0.00	0.00		
16.0	-4.00	0.00	0.00	0.00	0.00		
11.3	-3.50	0.00	0.00	0.00	0.00		
8.00	-3.00	0.00	0.00	0.00	0.00		
5.66	-2.50	0.33	0.33	0.17	0.17		
4.00	-2.00	0.22	0.22	0.12	0.29		
2.83	-1.50	0.41	0.41	0.22	0.50		
2.00	-1.00	0.37	0.37	0.19	0.70		
TOTAL GRAVEL			1.33	0.70	0.70		
1.41	-0.50	0.18	1.52	0.80	1.50		
1.00	0.00	0.36	3.05	1.60	3.10		
0.71	0.50	0.65	5.50	2.89	6.00		
0.50	1.00	0.99	8.38	4.41	10.40		
0.35	1.50	1.67	14.13	7.43	17.84		
0.25	2.00	3.47	29.37	15.45	33.29		
0.177	2.50	6.98	59.07	31.07	64.36		
0.125	3.00	4.40	37.24	19.59	83.95		
0.088	3.50	2.53	21.41	11.26	95.21		
0.0625	4.00	0.50	4.23	2.23	97.44		
TOTAL SAND			183.91	96.74	97.44		
0.0480	4.40	0.46	0.62	0.32	97.76		
0.0320	5.00	0.92	1.24	0.65	98.42		
0.0240	5.40	0.35	0.47	0.25	98.67		
0.0160	6.00	0.47	0.63	0.33	99.00		
0.0120	6.40	0.25	0.34	0.18	99.18		
0.0080	7.00	0.36	0.49	0.26	99.43		
0.0060	7.40	0.17	0.23	0.12	99.55		
0.0040	8.00	0.23	0.32	0.17	99.72		
0.0030	8.40	0.11	0.14	0.08	99.80		
0.0020	9.00	0.13	0.17	0.09	99.89		
0.0015	9.40	0.07	0.09	0.05	99.93		
0.0010	10.00	0.02	0.03	0.02	99.95		
<0.0010		0.07	0.09	0.05	100.00		
TOTAL MUD			4.87	2.56	100.00		

TABLE OF SEDIMENT STATISTICS

STATISTIC	MOMENT	INMAN	FOLK-WARD
Mean	2.216	1.938	1.965
Deviation	1.101	0.812	0.885
Skewness	0.460	-0.099	-0.164
Kurtosis	0.000	0.946	1.247
Median		2.019	
Skewness2		-0.444	
Percent Gravel	0.70		
Percent Sand	96.74		
Percent Mud	2.56		

SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S21-1



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                              SHELL, SOUTH DES BARRES, 1984

SAMPLE ID      S10-2

TOTAL GRAVEL+SAND+MUD WEIGHT  233.17 grams
SAND SUB-SAMPLE SPLIT WEIGHT   14.29 grams

SIZE FRACTION          WEIGHT IN GRAMS      WEIGHT PERCENT    COARSE SHELL    MACRO-ORGANICS
  mm       phi         uncor.    cor.        cor.   cumm.       (grams)          (grams)

32.0      -5.00         0.00     0.00        0.00    0.00
22.6      -4.50         0.00     0.00        0.00    0.00
16.0      -4.00         0.00     0.00        0.00    0.00
11.3      -3.50         0.00     0.00        0.00    0.00
 8.00     -3.00         0.00     0.00        0.00    0.00
 5.66     -2.50         0.00     0.00        0.00    0.00
 4.00     -2.00         0.00     0.00        0.00    0.00
 2.83     -1.50         0.15     0.15        0.06    0.06
 2.00     -1.00         0.59     0.59        0.25    0.32
-------------------------------------------------------------------------------------------
TOTAL GRAVEL                     0.74        0.32    0.32

 1.41     -0.50         0.07     1.13        0.48    0.80
 1.00      0.00         0.33     5.31        2.28    3.08
 0.71      0.50         0.48     7.73        3.31    6.39
 0.50      1.00         0.68    10.95        4.69   11.09
 0.35      1.50         1.18    18.99        8.15   19.23
 0.25      2.00         2.63    42.33       18.16   37.39
 0.177     2.50         4.79    77.10       33.07   70.45
 0.125     3.00         2.69    43.30       18.57   89.02
 0.088     3.50         1.20    19.32        8.28   97.31
 0.0625    4.00         0.19     3.06        1.31   98.62
-------------------------------------------------------------------------------------------
TOTAL SAND                     229.21       98.30   98.62

 0.0480    4.40         0.27     0.31        0.13   98.75
 0.0320    5.00         0.57     0.66        0.28   99.04
 0.0240    5.40         0.42     0.49        0.21   99.25
 0.0160    6.00         0.51     0.59        0.25   99.50
 0.0120    6.40         0.31     0.36        0.15   99.66
 0.0080    7.00         0.29     0.34        0.15   99.80
 0.0060    7.40         0.13     0.15        0.06   99.87
 0.0040    8.00         0.11     0.13        0.06   99.92
 0.0030    8.40         0.05     0.06        0.02   99.95
 0.0020    9.00         0.04     0.05        0.02   99.97
 0.0015    9.40         0.03     0.03        0.01   99.98
 0.0010   10.00         0.01     0.01        0.00   99.98
<0.0010                 0.03     0.04        0.02  100.00
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TOTAL MUD                        3.22        1.38  100.00


                              TABLE OF SEDIMENT STATISTICS

       STATISTIC                  MOMENT         INMAN        FOLK-WARD
    -----------------            --------       -------      -----------

    Mean                           2.102          1.833          1.869
    Deviation                      0.957          0.781          0.856
    Skewness                       0.216         -0.138         -0.188
    Kurtosis                       0.000          0.964          1.306
    Median                                        1.941
    Skewness2                                    -0.468

    Percent Gravel                 0.32
    Percent Sand                  98.30
    Percent Mud                    1.38
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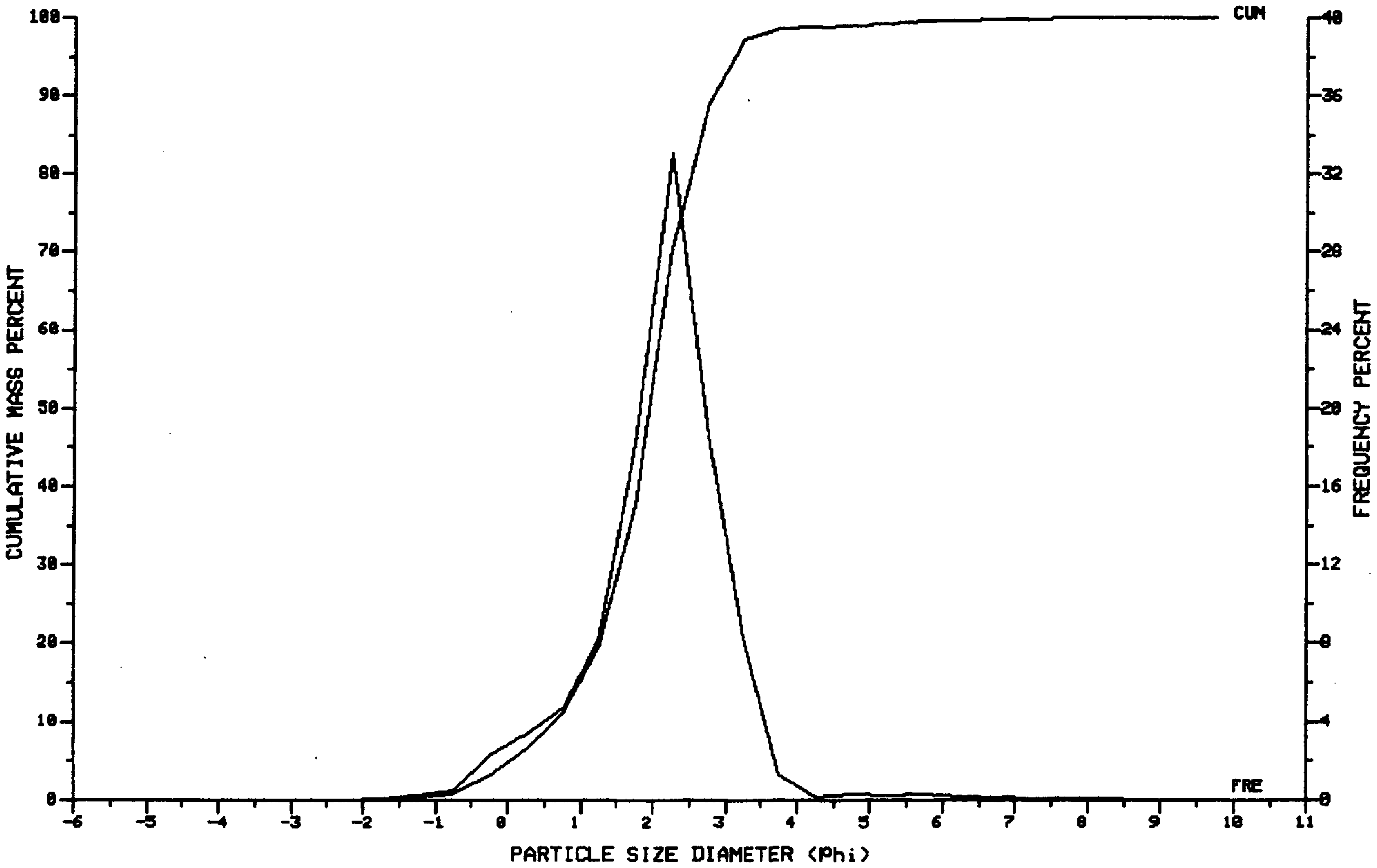
SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S10-2



SHELL, SOUTH DES BARRES, 1984

SAMPLE ID S13-1

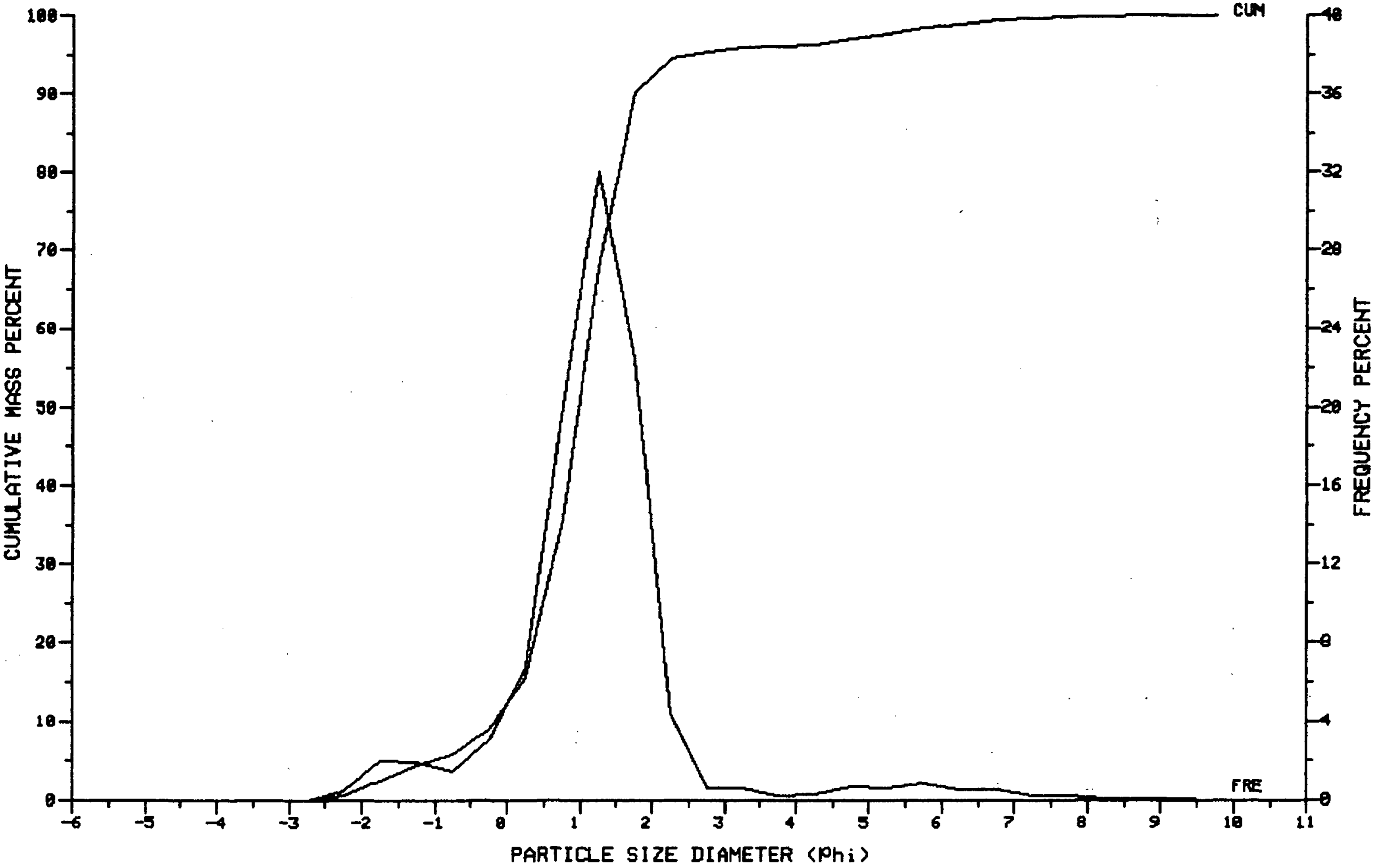
TOTAL GRAVEL+SAND+MUD WEIGHT 143.65 grams
SAND SUB-SAMPLE SPLIT WEIGHT 35.69 grams

SIZE FRACTION mm	phi	WEIGHT IN GRAMS uncor.	cor.	WEIGHT PERCENT cor.	cumm.	COARSE SHELL (grams)	MACRO-ORGANICS (grams)
32.0	-5.00	0.00	0.00	0.00	0.00		
22.6	-4.50	0.00	0.00	0.00	0.00		
16.0	-4.00	0.00	0.00	0.00	0.00		
11.3	-3.50	0.00	0.00	0.00	0.00		
8.00	-3.00	0.00	0.00	0.00	0.00		
5.66	-2.50	0.00	0.00	0.00	0.00		
4.00	-2.00	0.66	0.66	0.46	0.46		
2.83	-1.50	2.88	2.88	2.00	2.46		
2.00	-1.00	2.73	2.73	1.90	4.36		
TOTAL GRAVEL			6.27	4.36	4.36		
1.41	-0.50	0.56	2.07	1.44	5.81		
1.00	0.00	1.19	4.41	3.07	8.88		
0.71	0.50	2.63	9.74	6.78	15.65		
0.50	1.00	7.79	28.84	20.08	35.73		
0.35	1.50	12.41	45.95	31.99	67.72		
0.25	2.00	8.74	32.36	22.53	90.25		
0.177	2.50	1.69	6.26	4.36	94.60		
0.125	3.00	0.24	0.89	0.62	95.22		
0.088	3.50	0.24	0.89	0.62	95.84		
0.0625	4.00	0.09	0.33	0.23	96.07		
TOTAL SAND			131.74	91.71	96.07		
0.0480	4.40	0.35	0.38	0.27	96.34		
0.0320	5.00	0.87	0.95	0.66	97.00		
0.0240	5.40	0.76	0.83	0.58	97.58		
0.0160	6.00	1.05	1.15	0.80	98.38		
0.0120	6.40	0.66	0.72	0.50	98.89		
0.0080	7.00	0.65	0.71	0.49	99.38		
0.0060	7.40	0.28	0.30	0.21	99.59		
0.0040	8.00	0.24	0.26	0.18	99.77		
0.0030	8.40	0.10	0.10	0.07	99.85		
0.0020	9.00	0.08	0.09	0.06	99.91		
0.0015	9.40	0.05	0.06	0.04	99.94		
0.0010	10.00	0.01	0.01	0.01	99.95		
<0.0010		0.06	0.07	0.05	100.00		
TOTAL MUD			5.64	3.93	100.00		

TABLE OF SEDIMENT STATISTICS

STATISTIC	MOMENT	INMAN	FOLK-WARD
Mean	1.247	0.934	0.947
Deviation	1.281	0.676	0.878
Skewness	1.644	-0.057	-0.090
Kurtosis	0.000	1.636	1.573
Median		0.973	
Skewness2		-0.327	
Percent Gravel	4.36		
Percent Sand	91.71		
Percent Mud	3.93		

SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S13-1



SHELL, SOUTH DES BARRES, 1984

SAMPLE ID S20-1

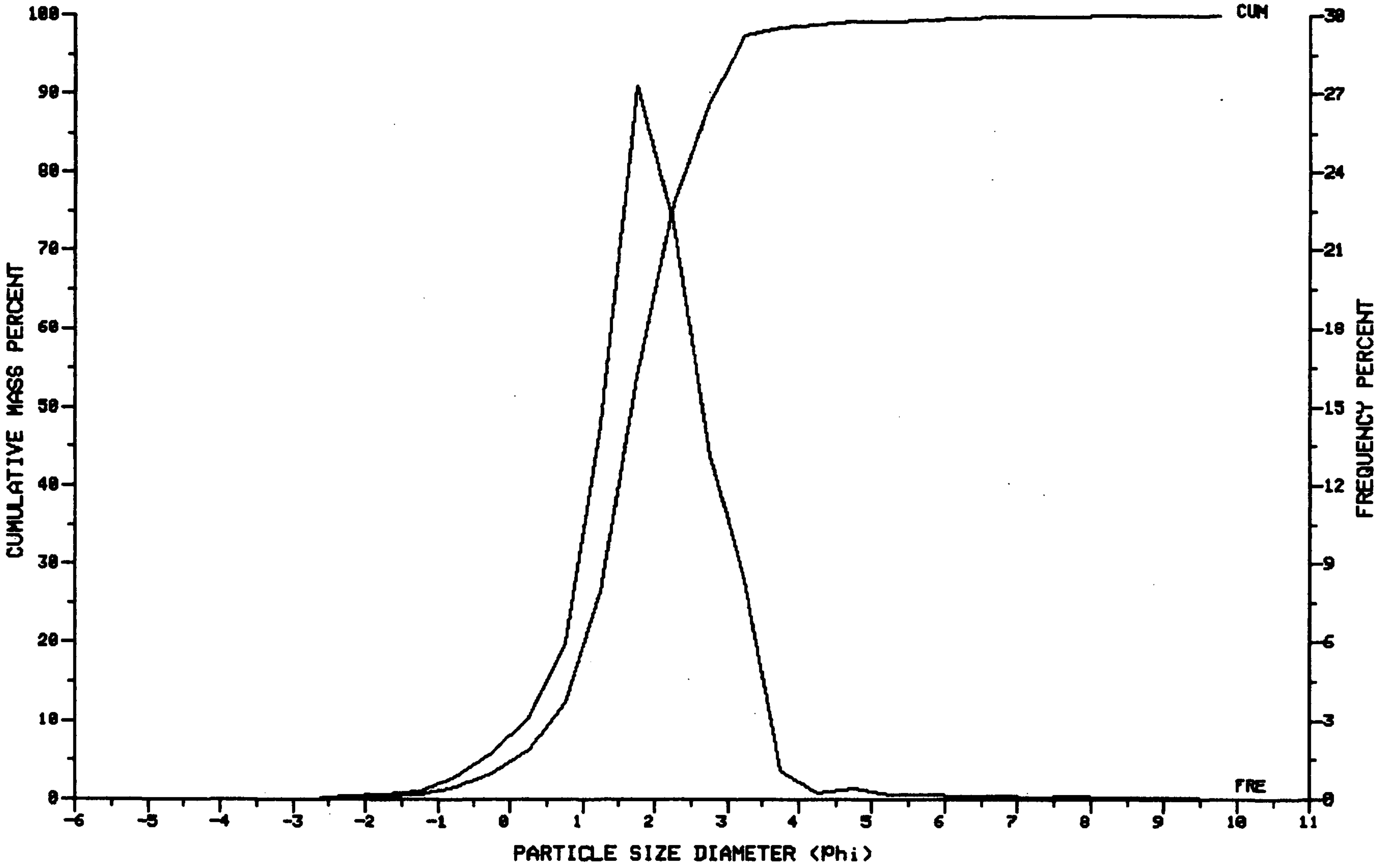
TOTAL GRAVEL+SAND+MUD WEIGHT 167.04 grams
SAND SUB-SAMPLE SPLIT WEIGHT 19.80 grams

SIZE FRACTION		WEIGHT IN GRAMS		WEIGHT PERCENT		COARSE SHELL	MACRO-ORGANICS
mm	phi	uncor.	cor.	cor.	cumm.	(grams)	(grams)
32.0	-5.00	0.00	0.00	0.00	0.00		
22.6	-4.50	0.00	0.00	0.00	0.00		
16.0	-4.00	0.00	0.00	0.00	0.00		
11.3	-3.50	0.00	0.00	0.00	0.00		
8.00	-3.00	0.00	0.00	0.00	0.00		
5.66	-2.50	0.00	0.00	0.00	0.00		
4.00	-2.00	0.19	0.19	0.11	0.11		
2.83	-1.50	0.29	0.29	0.17	0.29		
2.00	-1.00	0.46	0.46	0.28	0.56		
TOTAL GRAVEL			0.94	0.56	0.56		
1.41	-0.50	0.18	1.48	0.89	1.45		
1.00	0.00	0.35	2.89	1.73	3.18		
0.71	0.50	0.63	5.20	3.11	6.29		
0.50	1.00	1.21	9.98	5.98	12.27		
0.35	1.50	2.90	23.92	14.32	26.59		
0.25	2.00	5.53	45.62	27.31	53.90		
0.177	2.50	4.46	36.79	22.03	75.93		
0.125	3.00	2.66	21.94	13.14	89.07		
0.088	3.50	1.69	13.94	8.35	97.42		
0.0625	4.00	0.22	1.81	1.09	98.50		
TOTAL SAND			163.60	97.94	98.50		
0.0480	4.40	0.27	0.38	0.23	98.73		
0.0320	5.00	0.48	0.68	0.41	99.14		
0.0240	5.40	0.19	0.26	0.16	99.30		
0.0160	6.00	0.21	0.30	0.18	99.47		
0.0120	6.40	0.12	0.17	0.10	99.58		
0.0080	7.00	0.16	0.22	0.13	99.71		
0.0060	7.40	0.08	0.11	0.07	99.77		
0.0040	8.00	0.10	0.14	0.08	99.86		
0.0030	8.40	0.05	0.07	0.04	99.90		
0.0020	9.00	0.05	0.07	0.04	99.94		
0.0015	9.40	0.03	0.04	0.02	99.97		
0.0010	10.00	0.01	0.01	0.01	99.97		
<0.0010		0.03	0.04	0.03	100.00		
TOTAL MUD			2.50	1.50	100.00		

TABLE OF SEDIMENT STATISTICS

STATISTIC	MOMENT	INMAN	FOLK-WARD
Mean	1.943	1.718	1.705
Deviation	0.998	0.838	0.883
Skewness	0.548	0.048	-0.011
Kurtosis	0.000	0.827	1.213
Median		1.678	
Skewness2		-0.126	
Percent Gravel	0.56		
Percent Sand	97.94		
Percent Mud	1.50		

SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S20-1



SHELL, SOUTH DES BARRES, 1984

SAMPLE ID S14-4 (PRE-DRILLING)

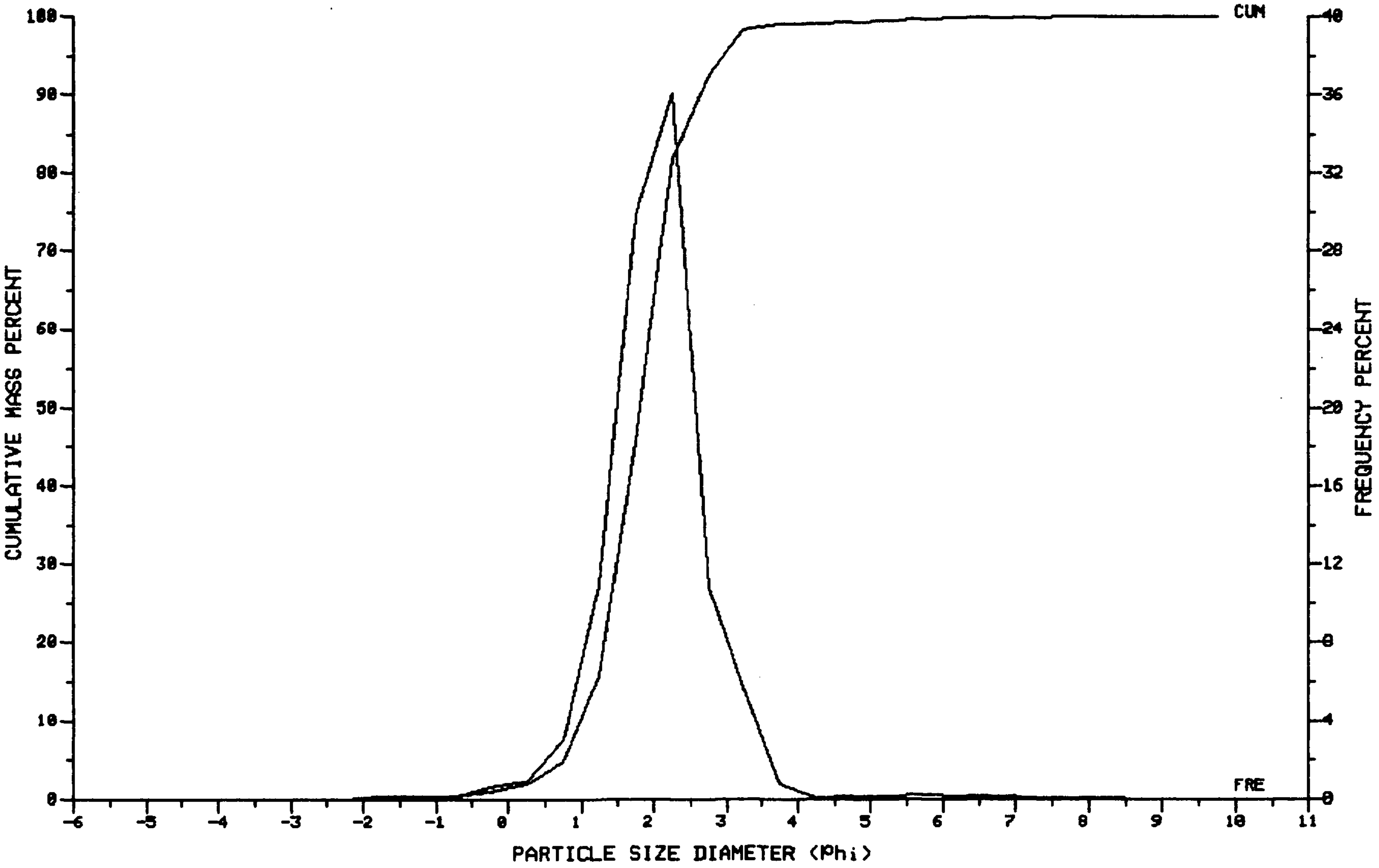
TOTAL GRAVEL+SAND+MUD WEIGHT 137.11 grams
SAND SUB-SAMPLE SPLIT WEIGHT 16.75 grams

SIZE FRACTION		WEIGHT IN GRAMS		WEIGHT PERCENT		COARSE SHELL	MACRO-ORGANICS
mm	phi	uncor.	cor.	cor.	cumm.	(grams)	(grams)
32.0	-5.00	0.00	0.00	0.00	0.00		
22.6	-4.50	0.00	0.00	0.00	0.00		
16.0	-4.00	0.00	0.00	0.00	0.00		
11.3	-3.50	0.00	0.00	0.00	0.00		
8.00	-3.00	0.00	0.00	0.00	0.00		
5.66	-2.50	0.00	0.00	0.00	0.00		
4.00	-2.00	0.00	0.00	0.00	0.00		
2.83	-1.50	0.24	0.24	0.18	0.18		
2.00	-1.00	0.13	0.13	0.09	0.27		
TOTAL GRAVEL			0.37	0.27	0.27		
1.41	-0.50	0.01	0.08	0.06	0.33		
1.00	0.00	0.10	0.81	0.59	0.92		
0.71	0.50	0.16	1.30	0.95	1.87		
0.50	1.00	0.51	4.14	3.02	4.89		
0.35	1.50	1.85	15.02	10.96	15.85		
0.25	2.00	5.04	40.92	29.85	45.69		
0.177	2.50	6.09	49.45	36.07	81.76		
0.125	3.00	1.82	14.78	10.78	92.54		
0.088	3.50	0.96	7.80	5.69	98.22		
0.0625	4.00	0.13	1.06	0.77	98.99		
TOTAL SAND			135.36	98.72	98.99		
0.0480	4.40	0.06	0.07	0.05	99.04		
0.0320	5.00	0.21	0.23	0.17	99.21		
0.0240	5.40	0.18	0.19	0.14	99.35		
0.0160	6.00	0.28	0.31	0.22	99.57		
0.0120	6.40	0.17	0.18	0.13	99.70		
0.0080	7.00	0.16	0.17	0.13	99.83		
0.0060	7.40	0.06	0.07	0.05	99.88		
0.0040	8.00	0.06	0.07	0.05	99.93		
0.0030	8.40	0.03	0.03	0.02	99.95		
0.0020	9.00	0.02	0.03	0.02	99.97		
0.0015	9.40	0.02	0.02	0.01	99.98		
0.0010	10.00	0.00	0.00	0.00	99.99		
<0.0010		0.02	0.02	0.01	100.00		
TOTAL MUD			1.38	1.01	100.00		

TABLE OF SEDIMENT STATISTICS

STATISTIC	MOMENT	INMAN	FOLK-WARD
Mean	2.059	1.803	1.805
Deviation	0.766	0.550	0.610
Skewness	1.144	-0.012	0.017
Kurtosis	0.000	1.008	1.203
Median		1.810	
Skewness2		0.092	
Percent Gravel	0.27		
Percent Sand	98.72		
Percent Mud	1.01		

SHELL, SOUTH DES BARRES, 1984
SAMPLE ID S14-4 (PRE-DRILLING)



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