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LONG TERM FATE AND PERSISTENCE OF STRANDED OIL FROM THE BIOS PROJECT, N.W.T., CANADA AND FROM THE METULA SPILL, TIERRA DEL FUEGO, CHILE

1987 RESULTS

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LONG TERM FATE AND PERSISTENCE OF STRANDED OIL FROM THE BIOS PROJECT, N.W.T., CANADA AND FROM THE METULA SPILL, TIERRA DEL FUEGO, CHILE

1987 RESULTS

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SUMMARY

In August, 1987, the site of the Baffin Island Oil Spill Project, Cape Hatt, N.W.T., was visited to make estimates of oil cover and to collect samples of oiled beach for subsequent chemical analysis.

The Backshore Control plots T1 and T2 showed little change from previous years, and the results suggest that any changes observed may be caused by non-random sampling introducing grain size differences and consequently oil content differences.

Of the low energy experiments in Bay 106 in 1982, only the backshore plots were reexamined. Again, little or no change was detected. The seaward berm appears to have been reworked by wave action between the sampling periods in 1985 and 1987.

The site of the experimental spill in Bay 11 in 1981 was reexamined and resampled in 1987. Different methods of ground estimates of beach cover indicate that the oiled cover is continuing to decrease, with 58% of beach length remaining oiled, representing an oiled area of 24% of the original oiled area, and incorporating 17% of the original spilled oil. The remaining oil is concentrated in the beach face or upper intertidal zone as an asphalt pavement material, containing about 60% of the remaining oil, and in the lower intertidal zone on rocky ridges. The oil appears to have the same compositional characteristics as in 1985, with high concentrations of oil being moderately weathered and low concentrations being heavily weathered.

Samples from a visit to the site of the 1974 Metula spill in January 1987 were analysed for comparison to the BIOS samples and to samples collected in 1985 at the site of the 1978 Amoco Cadiz spill. Some samples contained high concentrations of hydrocarbons. Some of these were clearly petroleum hydrocarbon, while others included significant portions of natural material. The high concentration petroleum related samples were weathered

to a similar extent as the high concentration BIOS samples, although they have been subject to 12 1/2 years of open water, compared to an open water exposure of less than 15 months for the BIOS oil. Samples from sandy, finer grain areas were highest in oil content.

RÉSUMÉ

En août 1987, le cap Hatt de l'île Baffin a été visité, dans le cadre du projet BIOS d'étude des déversements d'hydrocarbure, pour l'estimation des dépôts résiduels sur les plages et le prélèvement d'échantillons en vue de l'analyse.

Les placettes témoins T1 et T2, sur l'arrière-plage, avaient peu changé depuis les années antérieures, et le peu de changement observé peut avoir été causé par des échantillonnages non aléatoires qui sont à l'origine des différences de granulométrie et, par conséquent, des écarts dans les teneurs en hydrocarbures.

En 1982, la baie 106 avait servi à des expériences en milieu peu battu par les vagues. Seules les placettes de l'arrière-plage ont été réexaminées, et peu ou point de changements décelés. Le gradin de plage semble avoir été remaniée par l'action des vagues entre 1985 et 1987.

En 1987, on a aussi soumis à un nouvel examen et à un nouvel échantillonnage la scène du déversement expérimental de 1981, dans la baie 11. Selon les diverses méthodes d'estimation sur place du dépôt résiduel celui-ci continue de diminuer, n'étant plus que de 17 % de la quantité initiale et n'occupant plus que 58 % de la longueur de la plage, pour une superficie de 24 % de la superficie d'origine. Le dépôt se retrouve surtout sur la plage ou dans la zone intertidale supérieure, sous forme d'un pavement asphaltique où se retrouvent environ 60 % des hydrocarbures résiduels, ainsi que dans la partie inférieure de la zone intertidale sur des crêtes rocheuses. Sa composition semble la même qu'en 1985, de fortes concentrations d'hydrocarbures étant modérément altérées et de faibles concentrations forement altérées.

Les échantillons prélevés en janvier 1987 sur les lieux du déversement du Metula, en 1974, ont été analysés afin d'être comparés aux échantillons BIOS et aux échantillons prélevés en 1985 sur les lieux de la marée noire de l'Amoco Cadiz (1978). Certains échantillons renfermaient de fortes concentrations d'hydrocarbures. Certains de ces derniers étaient clairement des hydrocarbures pétroliers, tandis que d'autres renfermaient des fractions importants de matières naturelles. Les échantillons riches en matières pétrolières étaient à peu près aussi altérés que les échantillons BIOS très concentrés, même s'ils avaient été soumis pendant 12,5 années aux éléments du large, comparativement à une exposition de moins de 15 mois, dans le cas de l'expérience BIOS. Les échantillons des zones sablonneuses ou de substrats fins renfermaient le plus d'huile.

TABLE OF CONTENTS

PAGE

PAGE

LIST OF TABLES

LIST OF FIGURES

PAGE

1.0 INTRODUCTION

1.1 Objectives

The objectives of this project were to make observations and to collect data on stranded oil as a continuation of the shoreline component of the Baffin Island Oil Spill (BIOS) experiment that began at Cape Hatt in 1980. The field investigation involved resampling and resurveying in August 1987 of (a) oiled control and countermeasure plots at two sites in the "Z-lagoon" area and (b) the beach at "Bay 11" in Ragged Channel. Observations and measurements were made and samples of contaminated sediments were collected systematically in order to provide a data set that would be comparable with previous field studies at these sites. The samples were later analysed chemically to determine total extractable hydrocarbon concentrations and to evaluate the degree to which the oil had been weathered.

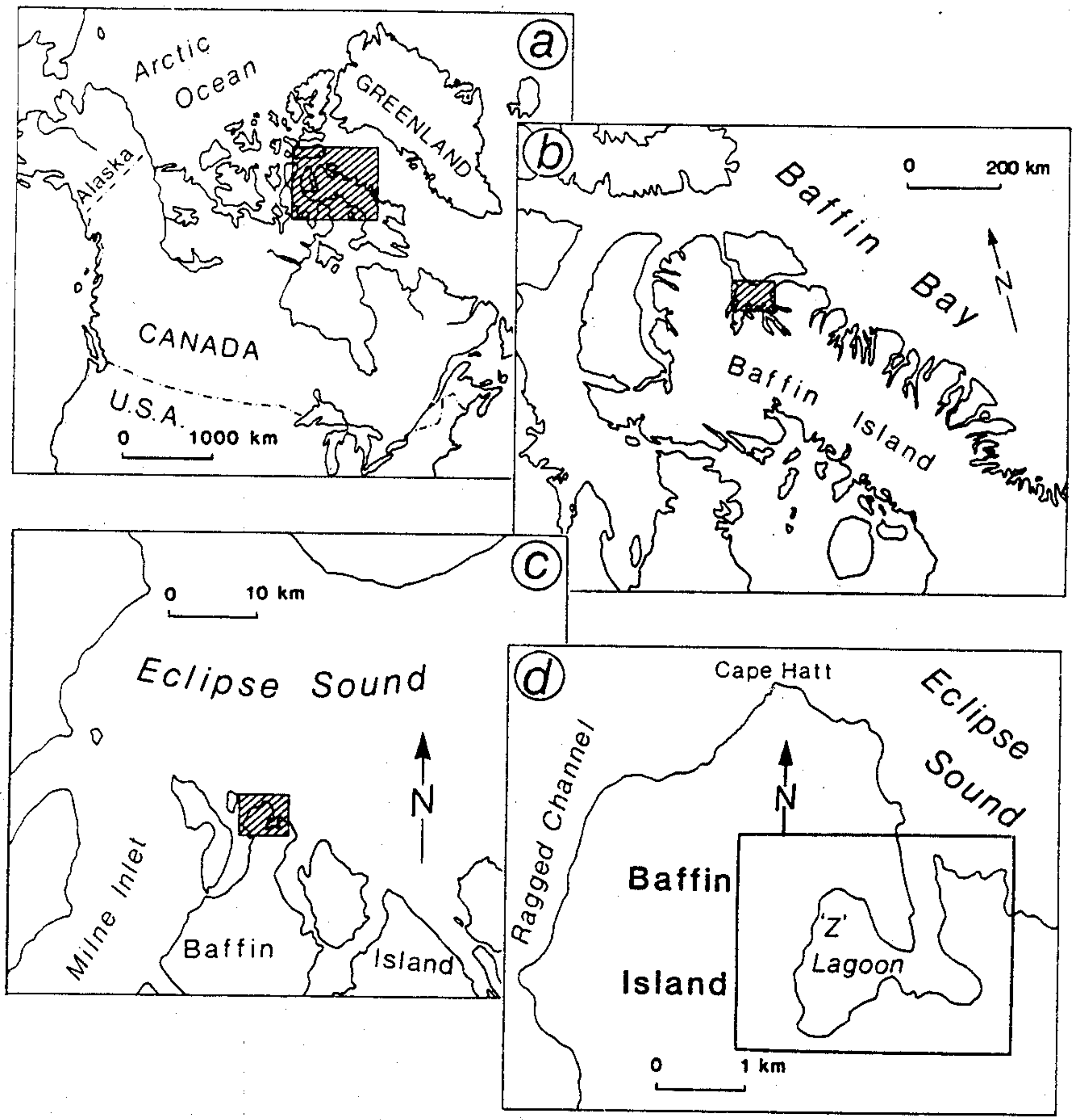
The observations and data collected since 1980 provide long-term results on the fate of stranded oil. These results can be compared with observations and data from real-world spill situations and, as a separate part of the overall program, field visits had been made to the "Amoco Cadiz" spill site in March 1985 (Owens and Robson, 1985; Owens, Robson and Humphrey, 1986) and to the "Metula" spill site in January 1987 (Owens and Robson, 1987a). These related projects involved observations and the collection of samples of oil that had been stranded for 7 and 12.5 years respectively.

1.2 Study Site

1.2.1 Cape Hatt Area

The shoreline component of the BIOS project was conducted on a number of beaches in the vicinity of Cape Hatt, northern Baffin Island, N.W.T. (72°31'N: 79°50'W) (Figure 1.1). Control and countermeasure plots were established in the intertidal zone in 1980, 1981 and 1982 and on the backshore in 1980 and 1982 on beaches in the "Z-lagoon" area on the east

Figure 1.1 Location of Cape Hatt and "Z-lagoon" Study Area.



coast of Cape Hatt (Figs. 1.1 and 1.2). As part of a separate study a nearshore release of 15 m^3 of aged crude oil in Ragged Channel 1981 was allowed to strand on a beach located on the western coast of the Cape Hatt peninsula. This beach is designated as "Bay 11" (Figure 1.2).

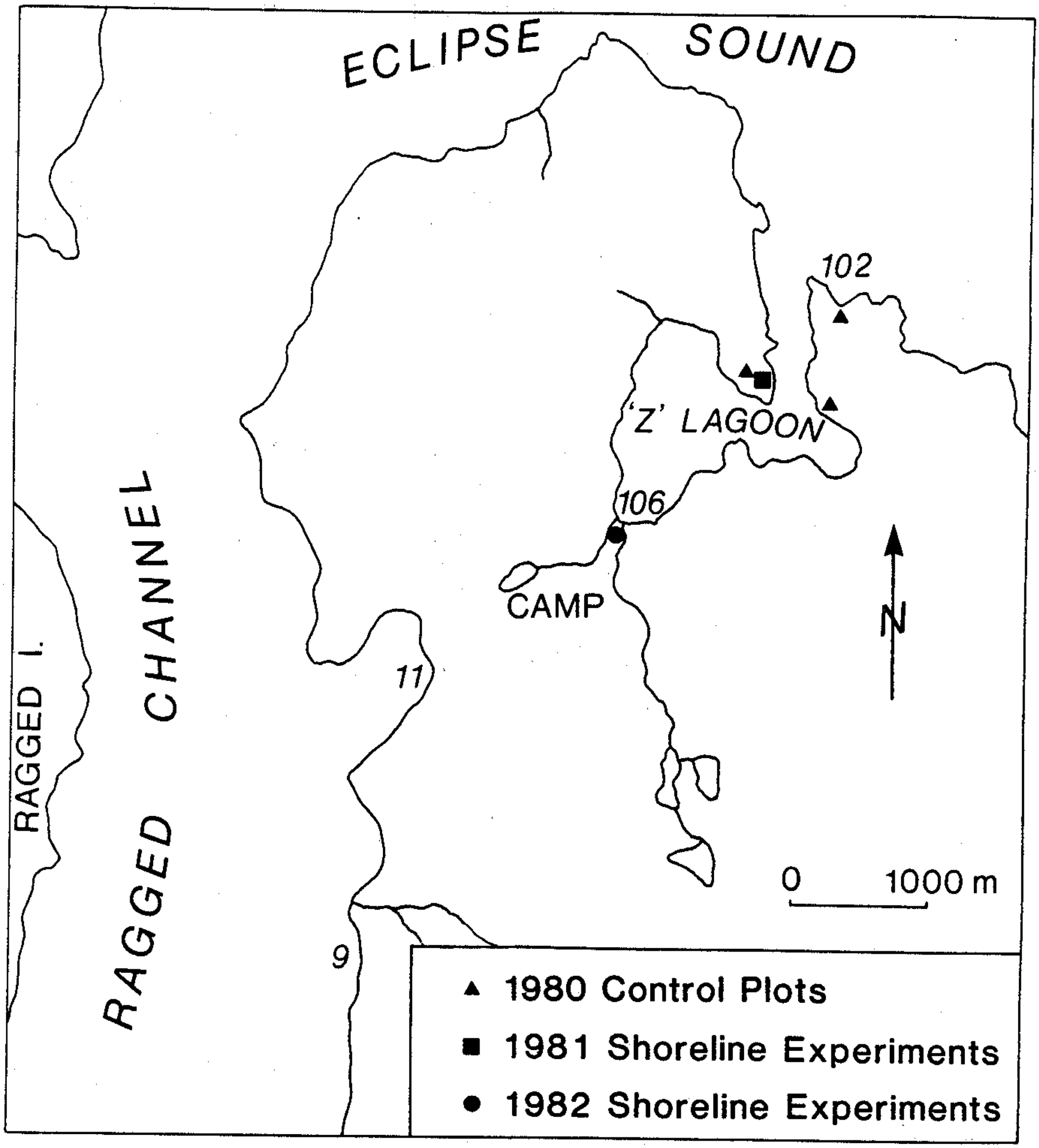
Tides in the Cape Hatt area are semi-diurnal and unequal in height and range between 1.0 m at neap and 2.0 m at spring tide (Buckley et al., 1987). This is an ice-dominated marine environment which has an average summer open-water season of 63 days per year (late July - early October), which may vary from as little as 35 days to a maximum of 90 days (Dickins, 1987). The intertidal zone is encapsulated by an ice foot and is therefore inactive, in terms of physical environmental processes (i.e. winds, waves, and tides), for much of the year. The intertidal areas are biologically barren, as is common in the Arctic.

1.2.2 Z-lagoon

This large embayment on the east coast of the Cape Hatt peninsula was selected for a series of shoreline experiments as it was sufficiently distant from the nearshore experiments in Ragged Channel to preclude cross-contamination and because it provided a number of suitable beaches with a range of wave-energy levels. The two beach sites in the "Z-lagoon" area which were resampled in 1987 were: (i) the backshore aged oil and emulsion control plots at "Crude Oil Point" (T1 and T2 respectively), which were laid down in 1980; and (ii) the backshore aged oil (IMC) and emulsion (IME) control and countermeasure plots at "Bay 106" (Figure 1.2), which were laid down in 1982. The Bay 106 countermeasure plots had been mixed by a roto-tiller in 1982 to evaluate if this mixing process would affect the rate and degree of weathering of the oils.

The Crude Oil Point plots were established on a low-angle slope ($<5^0$) about 0.5 m above the limit of wave activity. They have not been subject to marine processes and therefore provide a non-marine environment control reference for the intertidal data. Each plot is 40 m^2 in area at a location that is characterized by sandy gravel sediments which have a thin surface lag deposit of shingle.

Figure 1.2 Location of Beach Sites in "Z-lagoon" Area and Bay 11.



The Bay 106 plots were laid down above the beach berm, but below the upper limit of marine processes, to replicate oil that would become stranded at a very sheltered location during a period of spring tides and/or a storm surge. These plots could therefore be affected by marine processes only at the infrequent times of such events. The maximum fetch of Bay 106 within Z-lagoon is on the order of 1500 m, so that the plots would be affected only by small waves that could be generated during the short summer open-water season in this very sheltered environment. The berm sediments are pebble-cobble and grade into fine-grained sands on the backshore section of the plots.

1.2.3 Bay 11

This beach site, which is on the eastern shore of the Ragged Channel fjord (Figure 1.2), is exposed to waves with a fetch of less than 10 km and is subject to low wave-energy levels during the open-water season (wave heights usually less than 10 cm). No long-term wind data are available but observations indicate that the prevailing winds during the open-water season are from the northwest quadrant (Meeres, 1987). The beach is sheltered from the north and open to waves through a 60° arc between southwest and west-northwest and to refracted waves from the northwest. Over the 6-year period covered by the study (August 1981 to August 1987) the beach would have been ice-free, and therefore exposed to physical coastal processes, for a maximum of approximately 15 months. The beach is defined by two bedrock outcrops about 400 m apart and the intertidal width varies to a maximum of 50 m. A gravel-cobble ridge (an incipient boulder barricade) characterizes the lower intertidal zone and gives way landward to a trough or runnel of silt and sand. The upper intertidal zone has a sand-gravel beach face with a low cobble berm at the high-water mark. From the beach, the nearshore sea bed slopes at about 4 degrees and the poorly sorted fine-grained sediments have a mean size of 3.4ϕ (approx. 0.075 mm).

1.3 Previous Investigations and Reports

The BIOS Project was a large multi-disciplinary study conducted between 1980 and 1983 (Sergy and Blackall, 1987). The Shoreline Component of the project involved a series of studies over that period to evaluate selected countermeasure techniques and to monitor the fate of stranded oil. All of the studies used an aged Lagomedio crude oil and the experimental design of the different phases of the shoreline program is discussed by Owens and Robson (1987b). Following the BIOS investigations, conducted in 1980, 1981, 1982, and 1983, a further field study funded by the Environmental Studies Research Fund was conducted in 1985 to resurvey and resample the shoreline sites (Owens, Hope and Humphrey, 1986; Owens et al, 1986).

Intertidal and backshore control plots were established at three locations in the Z-Lagoon area in 1980 and shoreline countermeasure experiments were conducted in 1981 at "Crude Oil Point" (COP) and in 1982 at "Bay 106". The results of this set of investigations are summarized by Owens and Robson (1987b) and by Owens, Robson and Foget (1987).

At the Bay 11 site, the fate of 15 m^3 of the aged crude oil that was released in 1981 onto the surface of the nearshore water was monitored, in terms of concentrations and composition changes, in four major environmental components: the water column (Humphrey et al., 1987b); the intertidal beach sediments (Owens et al., 1987a: 1987b); the subtidal sediments (Boehm et al., 1987); and the tissue of selected benthic invertebrates (Humphrey et al., 1987a). Biodegradation of oil was monitored in the intertidal (Eimhjellen and Josefson, 1984) and in the subtidal sediments (Bunch and Cartier, 1984). The migration of oil from the beach into the subtidal sediments is considered by Owens, Sergy and Humphrey (1987).

The results from each of field investigations in the shoreline component and a discussion of the analytical results that are pertinent to this part of the BIOS project are presented as a series of unpublished reports and are listed in Table 1.1. Certain aspects of the shoreline program have been discussed in other publications:

(1) estimates of shoreline contamination: Owens, 1984b; 1987

(2) asphalt pavement formation: Owens, Robson and Humphrey, 1986; 1987.

Data collected from other spill sites as part of the overall program have been reported as follows:

(i) "Amoco Cadiz": Owens and Robson, 1985; Hope and Humphrey, 1986; Owens, Robson and Humphrey, 1986

(ii) "Metula": Owens and Robson, 1987a; Owens, Robson and Humphrey, 1987.

As this project has progressed it has been necessary to re-evaluate some of the preceding results. If any discrepancy is found between data sets or interpretations, then the most recent should be considered to be correct.

Table 1.1 List of Unpublished Annual Project Reports

(a) Shoreline Studies	- 1980:	Woodward-Clyde Consultants, 1981
	- 1981:	Owens, Harper and Foget, 1982
	- 1982:	Owens, Harper and Foget, 1983
	- 1983:	Owens, 1984a
	- 1985:	Owens, Hope and Humphrey, 1986
(b) Chemistry	- 1980:	Green, 1981 Boehm, 1981
	- 1981:	Green, Humphrey and Fowler, 1982 Boehm, Fiest and Hirtzer, 1982
	- 1982:	Humphrey, 1983 Boehm, 1983
	- 1983:	Humphrey, 1984 Boehm et al., 1984
	- 1985:	Owens, Hope and Humphrey, 1986

2.0 METHODS

2.1 Application or Release of the Oil

2.1.1 Z-lagoon Backshore Plots

Two forms of the same oil were used throughout the program: a Lagomedio crude oil that was artificially aged (8% by weight)(Dickins, Thornton and Cretney, 1987) and 50% water-in-aged crude oil emulsion. The emulsion was prepared on-site by recirculating a mixture of two barrels of sea water with two barrels of the aged crude oil through a pump and tank until the desired emulsion was created. Each four-drum batch of emulsion was labeled and, in an attempt to reduce the number of variables, only oil from the same batch was used on any single plot. A sample was collected for GC analysis from each batch of crude oil and emulsion prior to application. The emulsion was stable over a number of days. On one occasion, in 1983, an attempt was made to re-emulsify two drums of emulsion which had been made up the previous year. The emulsion had broken and intensive mixing did not cause the materials to re-emulsify.

Oil was applied to each plot as described below in a relatively even coating, to a thickness of 1cm for the aged crude oil and to a thickness of 2 cm for the water-in-oil emulsion, in order to approximate a large oil spill stranded on the shoreline. A lined trough was prepared at the base of each plot, prior to application of the oil, to collect any oil that would run down slope off the plot. In addition, plastic drip mats were located at the end of each plot to prevent contamination outside the designated plot area.

The application system consisted of an oil drum, mounted on the back of an All-Terrain Vehicle (ATV), which was connected by hoses and by a pump to an oil distribution pipe mounted on the rear of the ATV. The ATV traversed the test plot and oil was distributed behind the vehicle over a 2 m wide swath. The speed of the vehicle was determined by the calibrated flow rate (3.1 litres per second; 14 Imperial gallons per minute) necessary to cover the plot with a 1 cm thickness of crude oil and 2 cm of the emulsified oil (Woodward-Clyde Consultants, 1981; Owens, Harper and Foget, 1982).

2.1.2 Bay 11 Nearshore Release

On 19th August, 1981, approximately 15 m^3 of Lagomedio crude oil, which had been weathered artificially (8% by weight), was discharged onto the water surface adjacent to the shoreline of Bay 11 (Dickins, Thornton and Cretney, 1987). The period of discharge (15:40 to 21:40 hours) coincided with the ebbing tide. The oil slick was carried to the shoreline by a prevailing onshore breeze and was contained within a boom that was attached to the north and south ends of the bay. At the end of the discharge period (which was low tide), operations commenced to remove oil which had not stranded on the beach from the water surface by skimming and sorbents. Removal of oil from the water surface continued from the evening of 19th August to 16:00 on 21st August, when it was decided that there was insufficient refloating of oil from the shoreline to continue operations. Four complete tidal cycles had elapsed by this time. A total of 58 drums of oil and water-in-oil emulsion, or approximately 5.5 m^3 of oil, was recovered from the water surface. The estimated loss by dissolution during the discharge is 0.26 m^3, to evaporation during discharge is 1.95 m^3, and to evaporation over the subsequent 48-hour period is 0.45 m^3 (Dickins, Thornton and Cretney, 1987). On this basis about 6.8 m^3 of oil contaminated the adjacent beach.

2.2 Field Observations and Measurements

Field surveys were conducted in July/August 1980 in the Z-lagoon area and in July/August 1981, August 1982, August 1983, August 1985 and August 1987 in both the Z-lagoon and Bay 11 areas. During each survey colour slides were taken of the plots and of the intertidal areas and each year aerial colour photographs were taken from a helicopter.

Surveys of the distribution of surface oil on the intertidal zone at Bay 11 were conducted along a series of 19 transect lines, set 20 m apart along shore perpendicular to the shoreline. The lines were marked by backshore stakes so that repetitive surveys could be conducted. Visual observations to record the percent oil cover to the nearest 5% were taken at a 2-m interval along each profile, each observation therefore represents 40 m^2. From this data the observations were grouped into five major categories (no visible oil, 0%: light cover, 5 - 20%: light to moderate cover, 25 - 45%: moderate to heavy cover, 50 - 70%: and heavy cover, 75 - 100%). The data collected in 1983, 1985 and 1987 used pacing, rather than taping which was used in 1981 and 1982, to measure distances along the transect lines. Cross checking by two independent observers in 1983 established the repeatability of the technique to be on the order of ±5% (Owens 1984b). In both 1985 and 1987 the visual observations were made by two independent observers. As an indication of the good agreement achieved each year, in 1987 observer 'A' recorded a total oiled area of 2320 m^2 and a total of 11 values for oil cover >50%, whereas observer 'B' recorded a total oiled area of 2240 m^2 and 11 values for oil cover >50%.

The length of the Bay 11 intertidal shoreline where visible oil is present is determined from the mapped data. This provides a simple measure of the extent of shoreline contamination. The grouped data are used to provide a measure of the area and degree of contamination.

A second stage description of the degree of contamination on the Bay 11 shore is provided by the Equivalent Area of 100% Oil Cover (EA), which is obtained by integrating the per cent oil cover with the area. Thus a total of 9 observations (equal to an area of 360 m^2) with a 10% oil-cover would provide an EA value of 36 m^2, and 5 observations (equal to an area of 200 m^2) of 80% would give an EA value of 160 m^2. The EA for each set of observations is obtained by summing the 21 individually calculated values.

The Average Surface Oil Cover for the contaminated area of the Bay 11 beach is obtained by division of the EA value by the total oiled area value.

In addition to the systematic ground measurements at Bay 11, visual estimates of the total oil cover on the beach were made in 1983, 1985 from (a) a helicopter flying at approximately 100 m elevation and each year from (b) a rock outcrop at the northern end of the study beach, approximately 5 m above the high-water mark. No aerial estimates were made in 1987 due to the presence of large amounts of stranded ice in the intertidal zone at the time of the overflight.

2.3 Sample Collection

Sediment samples up to 2.4 L in size, or subsamples that were composited later with a total volume of between 2 and 2.5 L, were collected from the surface (top 2 cm) and the subsurface (5 to 10 cm depth) of the plots and of the intertidal beach. All of the samples were analyzed for total extractable hydrocarbons to determine the oil-in-sediment concentration and selected samples were analyzed for composition by gas chromatography.

2.3.1 Z-lagoon Backshore Plots

The pattern of sample collection varied from plot to plot and from year to year. Surface and subsurface samples were collected from the Crude Oil Point backshore control plots (T1 and T2) on the day the oil was laid down (20 August 1980) and thereafter 2 days (22 August), 4 days (24 August) and 8 days (28 August) after the oil was laid down. Subsequent sampling took place on two occasions in 1981 and 1982, and on one occasion each in 1983, 1985 and 1987. The number of samples collected on each occasion and whether the sample was composited is indicated in Table 3.1.

At Bay 106 the first set of surface and subsurface samples were collected on 14 August 1982, the day after the oil was laid down, from the berm and the backshore parts of each of the backshore crude and emulsion plots (IMC and IME respectively). The next day one half of each plot was mixed and thereafter samples were collected from the berm and backshore parts of each of the unmixed (IMC-e and IMC-e) and mixed (IMC-c and IME-e) sections later the same day (15 August), one week later (22 August), one month later (15 September), an on one occasion each in 1983, 1985, and 1987.

Table 2.1 Diagnostic weathering ratios.

RATIO	DEFINITION	LAGOMEDIO Fresh	LAGOMEDIO Aged	METULA Fresh
ALK/ISO	Sum(nC14-18) / Farn+TM13+Nor+Pris+Phyt	2.4	2.5	
SHWR	Sum(nC12-25) / Sum(nC17-25)	2.9	2.3	
AWR	All benzenes, naphthalenes, fluorenes, phenanthrenes and dibenzothiophenes (DBTs) / phenanthrenes and DBTs	4.3	3.5	
CPI	2*(nC27+nC29) / nC26+2*nC28+nC30	1.0	1.0	1.0
PRIS/PHYT	Pristane/Phytane	0.9	0.7	
C18/PHYT	nC18/Phytane	1.6	1.6	

2.3.2 Bay 11 Intertidal Beach

Samples were taken on three occasions in 1981 (one day, one week, and three weeks after the release) and on one occasion in each of the 1982, 1983, 1985 and 1987 field surveys. A surface and a subsurface sample was collected along each of 3 beach profiles in 1981 and 4 profiles in 1982, 1983, 1985 and 1987 from the lower, middle and upper one-third of the intertidal zone. This sample set was intended to provide data on changes in the total hydrocarbon (t-h) content of the sediments through time. In 1983, 1985 and 1987 additional samples were collected to provide data on specific features, in particular the asphalt pavement that had formed by 1983.

2.3.3 Bay 11 Subtidal Samples

Since 1981, subtidal sediment samples have been collected from the area adjacent to the beach in Bay 11. Up to 1983, these samples were collected by divers and corresponded to the benthic study transects (Boehm et al 1987). In 1985 and 1987 the samples were collected by Ponar grab from a rubber boat.

2.4 Sample Analysis

2.4.1 Total Extractable Hydrocarbons

The total hydrocarbon analysis by infra-red spectrophotometry consisted of a solvent extraction, using Freon 113, followed by measurement of a CH_2 absorbtion at 2850 cm^{-1}. The detection limit was 30 $mg{\cdot}kg^{-1}$, with a precision at low concentrations of 10 $mg{\cdot}kg^{-1}$ and of 1% at high concentrations. Sampling accuracy and the validity of the analytical results are discussed by Humphrey (1984) and by Owens and Robson (1987).

The results were grouped into data sets and 't-tests' were run to determine the statistical significance of (a) changes between successive data sets from the same plots or areas, or (b) the differences between paired plots from the same year (see Section 2.7).

2.4.2 Gas Chromatography

Extraction, fractionation and analysis of the samples was based on the method of Brown et al. (1979). Gas chromatography with flame ionization detection (GC/FID) was used to quantify the n-alkanes and isoprenoids, whereas selected parent and alkylated benzenes and polynuclear aromatics were quantified by gas chromatography with mass spectrometry (GC/MS).

Two types of alkane analyses were performed: for the shoreline samples, a compositional analysis was performed. Rather than quantify all components of the analysis, the individual compounds were assigned relative concentrations, using nC-20 (twenty carbon normal alkane, against which other peaks are determined) as the standard. For the subtidal sediments, each component was quantified using internal standards.

2.5 Bay 11 Intertidal Surface Oil Budget Computations

2.5.1 Volume of Oil

Two methods were developed to calculate the volume of surface oil on the beach. The first method is based on changes in the distribution of the surface oil cover, whereas the second involves use of the total-hydrocarbon data and the total oiled area.

The first, and more simplistic approach, uses the initial volume of stranded oil and relates this to changes in the EA value. A change in the Equivalent Area (EA) value from one data set to the next is considered to reflect a change in the volume of surface oil (top 2 cm) on the beach. Thus, if the EA value is reduced by half between two surveys, the volume of surface oil is assumed also to have halved over that same time interval. The initial surface oil volume estimate of 5.3 m^3 on 19 August 1981 and the Equivalent Area of 100% Oil Cover of 4850 m^2 on 26 August 1981, are the baselines for this method.

The second ("Volume") method integrates the total-hydrocarbon concentrations with the oil distribution data. The total area of the oiled beach, 8,570 m^2 in August 1981, is multiplied by the sample depth of 2 cm to give a volume of the oiled beach surface at the time of 171.4 m^3. The weight of the surface beach material, to 2 cm depth, is a product of the volume times the assumed density of the beach sediments (1.6); 274 metric tonnes or 274,000 kg. As the mean oil concentration is 17,400 $mg \cdot kg^{-1}$ on 19 August 1981, and as there are 274,000 kg of sediment, multiplication gives 4,772 kg of oil on the beach on that date. Using a density of 890 $kg \cdot m^3$ for the oil, this converts to a volume of 5.3 m^3 of oil on the beach surface on 19 August 1981.

Calculations for volumes of the asphalt pavement use a depth of 5 cm, which corresponds to the observed thickness of the pavement.

2.5.2 Volume of Contaminated Sediments

A simple volume can be calculated by multiplying the total area with an oil cover by the depth of contamination. This value reflects the total volume of oil-contaminated sediments that would have to be removed and disposed if the beach were to be cleaned. For example, in 1985 the calculation, assuming an average oil depth of 10 cm, produces an estimated volume of contaminated sediments of 440 m^3. The depth of 10 cm is used as this is taken to be the minimum average depth of sediment that could be removed by manual or mechanical techniques. This volume is therefore the cleanup volume rather than an actual oil concentration volume.

A second method is used to estimate the actual volume of contaminated surface material and includes a weighting factor that is related to the distribution of oil. This Equivalent Area (EA) method involves multiplication of the 100% EA value by the assumed depth of oil penetration (2 cm: see discussion of "Volume " method in 2.5.1 above) to produce a volume of 24 m^3 in 1985.

2.6 Weathering Ratios

Three diagnostic ratios were used to describe weathering (Table 2.1). Biodegradation is indicated by the Alkane-Isoprenoid Ratio (ALK/ISO) which approaches 0 as the n-alkanes are preferentially depleted. Evaporative weathering is indicated by the Saturated Hydrocarbon Weathering Ratio (SHWR), which approaches 1.0 as low-boiling point saturated hydrocarbons (n-C_{10} to n-C_{17}) are lost by evaporation. The Aromatic Weathering Ratio (AWR) approaches 1.0 as low-boiling point aromatics are lost by evaporation and/or dissolution (Boehm et al., 1987).

2.7 Statistical Analysis of Results

A series of t-tests were conducted in order to examine the results of the sample analyses and to determine if differences in the means of sample sets through time are statistically significant. The data were grouped into sets, usually an annual sample set from each plot or area, and both F-tests and t-tests were run using SPSS/PC software (SPSS Inc. 1984) to compute the equality of variances and of means respectively. Two examples of output from the program are given in Tables 2.2 and 2.3, which compare surface sample total hydrocarbon results from the 1980 backshore crude oil control plot (T1). In the first example (Table 2.2), a data set of all values from eight composite samples collected in 1980 (Group 1) is compared to four composite samples obtained in 1981-1982 (Group 2) to test if the two could have come from the same population. The second example (Table 2.3) compares the same 1981-1982 data set (Group 1 in this data set) with eight individual samples collected in 1983 and 1985 (Group 2) (see also Tables 3.1 and 3.2). The null hypothesis states that the two sample sets come from the same population; if this is rejected then it is assumed that the two sample sets come from different populations.

In the method used in this software an F-test is initially applied to the two population variances. If the F-test shows that the significance level is less than 95% (i.e. a value greater than 0.05 on the "two-tail probability" column) then the hypothesis that the population variances are equal is rejected and the "separate variance estimate" 't' value is used. If the significance level for the F-test is greater than 95% it is accepted that the data sets are from the same population and the "pooled variance estimate" 't' value is considered appropriate and used. The purpose of this preliminary test is to evaluate whether sample variances are

Table 2.2 Example of t-test for 1980 (Group 1) versus 1981-1982 (Group 2) T1 surface sample total hydrocarbon results.

Group 1: GRP EQ 1 t-test for: THC		Group 2: GRP EQ 2					
		Number of cases	Mean	Standard Deviation	Standard Error		
Group 1		8	49362.5	19683.8	6959.3		
Group 2		4	29850.0	2771.9	1385.9		
		Pooled Variance Estimate			Separate Variance Estimate		
F Value	2-Tail Prob.	t Value	Deg. of Freedom	2-Tail Prob.	t Value	Deg. of Freedom	2-Tail Prob.
50.43	0.008	1.93	10	0.083	2.75	7.54	0.027

Table 2.3 Example of t-test for 1981-1982 (Group 2) versus 1983- 1985 (Group 3) T1 surface sample total hydrocarbon results.

Group 1: GRP EQ 2 t-test for: THC		Group 2: GRP EQ 3					
		Number of cases	Mean	Standard Deviation	Standard Error		
Group 1		4	29850.0	2771.9	1385.9		
Group 2		8	12262.5	4362.2	1542.3		
		Pooled Variance Estimate			Separate Variance Estimate		
F Value	2-Tail Prob.	t Value	Deg. of Freedom	2-Tail Prob.	t Value	Deg. of Freedom	2-Tail Prob.
2.48	0.490	7.27	10	0.000	8.48	9.07	0.000

sufficiently alike to support the assumption that they are from the same population and it is particularly valuable when a relatively small number of samples is involved.

The F-test in the example in Table 2.2 indicates that there is a 0.008 (or 99.2%: which is definitely significant, see Table 3.3 for definitions of levels of significance) probability that the variances are similar and the calculated value of 1.93 for the pooled variance is taken. In the second example (Table 2.3) the probability value is 0.490 (i.e. only 49%: or not significant likelihood that they are from the same population) and a separate variance value of 8.48 for 't' is used.

The t-test for the example in Table 2.2 indicates a 0.083 (greater than 90% but less than 95%) probability that the two sample sets are from the same population. By comparison, the results from the second example (Table 2.3) show a confidence greater than 99.5% that the sample sets are from the same population.

3.0 1980 BACKSHORE CONTROL PLOTS

3.1 Results 1980 to 1985

3.1.1 Total Extractable Hydrocarbons

The surface oil on both of the plots had a dark gray, weathered appearance by 1985, but the subsurface oil was black and still relatively fresh in appearance.

The total hydrocarbon concentrations in the surface sediments on the aged crude plot (T1) for the period 1980 to 1985 indicate that there had been a reduction in the amount of oil in these sediments (Table 3.1). The highest single sample value in 1985 (19,900 $mg{\cdot}kg^{-1}$) was lower than all of the individual sample values for the period 1980 to 1982 (Table 3.2a). A statistical test on the data indicates that, although the change between the 1980 and the combined 1981-82 data sets is probably significant, the change between the 1981-82 and the 1983-85 results is highly significant (Table 3.2b). The highest single sample value is one of 85,300 $mg{\cdot}kg^{-1}$, collected from the T1 plot on 22 August 1980.

The t-h concentrations of the subsurface sediment samples on T1 were initially (1980) about half the surface sediment values (Table 3.1) and progressively decreased so that by 1985 the highest single value (11,100 $mg{\cdot}kg^{-1}$) was lower than that of any previous individual sample from 1980 to 1982. The more significant reduction occurred between the 1981-82 and 1983-85 data sets, rather than in the period immediately following the oiling between 1980 and 1981-82, as was also the case for the surface sediments on this plot (Table 3.3b).

The surface oil-in-sediment concentrations on the emulsion plot (T2) were initially much lower than those on the crude oil plot and remained in the same range over the period 1980 to 1985 (Tables 3.1 and 3.2). The data show no evident or statistically valid trends.

Table 3.1 Total Extractable Hydrocarbon Content of 1980 Backshore Control Plot Samples (mg kg^{-1})

DATE	1980				1981		1982		1983	1985	1987
PLOT	20 Aug⁺	22 Aug⁺	24 Aug°	28 Aug°	28 July°	29 Aug°	10 Aug°	2 Sept°	20 Aug*	11 Aug*	11 Aug*
T1 (C) sf	40,100	58,300	33,800	65,800	28,400	34,000	28,300	28,700	8,775	15,750	27,000
sb	23,200	30,000	35,000	17,100	24,300	21,000	15,800	14,700	9,475	5,450	17,250
T2 (E) sf	13,100	19,700	12,700	60,000	14,400	16,000	16,700	17,800	22,500	10,675	26,250
sb	15,400	27,100	13,300	58,100	20,600	18,000	16,800	13,500	5,917	6,225	16,250

C: Crude Oil plot
E: Emulsion plot

sf: surface samples
sb: subsurface samples

+ : Mean value of 3 composite samples
o : Value from one composite sample
* : Mean value of 4 samples

Table 3.2(a) Mean and Range of Total Extractable Hydrocarbon (t-h) Values (mg kg^{-1}): 1980 Backshore Control Plots, Surface Sediment Samples

	T1 - CRUDE CONTROL			T2 - EMULSION CONTROL		
YEAR	n	Mean	Range	n	Mean	Range
1980	8⁺	49,400	22,400 - 85,300	8⁺	21,400	9,400 - 60,000
1981-82	4⁺	29,900	28,300 - 34,000	4⁺	16,200	14,400 - 17,800
1983-85	8	12,300	6,400 - 19,900	8	16,600	5,200 - 28,000
1987	4	27,000	19,000 - 39,000	4	26,250	19,000 - 40,000

+ composite samples

Table 3.2(b) Results of Statistical Tests (Student's t test) on t-h data to Evaluate Level of Confidence in (1) Change between Successive Surface Sediment Data Sets and (2) Similarity between the Surface Sediments on the 1980 Crude and Emulsion Control Plots

	(1): T1 - CRUDE CONTROL		(1): T2 - EMULSION CONTROL		(2) SIMILARITY BETWEEN PLOTS
DATA SET	n	Level of Confidence of Change	n	Level of Confidence of Change	level of confidence
1980	8⁺		8⁺		>99.5% ***
		95% *		70% o	
1981-82	4⁺		4⁺		>99.5% ***
		>99.5% ***		<50% o	
1983-85	8		8		90% o
		97.5% **		90% o	
1987	4		4		<50%
1980 vs 1987		97.5% **		70% o	

+ composite samples
o change between successive data sets not significant: difference between plots not significant
* change between successive data sets probably significant: difference between plots probably significant
** change between successive data sets definitely significant: difference between plots definitely significant
*** change between successive data sets highly significant: difference between plots highly significant

Table 3.3(a) Mean and Range of Total Extractable Hydrocarbon (t-h) Values (mg kg^{-1}): 1980 Backshore Control Plots, Subsurface Sediment Samples

	T1 - CRUDE CONTROL			T2 - EMULSION CONTROL		
YEAR	n	Mean	Range	n	Mean	Range
1980	8^{+}	26,500	16,500 - 56,200	8^{+}	24,900	9,100 - 58,000
1981-82	4^{+}	19,000	14,700 - 24,300	4^{+}	17,200	13,500 - 20,600
1983-85	8	6,000	1,100 - 11,100	8	6,070	570 - 12,600
1987	4	17,250	11,000 - 26,000	4	16,250	12,000 - 24,000

\+ composite samples

Table 3.3(b) Results of Statistical Tests (Student's t test) on t-h data to Evaluate Level of Confidence in (1) Change between Successive Subsurface Sediment Data Sets and (2) Similarity between the Subsurface Sediments on the 1980 Crude and Emulsion Control Plots

	(1): T1 - CRUDE CONTROL		(1): T2 - EMULSION CONTROL		(2) SIMILARITY BETWEEN PLOTS
DATA SET	n	Level of Confidence of Change	n	Level of Confidence of Change	level of confidence
1980	8^{+}		8^{+}		<50% o
		80% o		70% o	
1981-82	4^{+}		4^{+}		70% o
		>99.5% ***		>99.5% ***	
1983-85	8		8		<50% o
		97.5%**		97.5%**	
1987	4		4		<50% o
1980 vs 1987		90% o		80% o	

\+ composite samples
o change between successive data sets not significant: difference between plots not significant
* change between successive data sets probably significant: difference between plots probably significant
** change between successive data sets definitely significant: difference between plots definitely significant
*** change between successive data sets highly significant: difference between plots highly significant

The t-h results from the subsurface samples on T2 are very similar to those from T1 in terms of the magnitudes of both the mean and range of values and in terms of the apparent reduction in the concentrations over the study period.

The statistical tests on the surface sediment data support the fact that the two plots were significantly different up to and including 1982, with considerably higher t-h concentrations on the crude plot (T1). The progressive reduction in surface t-h values on T1 after the 1980 field season resulted in the mean and range of values being on the same order as the T2 plot by 1983-85. By contrast, the subsurface t-h concentrations on the two plots were initially similar and subsequently decreased in a similar manner through time.

3.1.2 Weathering Ratios:

The SHWR results for the surface sediment samples on both plots (Table 3.4a) show an initial lowering of values, and therefore active evaporative weathering, prior to the 1981 sampling. Thereafter the values have been relatively stable. No subsurface samples were analyzed in 1980, but the subsequent results suggest that evaporative weathering rates were slower when compared to the rates on the surface, in particular on the emulsion plot (T2) which appears to have been subject to relatively little change (note: the SHWR of the original batch of aged crude oil delivered to the study area is 2.28).

The ALK/ISO ratios of the surface and the subsurface sediment samples on both plots (Table 3.4b) appear to have reduced slowly over the study period. There is no evident difference in the ratios between the plots nor between the surface and subsurface sediments.

The few AWR ratios that were measured (Table 3.4c) indicate that by 1985 weathering on the surface and subsurface of T1 had progressed at a similar rate, whereas on T2 the subsurface sediments had weathered at a considerably slower rate than the surface sediments on both plots and the subsurface sediments on T1.

Table 3.4(a) Saturated Hydrocarbon Weathering Ratio (SHWR) Values from 1980 Backshore Control Plot Samples

	SURFACE							SUBSURFACE			
	1980 20 Aug	1980 28 Aug	1981	1982	1983	1985	1987	1981	1983	1985	1987
T1 Crude	2.2	2.2	1.6	1.6	1.1	1.6	1.4	1.7	1.8	1.9	2.2
T2 Emulsion	2.1	2.1	1.6	1.3	1.4	1.1	1.3	2.0	2.2	2.2	1.8

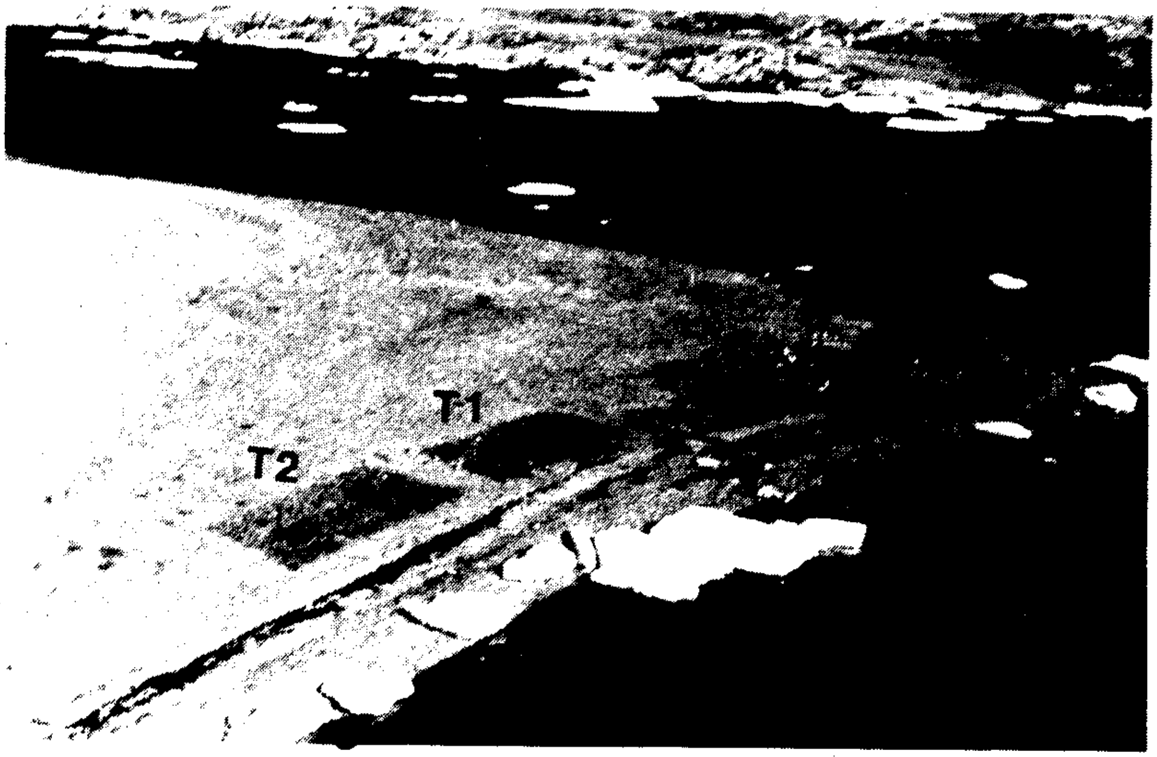
Table 3.4(b) Alkane/Isoprenoid Ratio (ALK/ISO) Values from 1980 Backshore Control Plot Samples

	SURFACE							SUBSURFACE			
	1980 20 Aug	1980 28 Aug	1981	1982	1983	1985	1987	1981	1983	1985	1987
T1 Crude	2.6	2.8	2.1	2.4	1.9	2.0	3.1	2.5	2.2	2.1	2.9
T2 Emulsion	2.6	2.6	2.4	2.4	2.2	1.8	3.1	2.6	2.2	2.3	2.9

Table 3.4(c) Aromatic Weathering Ratio (AWR) Values from 1980 Backshore Control Plot Samples

	SURFACE							SUBSURFACE			
	1980 20 Aug	1980 28 Aug	1981	1982	1983	1985	1987	1981	1983	1985	1987
T1 Crude	3.5	3.1	2.0	-	-	1.8	1.8	-	-	1.9	4.4
T2 Emulsion	-	-	3.1	-	-	1.3	1.9	-	-	2.7	2.4

Figure 3.1 Aerial view of T1 and T2 at mid-tide. 87-08-11



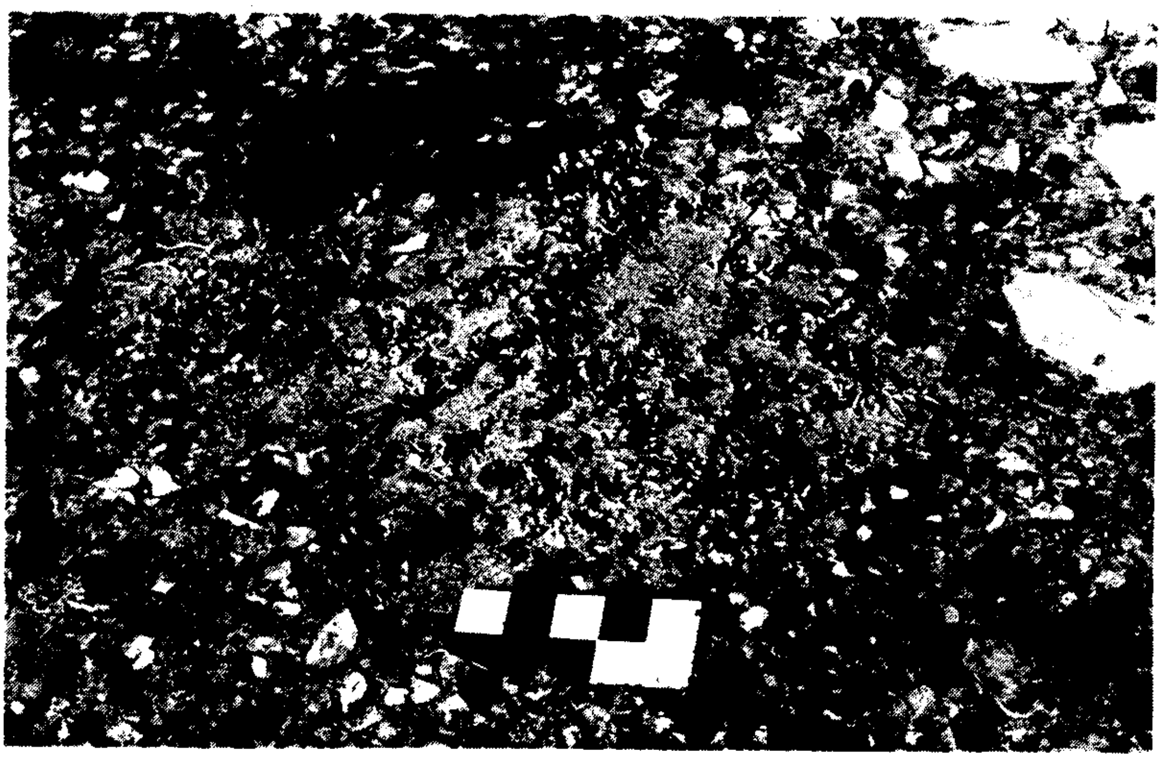


Figure 3.2 Ground view of the surface of T1. Note the arctic willow. The scale is 25 cm. 87-08-11

3.2 Results 1987

3.2.1 Total Extractable Hydrocarbons

The surface appearance of the oil had changed little since 1985, although the cover of wind-blown fine-grained sediment appeared to be greater (compare Figure 3.1 and 3.2 with Figures 2.2 and 2.3 in Owens, Hope and Humphrey 1986).

The total hydrocarbon results for the surface sediment samples on both plots (Tables 3.1 and 3.2) show individual and mean values that are higher than previous 1983 and 1985 values, but that are similar to 1981 and 1982 results. It is thought that these differences are due primarily to use of a predetermined sample location pattern that was set up in 1980 and that resulted in collection of the 1983-1985 sample set from sediments that were coarser than the 1981-1982 and 1987 samples. It is postulated that there has been virtually no change in the total hydrocarbon content of the surface sediments in the years since 1980. Differences from one set to another are thought to be due to a non-uniform sediment size distribution and are thus more an artifact of the sampling design rather than of actual changes in the oil content of the sediments.

Comparison of the results using a t-test shows that between the 1983-85 and the 1987 data sets there is a significant difference between the two on T1. The t-tests show also that there is a significant difference between the 1980 and 1987 data sets on the crude control plot (T1) (Table 3.2(b)), but not between the 1981-1982 and 1987 sets (not tabulated; pooled variance 2-tail probability value 0.553). The emulsion plot (T2) has apparently undergone little or no significant change over the entire study period. These results support the discussion of the previous paragraph. Comparison between the crude and emulsion plots shows that initially (1980 to 1982) the plot surfaces were significantly different in terms of the oil content, but after 1982 there was no significant difference between the plots. This can be attributed to the initial differences in the type of oil and the subsequent change in the character of the crude oil through time. Although the same quantities of oil were laid down on each plot, the emulsion had been physically mixed and had thus been artificially weathered and had lost a significant proportion of the lighter fractions.

The results described for the surface sediments are mirrored in the subsurface samples from both plots (Tables 3.1 and 3.3). Mean and individual values are higher than the 1983-85 data set and are at the same oil content levels as the 1981-82 data. On these plots at no time has there been any difference between the crude and emulsion data sets. The t-tests (Table 3.3(b)) indicate no significant change between the 1980 and 1987 data sets on both plots.

3.2.2 Weathering Ratios

The ratios calculated for the 1987 samples indicate that the degree of weathering has not changed over the two years since 1985. The SHWR is essentially the same, whereas the ALK/ISO ratio is higher. Indeed, this ratio indicates a less biodegraded oil in 1987 than in 1985. The AWR values also indicate little or no change in two years. The high t-h values noted above are consistent with the ratios: high concentrations of oil weather more slowly than do low concentrations, and any biodegradation which may be occurring is masked by the high concentration.

3.3 Discussion

The trends that were apparent in 1985 data are now thought to have been affected by the sampling pattern and that in reality there has been little or no change in the surface or subsurface oil content of the sediments after the 1980 data set. We recommend and propose to test the belief that the sample pattern, as set up prior to the first collection in 1980, has affected the post-1980 results. In the event that a further field visit is made to the site, this would be done by the collection of stratified samples, based on the observed distribution of surface sediments and the analysis of these samples would include grain size as well as chemical analyses.

There has been little change in the oil content through time, with the exception of an initial decrease in the reduction of the oil content of the T1 surface sediments as light fractions of the crude oil were weathered. The oil at this site has never formed a hard surface crust nor has it resembled an asphalt pavement. As this is also the case on the Bay 106 backshore control plots, it can be assumed that one of the elements necessary for the formation of an asphalt pavement is contact with (sea) water.

4.0 1982 EXPERIMENTS - BAY 106 EXPERIMENTS

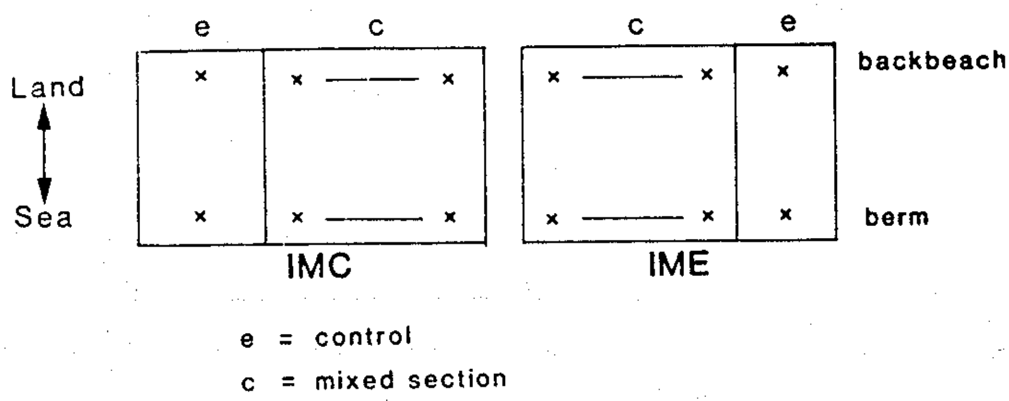
4.1 Results 1982 to 1985

4.1.1 Total Extractable Hydrocarbons

The surface t-h concentrations on both of the control plots (Figure 4.1) did not change significantly through time, although 3 of the 4 values obtained in 1985 were the lowest in the entire series (Tables 4.1 and 4.2a). The values from both of the mixed plots show a higher degree of uniformity and the mean values for the 1982 and 1983-85 data sets from both plots are virtually identical. The statistical test on the similarity between the paired crude and emulsion plots (Table 4.2b) indicates that there was a significant difference between the IMC control and IMC mixed plots in 1982, but not in the subsequent 1983-85 data set. The comparison between the IME control and IME emulsion plots shows some difference in 1982, but not one that is statistically significant. The conclusion drawn from the surface data is that the mixing activity was significant initially in reducing the t-h concentrations on the crude plot. The mixing process initially accelerated natural physical weathering processes, in particular on the crude oil plot, but over the study period the control plots exhibited the same reduction of t-h concentrations, albeit at a slower rate, so that the reduction by mixing on both plots was only a short-term effect.

The subsurface t-h concentrations on both of the control plots did not change significantly through time (Tables 4.1 and 4.3a). The berm concentrations are higher than those from the backbeach section of the plots in every case, often greater by an order of magnitude or more, due to the difference in sediment type that resulted in greater penetration of oil on the coarser berm sediments. This latter pattern is not evident on the two mixed sections of the plots as oil was forced into the subsurface sediments by the action of the roto-tiller. The t-h concentrations on both mixed plots were significantly reduced between the 1982 and 1983-85 data sets (Table 4.3b). The statistical test on the similarity between the

Figure 4.1 Location of Bay 106 Backshore Plots



Abbreviations:	I	Bay 106
	M	Backshore Mixing Experiment Plots
	C	Crude Oil
	E	Emulsion
	c	centre section - mixed
	e	end section - control

Table 4.1 (a) Total Extractable Hydrocarbon Results (mg kg^{-1}): 1982 Bay 106 Backshore Plot Sediment Samples

		SURFACE						
		1982				1983	1985	1987
		Pre-Test 14 Aug	Post-Test 15 Aug	22 Aug	15 Sept	20 Aug	10 Aug	11 Aug+
IMC	control berm	106,000	66,900	88,600	57,100	62,000	47,000	18,500
	control back beach	23,800	20,600	38,200	32,600	22,000	12,500	24,000
	mixed berm	56,500	23,200	18,700	31,100	31,000	25,900	12,700
	mixed back beach	24,200	12,700	14,500	18,200	11,000	12,500	10,350
IME	control berm	12,400	7,730	8,640	5,350	11,000	11,300	7,400
	control back beach	18,400	34,500	40,000	65,200	14,000	11,800	17,000
	mixed berm	17,100	9,270	13,800	8,510	7,400	24,200	8,500
	mixed back beach	42,200	12,300	24,800	16,700	11,000	15,300	10,950

+ Mean of two samples

Table 4.1 (b) Total Extractable Hydrocarbon Results (mg kg^{-1}): 1982 Bay 106 Backshore Plot Sediment Samples

		SUBSURFACE						
		1982				1983	1985	1987
		Pre-Test 14 Aug	Post-Test 15 Aug	22 Aug	15 Sept	20 Aug	10 Aug	11 Aug+
IMC	control berm	2,200	1,420	1,860	7,380	930	9,700	19,500
	control back beach	100	570	170	590	480	60	990
	mixed berm	7,010	-	26,900	22,500	2,300	6,200	14,200
	mixed back beach	270	8,400	9,400	7,510	4,500	1,800	5,600
IME	control berm	14,500	11,200	11,500	12,800	7,100	12,300	7,250
	control back beach	140	120	220	3,050	280	37	920
	mixed berm	17,900	12,600	7,670	11,500	7,800	9,400	8,300
	mixed back beach	360	11,900	15,100	15,100	5,500	7,300	7,220

+ Mean of two samples

Table 4.2(a) Mean of Total Extractable Hydrocarbon (t-h) Values (mg kg^{-1}): Bay 106 1982 Backshore Plots, Surface Sediment Samples

	IMC - CRUDE PLOT				IME - EMULSION PLOT			
	CONTROL		MIXED		CONTROL		MIXED	
YEAR	n	Mean	n	Mean	n	Mean	n	Mean
1982	10	51,500	6	19,700	10	25,200	6	14,200
1983-85	4	35,900	4	20,100	4	12,000	4	14,500
1987	4	21,250	4	11,525	4	12,200	4	9,750

Table 4.2(b) Results of Statistical Tests (Student's t test) on t-h data to Evaluate Level of Confidence in (1) Change between Successive Surface Sediment Data Sets and (2) Similarity between the Surface Sediments on the Bay 106 1982 Backshore Plots

	(1) IMC CONTROL		IMC MIXED		IME CONTROL		IME MIXED		(2): SIMILARITY BETWEEN	
DATA SET	n	Level of Confidence	n	Level of Confidence	n	Level of Confidence	n	Level of Confidence	IMC PAIR	IME PAIR
1982	10		6		10		6		97.5%**	90%°
		80%°		<50%°		80%°		<50%°		
1983-85	4		4		4		4		80%°	70%°
		80%°		90%°		<50%°		80%°		
1987	4		4		4		4		97.5%**	60%°
1982 vs 1987		95%*		95%*		95%*		90%°		

o change between successive data sets not significant: difference between plots not significant
* change between successive data sets probably significant: difference between plots probably significant
** change between successive data sets definitely significant: difference between plots definitely significant
*** change between successive data sets highly significant: difference between plots highly significant

Table 4.3(a) Mean of Total Extractable Hydrocarbon (t-h) Values (mg kg^{-1}): Bay 106 1982 Backshore Plots, Subsurface Sediment Samples

YEAR	IMC - CRUDE PLOT				IME - EMULSION PLOT			
	CONTROL		MIXED		CONTROL		MIXED	
	n	Mean	n	Mean	n	Mean	n	Mean
1982	10	2,160	5	14,900	10	7,180	6	12,300
1983-85	4	2,790	4	3,700	4	4,930	4	7,500
1987	4	10,245	4	9,900	4	4,085	4	7,760

Table 4.3(b) Results of Statistical Tests (Student's t test) on t-h data to Evaluate Level of Confidence in (1) Change between Successive Subsurface Sediment Data Sets and (2) Similarity between the Subsurface Sediments on the Bay 106 1982 Backshore Plots

DATA SET	(1) IMC CONTROL		IMC MIXED		IME CONTROL		IME MIXED		(2): SIMILARITY BETWEEN	
	n	Level of Confidence	n	Level of Confidence	n	Level of Confidence	n	Level of Confidence	IMC PAIR	IME PAIR
1982	10		5		10		6		>99.5 %***	90 %
		60%°		97.5%**		70%°		>99.5%***		
1983-85	4		4		4		4		60%°	70%°
		80%°		70%°		<50%°		<50%°		
1987	4		4		4		4		97.5%**	60%°
1982 vs 1987		95%*		60%°		80%°		80%°		

o change between successive data sets not significant: difference between plots not significant
* change between successive data sets probably significant: difference between plots probably significant
** change between successive data sets definitely significant: difference between plots definitely significant
*** change between successive data sets highly significant: difference between plots highly significant

paired crude and emulsion plots (Table 4.3b) indicates that there was a highly significant difference between the IMC control and IMC mixed plots in 1982, but not in the subsequent 1983-85 data set. The comparison between the IME control and IME emulsion plots shows some difference in 1982, but not one that is statistically significant. The conclusion drawn is that the mixing process initially caused an increase in subsurface t-h concentrations, in particular on the crude oil plot. The values on both mixed plots were significantly reduced in the subsequent data set and no statistical difference exists between the two sets of control and mixed plots in the 1983-85 data sets, so that the elevated subsurface t-h concentrations due to mixing were only a short-term effect.

4.1.2 Weathering Ratios

The surface sample SHWR values (Table 4.4a) show no major trends other than a reduction in the ratio on all plots after the 1982 data set. The subsurface ratios in 1983 were higher than those from the corresponding surface samples, with one exception (IME control, backbeach), and the ratios were lowered on the crude plots between 1983 and 1985, but remained high on the emulsion plots. The mixing activity had no apparent effect on the rate of evaporative weathering in the short- or long-term periods covered by these results.

The surface and subsurface sample ALK/ISO ratios (Table 4.4b) provide no major indication of biodegradation, except on the crude control plot surface which exhibits a trend similar to that obtained from surface of the Crude Oil Point backshore crude control plot over a similar 3-year period from 1980 to 1983 (Table 3.4b).

The few AWR values, obtained largely from the control plot samples (Table 4.4.c), show some reduction in values on the crude control plot, but little or no evidence of a trend on the emulsion samples.

Table 4.4 Weathering Ratios for Bay 106 1982 Backshore Plot samples: berm samples were collected only in 1983
(a) Saturated Hydrocarbon Weathering Ratio (SHWR)
(b) Alkane/Isoprenoid Ratio (ALK/ISO)
(c) Aromatic Weathering Ratio (AWR)

(a) SHWR

		SURFACE						SUBSURFACE			
		1982 Backbeach 15 Aug	1982 Backbeach 22 Aug	1983 Berm	1983 Backbeach	1985 Backbeach	1987 Backbeach	1983 Berm	1983 Backbeach	1985 Backbeach	1987 Backbeach
Crude Control	IMC	2.0	2.2	1.5	1.4	1.6	1.3	2.4	1.9	1.5	1.4
Crude Mixed	IMC	2.6	2.0	1.6	1.7	1.8	1.5	2.1	2.0	1.8	2.3
Emulsion Mixed	IME	2.3	2.0	1.7	1.6	1.6	1.4	2.0	2.1	2.3	1.7
Emulsion Control	IME	2.3	1.8	1.7	1.5	1.6	1.4	2.0	1.6	2.3	1.7

(b) ALK/ISO

Crude Control	IMC	2.6	2.7	2.2	1.9	1.7	0.8	2.3	2.1	1.5	2.3
Crude Mixed	IMC	2.5	2.7	2.3	2.2	2.0	2.8	2.3	2.1	2.0	2.7
Emulsion Mixed	IME	2.6	2.6	2.3	2.4	2.4	1.2	2.2	2.3	2.4	1.5
Emulsion Control	IME	2.6	2.9	2.1	1.4	2.3	2.3	2.3	2.0	2.4	2.7

(c) AWR

Crude Control	IMC	2.8	2.0	2.3	1.7	1.5	1.2	-	3.1	1.9	366
Crude Mixed	IMC	-	-	-	-	3.0	1.6	-	-	2.3	3.1
Emulsion Mixed	IME	-	-	-	-	2.3	1.7	-	-	3.8	54
Emulsion Control	IME	2.4	2.1	2.8	1.8	2.6	1.4	-	2.0	3.7	2.4

4.2 Results 1987

4.2.1 Total Extractable Hydrocarbons

The means (of two samples) at each location in 1987 show that the backshore surface and subsurface on IMC and all of the surface and subsurface IME samples were in the same range as samples previously collected and analysed in 1983 and 1985. Apparent reworking of the surface and subsurface sediments on the IMC berm section resulted in a reduction of the surface oil content and an increase in the subsurface values on both the control and mixed section of this plot (Table 4.1). This reworking of the berm section of IMC at some time following the 1985 sample collection, by wave action, is a plausible and probable explanation for the change in the oil content of the sediments. The remaining samples, as with those from T1 and T2, have not changed significantly as they are weathering only slowly due to terrestrial degradation processes in a backshore, non-marine, environment.

4.2.2 Weathering Ratios

The SHWR ratios (Table 4.4a) show little change between and 1985 and 1987. The two subsurface samples from the IME plot have values that are reduced by 0.6, 5 of the remaining 6 samples were reduced by 0.1-0.3, and one sample (IMC, mixed subsurface) increased by 0.5. With one exception, the IME, mixed subsurface value of 2.3, the values range between 1.4 and 1.7 and have therefore weathered to approximately the same degree. The comparable values for T1 and T2 are in the same range, 1.3 to 1.8, with one value of 2.2.

The ALK/ISO ratios (Table 4.4b) from the 1987 analyses are variable and show little consistency to the 1985 values, as some have increased by as much as 0.8 and some have decreased by as much as 1.2. The one trend that is evident from the 1987 data set is that surface values (mean 1.45) are considerable lower than the subsurface values (mean 2.6).

The AWR data for these plots is again consistent with the surface oil weathering faster than the subsurface oil. Some of the results (Table 4.4c) are extreme; these ratios are caused by high naphthalene concentrations in the samples. These may be artifacts.

4.3 Discussion

Twelve of the 16 t-h sample values from 1987 are in the same range as those from 1983 and 1985, with the exceptions being those from the IMC berm plot (Figure 4.2). On the latter, the oil content of the berm control and mixed plot surface samples was reduced and that of the subsurface samples was increased. This can be explained by a natural mixing or reworking of the sediments on the seaward section of the two plots by wave action at some time between 1985 and 1987.

Figure 4.2 Aerial view of the IM backshore plots,
Bay 106, 87-08-11

5.0 1981 RAGGED CHANNEL PROJECT-BAY 11

5.1 Results 1981 to 1985

5.1.1 Surface Oil Distribution

Visual observations on surface oil cover have been made in a systematic manner each year and these results have been used to prepare of a series of maps to show the distribution of surface oil. The length of oiled beach, measured from the oil distribution maps, decreased by approximately one-third whereas the area of beach with an oil cover decreased by half between 1981 and 1985 (Table 5.1). The most significant change took place on those beach sections with an oil cover between 50 and 100%, which decreased in total from 4855 to 1170 m^2 over that period (Table 5.2). By contrast, the total area with a cover between 0.1 and 49% was reduced only from 3715 to 3270 m^2. A measure of the change in the degree or magnitude of the contamination is given by the 100% Equivalent Area (EA) value which decreased by three-quarters over the period (Table 5.3) (Owens et al., 1987b).

In 1983 two observers estimated the oil cover, initially from a helicopter and secondly from a ground location, in order to compare the accuracy of point observations with the systematic observations (Owens, 1984b; 1987). This evaluation indicated that aerial and ground estimates were generally of poor accuracy and may significantly underestimate the true extent of oil distribution (Table 5.1). An important element in the unreliability of the point observations related to changes in the colour of the surface oil due to (a) wet versus dry conditions and (b) the weathering of the oil.

5.1.2 Total Extractable Hydrocarbons

The analyses of the repetitive samples collected from the intertidal beach surface sediments shows (i) a general decrease in t-h concentrations through time and (ii) usually higher concentrations in the upper and middle samples as compared to the lower intertidal zone sample (Table 5.4). The

Table 5.1 Visual Oil Cover Estimates versus Measured Oil Distribution

YEAR	VISUAL ESTIMATES OF OIL COVER		MEASURED DISTRIBUTION OF OIL		
	Aerial	Ground	Area With Oil Cover	Length of Oiled Beach	
1981	-	-	58%	275m	92%
1982	-	-	65	250	83
1983	35%	45-50%	26	190	63
1985	10-15	15-20	30	180	60
1987	*	5-10	15	160	58

* No estimate because of ice in ITZ

Table 5.2 Surface Oil Distribution

YEAR	SURFACE OIL COVER BY CATEGORY (m^2)					TOTAL OILED AREA (m^2)
	0%	0.1-24%	25-49%	50-74%	75-100%	
1981	6200	2015	1700	1145	3710	8570
1982	5170	5200	1775	1320	1305	9600
1983	10845	2120	840	350	615	3925
1985	10330	1830	1440	660	510	4440
1987	12530	1040	560	280	360	2240
% Change 1981-1987	+102	-48	-67	-76	-90	-74

Table 5.3 Changes in Estimated Oil Content of Beach 1981 - 1987

YEAR	Total Oiled Area (m^2)	Average Surface Oil Cover (%)	Equivalent Area of 100% Oil Cover (m^2)	Percentage of Beach Area Oiled (%)	Percentage of Initial Oil Remaining (%)
1981	8570	57	4850	58	100
1982	9600	34	3282	65	67
1983	3925	34	1337	25	28
1985	4440	27	1200	30	33
1987	2240	36	800	15	17

Table 5.4 Bay 11 Intertidal Sediment Samples: Total Extractable Hydrocarbons (oil-in-sediment by weight: mg kg^{-1}). Mean of Bay 11 Repetitive Surface Samples (based on 3 samples collected in each zone from the 0 to 2 cm depth interval on Profiles 2, 4 and 6).

DATE	UPPER INTERTIDAL ZONE	MIDDLE INTERTIDAL ZONE	LOWER INTERTIDAL ZONE	OVERALL MEAN
19 Aug 1981*	28,000	19,300	4,850	17,400
20 Aug 1981	8,830	3,790	8,600	7,070
28 Aug 1981	7,010	7,980	4,950	6,650
15 Sept 1981	7,060	6,810	3,770	5,880
10 Aug 1982	8,370	2,970	1,860	4,400
16 Aug 1983	28,600	5,980	990	11,900**
9 Aug 1985	3,970	1,320	642	1,980
12 Aug 1987	16,340	1,750	36+	6,793++

* mean of 2 samples from each zone - Profiles 4 and 6.

** two of the upper intertidal zone samples were collected from the newly-formed asphalt pavement; if these are excluded, the mean of the remaining 7 samples is 3,120 mg kg^{-1}

\+ mean of Profiles 2,6

++ mean of eight samples

statistical tests show that in all cases there was no significant difference between (1) subsequent data sets and (2) between the combined 1981 data set versus the combined 1982+1983+1985 data set.

The results from the repetitive subsurface sediment samples show no trends either in time or space (Table 5.5). The values are generally one or two orders of magnitude lower than those for the surface samples, although this is not universally applicable.

There was considerable heterogeneity in the t-h values from the sediment samples, which can be attributed in part to variations in the grain size distribution of the sediments. However, the changes in the t-h concentrations can be considered to be real. Some of the sampling did produce consistent values, for example on Profile 6 in 1981 the 4 repetitive samples collected from the upper, middle and lower intertidal zones were in the range 16000-20000, 6090-7560, and 2830-8270 $mg \cdot kg^{-1}$ respectively.

Sediment samples were also collected on a subjective basis to reflect observed differences in the surface oil cover that corresponded to morphological beach features. These data (Table 5.6) indicate that the highest t-h concentrations were associated with the beach-face asphalt pavement (the range of values for the 6 surface samples was 12,000 to 25,000 $mg \cdot kg^{-1}$), with a secondary concentration of high values on the surface of the lower beach-ridge pavement. Although the mean value of the repetitive samples progressively decreased through time, if all the surface sediment samples that were collected in 1983 and 1985 are included in the calculation of the mean ((c) in Table 5.7) then this value had apparently changed little since 20 August 1981.

5.1.3 Oil Volume

The computed volume of oil remaining in the surface sediments of the beach in 1985 was about one-quarter of the initial volume of oil that was stranded in 1981 (Table 5.8). The total volume of contaminated sediments

Table 5.5 Bay 11 Intertidal Sediment Samples: Total Extractable Hydrocarbons (oil-in-sediment by weight: mg kg^{-1}). Mean of Bay 11 Repetitive Subsurface Samples (based on 3 samples collected in each zone from the 5 to 10 cm depth interval on Profiles 2, 4 and 6).

DATE	UPPER INTERTIDAL ZONE	MIDDLE INTERTIDAL ZONE	LOWER INTERTIDAL ZONE	OVERALL MEAN
20 Aug 1981	263	93	146	168
28 Aug 1981	2,050	293	356	900
15 Sept 1981	96	310	271	226
10 Aug 1982	2,670	310	126	1,030
16 Aug 1983	710	1,270	424	803
9 Aug 1985	124	391	1,080	533
12 Aug 1987	6,543 (38)+	1,110	49	2,567 (513)+

\+ discounts one outlier

Table 5.6 Bay 11 Intertidal Sediment Samples: Total Extractable Hydrocarbons (oil-in-sediment by weight: mg kg^{-1}). Mean Values of Additional Surface Samples Collected in 1983, 1985, and 1987 in Different Morphological Segments of the Intertidal Zone.

	YEAR	n	SURFACE	n	SUBSURFACE
Beach Face (asphalt pavement)	1983	6	19,800	6	1,240
	1985	6	19,000	5	6,440
	1987	6	16,200	3	6,543
Mid-beach Trough	1983	3	480	3	10
	1985	1	1,700	-	-
	1987	3	3,400	-	-
Lower Beach Ridge	1983	4	7,900	4	2,600
	1985	3	11,600	-	-
	1987	6	5,300	-	-

Table 5.7 Time Series of Mean Total Extractable Hydrocarbon Concentrations and Computed Oil Volumes: 1981 - 1987

DATE	Number of Samples	MEAN SURFACE TOTAL HYDROCARBON CONCENTRATION (mg kg^{-1})	SURFACE OIL VOLUME	
			100%EA Method	Volume Method
19 Aug 1981	6	17,400	<5.3 m^3>	5.3 m^3
20 Aug 1981	9	7,100	-	2.2
28 Aug 1981	9	6,700	-	2.0
15 Sept 1981	9	5,900	-	1.8
10 Aug 1982	9	4,400	3.6	1.5
16 Aug 1983 (a)	9	11,870	-	1.6
16 Aug 1983 (b)	10	4,800	-	0.6
16 Aug 1983 (c)	19	8,150	1.5	1.1
9 Aug 1985 (a)	9	1,980		
9 Aug 1985 (b)	14	12,530		
9 Aug 1985 (c)	23	8,400	1.3	1.3
12 Aug 1987 (a)	8	6,800		
12 Aug 1987 (b)	21	6,360		
12 Aug 1987 (c)	29	6,480	0.9	0.52

Note: In 1983, 1985 and 1987 the (a) samples were collected at the same nine locations as the previous sample sets; the (b) samples were at additional selected locations; and (c) = (a) + (b).

Table 5.8 Estimated Intertidal Oil Budgets

	VOLUME OF OIL		VOLUME OF CONTAMINATED SEDIMENTS	
YEAR	Equivalent Area(EA) Method	Computed Hydrocarbon Volume Method	Equivalent Area(EA) Method	Simple Volume Method
1981	<5.3m^3>	5.3m^3	97m^3	860m^3
1982	3.6	1.5	65	960
1983	1.5	1.1	27	370
1985	1.3	1.3	24	440
1987	0.9		16	220

was reduced by approximately one-half to one-quarter, depending on the method used to calculate the value (see section 2.5.2).

5.1.4 Weathering Ratios

The SHW ratios have remained low following the initial drop in values in 1981 (Table 5.9a), associated with the loss of the n-C_{10} to n-C_{17} saturated hydrocarbons by evaporation. The only change through time has been the increase in the proportion of low values, so that by 1985 4 of the 6 ratios were at the minimum value of 1.0. The changes between both the August 1981-September 1981 and September 1981-August 1982 data sets are significant at the 99.5% confidence level.

Changes in the ALK/ISO ratios are similar (Table 5.9b), although in this case the major reduction in the mean of the ratios, due to depletion of the n-alkanes by biodegradation, occurred in the period between the September 1981 and August 1982 sample intervals. This change is significant at the 99.5% confidence level (highly significant).

A major distinction was found in the weathering ratios of samples with high (>5,000 $mg{\cdot}kg^{-1}$) versus low (<5,000 $mg{\cdot}kg^{-1}$) t-h concentration. Evaporative weathering, as shown by the SHWR, was significantly lower in the high t-h samples (Table 5.10). This pattern was also reflected in the $C\text{-}_{18}$/Phytane Ratio and the Aromatic Weathering Ratio (AWR). The chromatograms for the high concentration samples are less weathered and include distinct, well-resolved alkanes, from about $C\text{-}_{10}$ up, and a low UCM (unresolved complex mixture). By contrast the chromatograms from the low t-h concentration samples show much greater weathering and include a significant UCM and loss of alkanes relative to isoprenoids, although some alkanes can be resolved. Thus, weathering has occurred at different rates depending upon the concentration of the oil in the sediments.

5.1.5 Asphalt Pavement

A major change in the character of the oil cover occurred with the formation of an asphalt pavement following the August 1982 field survey and

Table 5.9 Weathering Ratios: Bay 11 Repetitive Surface Sediment Samples (Profiles 4 and 6, except 1982 = Profiles 2 and 6)

(a) Saturated Hydrocarbon Weathering Ratio (SHWR)

DATE	n	mean	number of samples with ratio = 1.00
20 Aug 1981	6	2.6	0
15 Sept 1981	6	1.6	0
10 Aug 1982	6	1.1	1
16 Aug 1983	6	1.4	2
9 Aug 1985	6	1.3	4
12 Aug 1987	4	1.0	2

(b) Alkane/Isoprenoid Ratio (ALK/ISO)

DATE	n	mean	number of samples with ratio < 1.00
20 Aug 1981	6	2.7	0
15 Sept 1981	6	2.6	0
10 Aug 1982	6	1.1	2
16 Aug 1983	6	1.3	3
9 Aug 1985	6	0.7	4
12 Aug 1987	5	1.3	3

Table 5.10 Bay 11 Weathering Indices: (a) Intertidal Sediment Samples - mean value of indices from low and high total hydrocarbon concentration samples; and (b) Original Lagomedio Crude Oil

th (mg kg^{-1})	YEAR	n	SHWR	ALK/ISO	C18 PHYT	PRIS PHYT	AWR
(a) < 5000	1983	17	1.06	1.22	-	-	-
	1985	10	1.14	0.6	0.45	0.5	1.64
	1987	4	1.1	1.2			
> 5000	1983	17	1.58	1.77	-	-	-
	1985	6	1.58	0.7	1.22	0.65	2.18
	1987	5	1.65	1.8			
(b) Aged Crude		-	2.28	2.50	1.61	0.74	3.47

prior to the August 1983 site visit. Although relatively small in area (325 m^2 and 205 m^2 in 1983 and 1985 respectively), the pavement contained approximately two-thirds of the oil contaminated sediments on the beach in 1983 and one-third in 1985 (Tables 5.11 and 5.12). Oil concentrations from pavement samples averaged 20,000 $mg \cdot kg^{-1}$ in both 1983 and 1985 (Table 5.6) and these samples showed relatively little weathering as compared to non-pavement samples with low t-h concentrations (Table 5.10).

5.1.6 Subtidal Sediments

In 1983 and 1985, transects perpendicular to the shoreline were sampled and analysed for presence of oil. Although it was clear that oil was entering the subtidal area near the south end of the oiled beach, this oil did not appear to be spreading beyond the oiled area, and appeared to be at a steady state concentration. The concentrations varied from about 15 $mg \cdot kg^{-1}$ in deeper sediments to 7600 $mg \cdot kg^{-1}$ adjacent to the oiled low tide ridge. By 1985, many hydrocarbon compositions were not distinguishable from natural material.

5.2 Results 1987

5.2.1 Surface Oil Distribution

No aerial estimates of the surface oil cover were attempted as the intertidal beach had many stranded floes at the time of the first overflight on 11 August (Figure 5.1). Two ground estimates indicated an oil cover of 5 to 10%, as compared to a measured ground cover of 15% (Table 5.1). This measured oil cover of 2240 m^2 in 1987 is half that of the 1985 cover (4440 m^2). The length of oiled beach in 1987 was only slightly reduced from 1985 (180 to 160 m) as the major changes in oil distribution occurred in the intertidal zone rather than in the continuous, but narrower, layer of oil at the mean high water level (Figure 5.2).

Table 5.11 Asphalt Pavement Data

	Pavement Area	Volume of Contaminated Sediments in Pavement	Percent of Total Contaminated Sediments on Beach	Volume of Oil in Pavement (Volume Method)	Percent of Total Oil Volume on Beach
1983	325 m^2	16.25 m^3	60%	0.6 m^3	55%
1985	205 m^2	10.25 m^3	32%	0.35 m^3	27%
1987	220 m^2	11.00 m^3	70%	0.32 m^3	61%

Table 5.12 Estimated Oil Budget for Bay 11, August 1983

	AREA (m2)	MEAN TOTAL HYDROCARBON CONCENTRATION ($mg\ kg^{-1}$)	COMPUTED OIL VOLUME (m^3)
Asphalt Pavement	325	20,000	0.58
Remaining Area	3,600	3,500	0.45
TOTAL	3,925	-	1.03

Figure 5.1 Aerial view of Bay 11. Approximate locations of profiles 4 and 7 are indicated. 87-08-11

Figure 5.2(a) Bay 11 Surface Oil Distribution, 26 August, 1981.

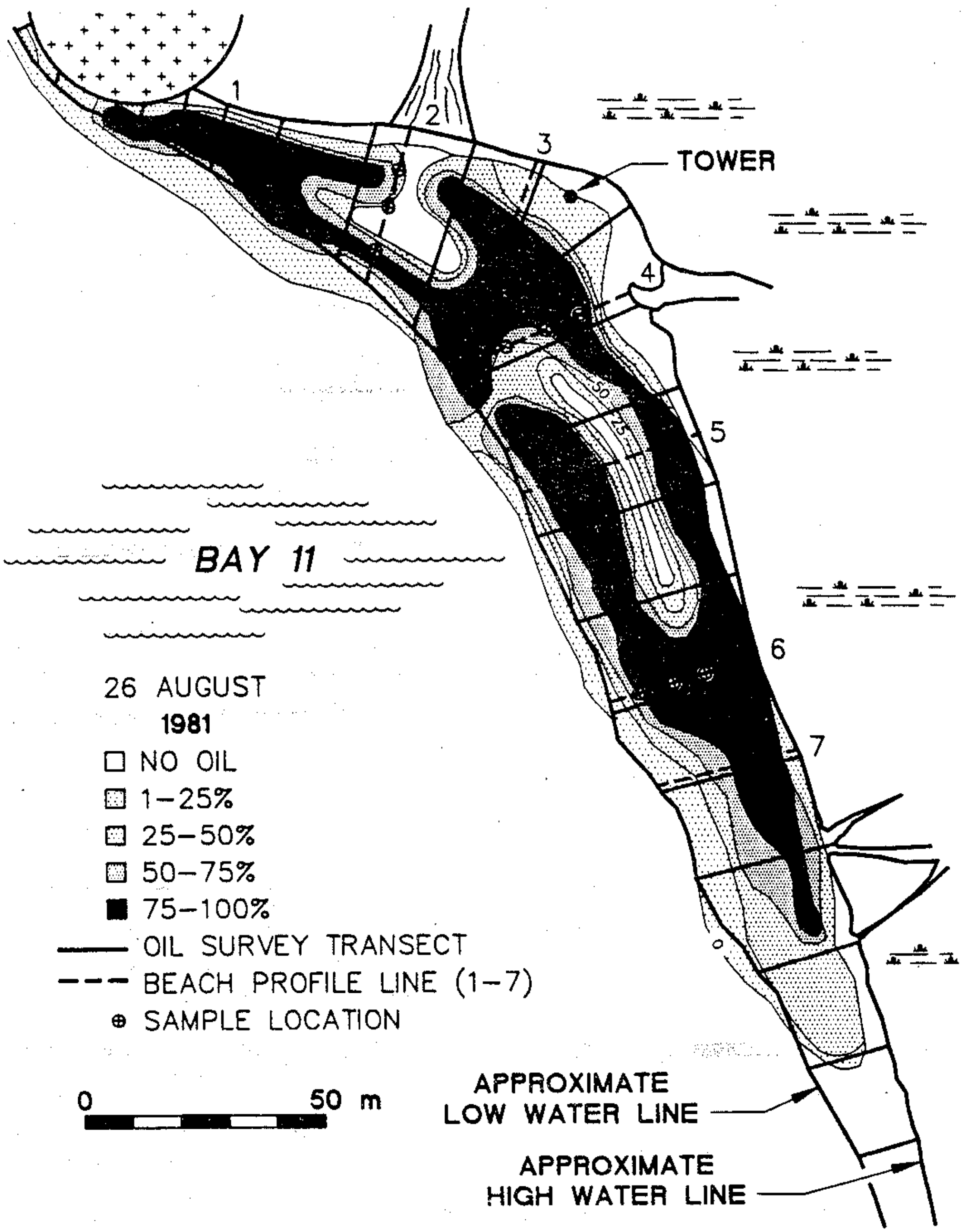


Figure 5.2(b) Bay 11 Surface Oil Distribution, 11 August, 1982.

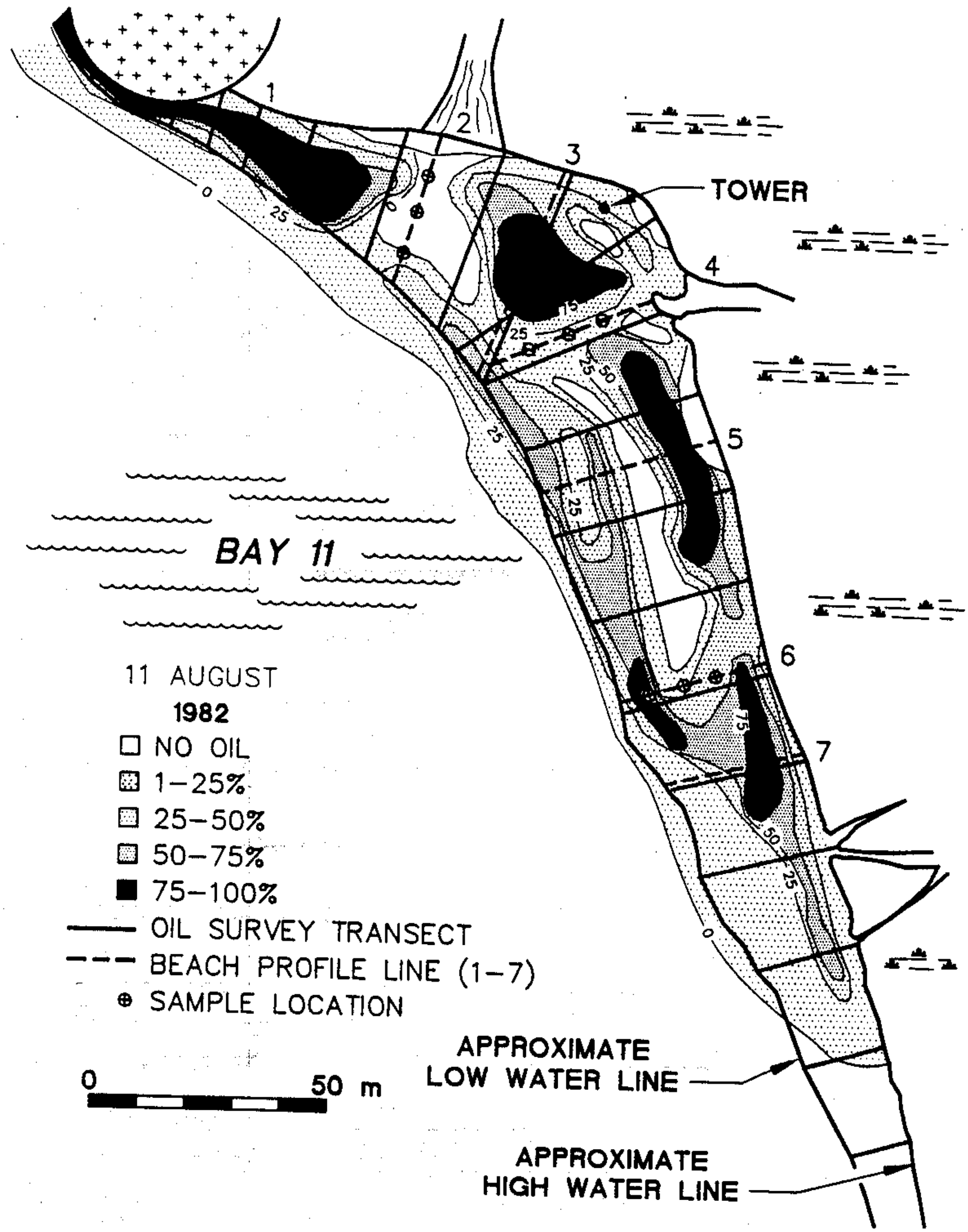


Figure 5.2(c) Bay 11 Surface Oil Distribution, 15 August, 1983.

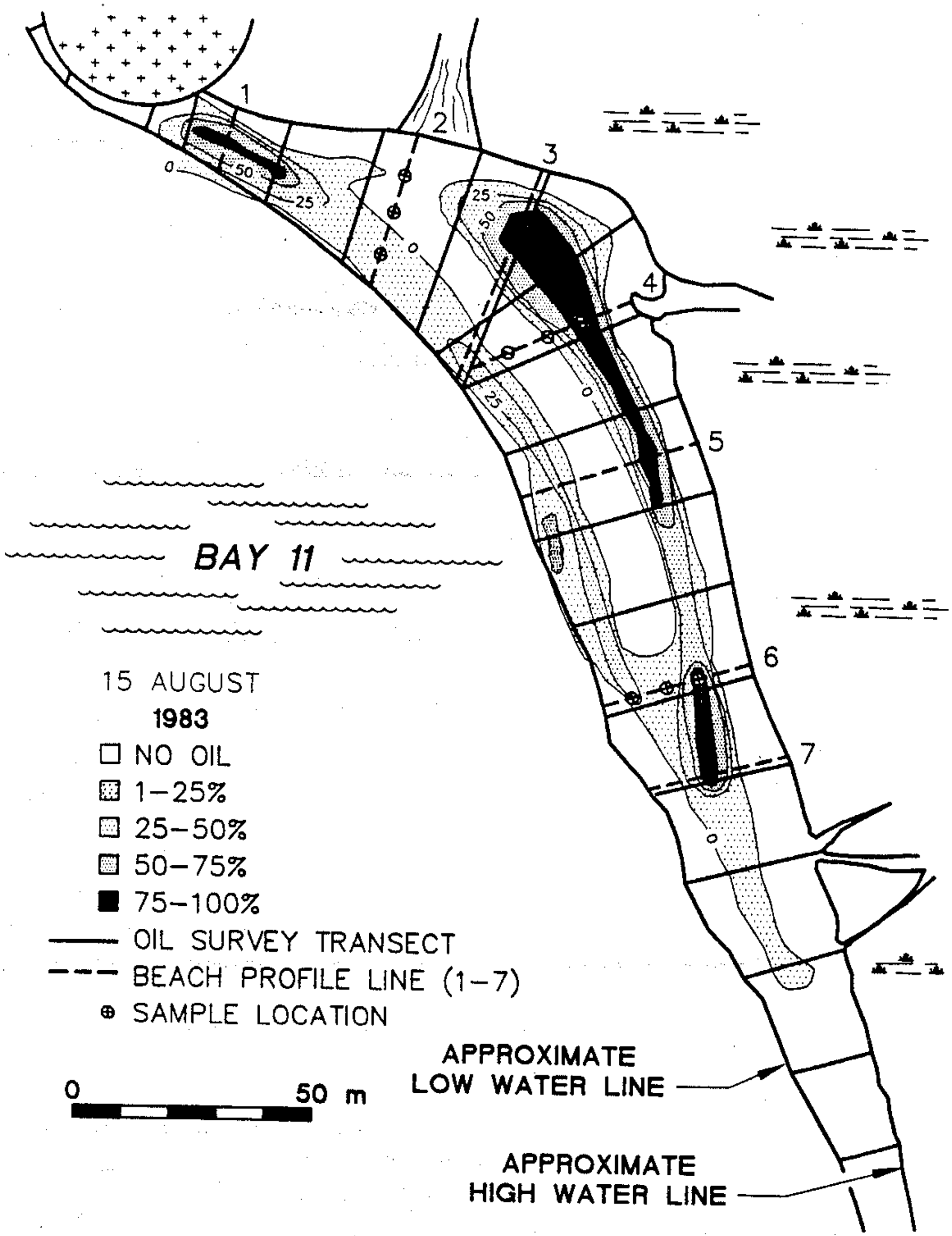


Figure 5.2(d) Bay 11 Surface Oil Distribution, 9 August, 1985.

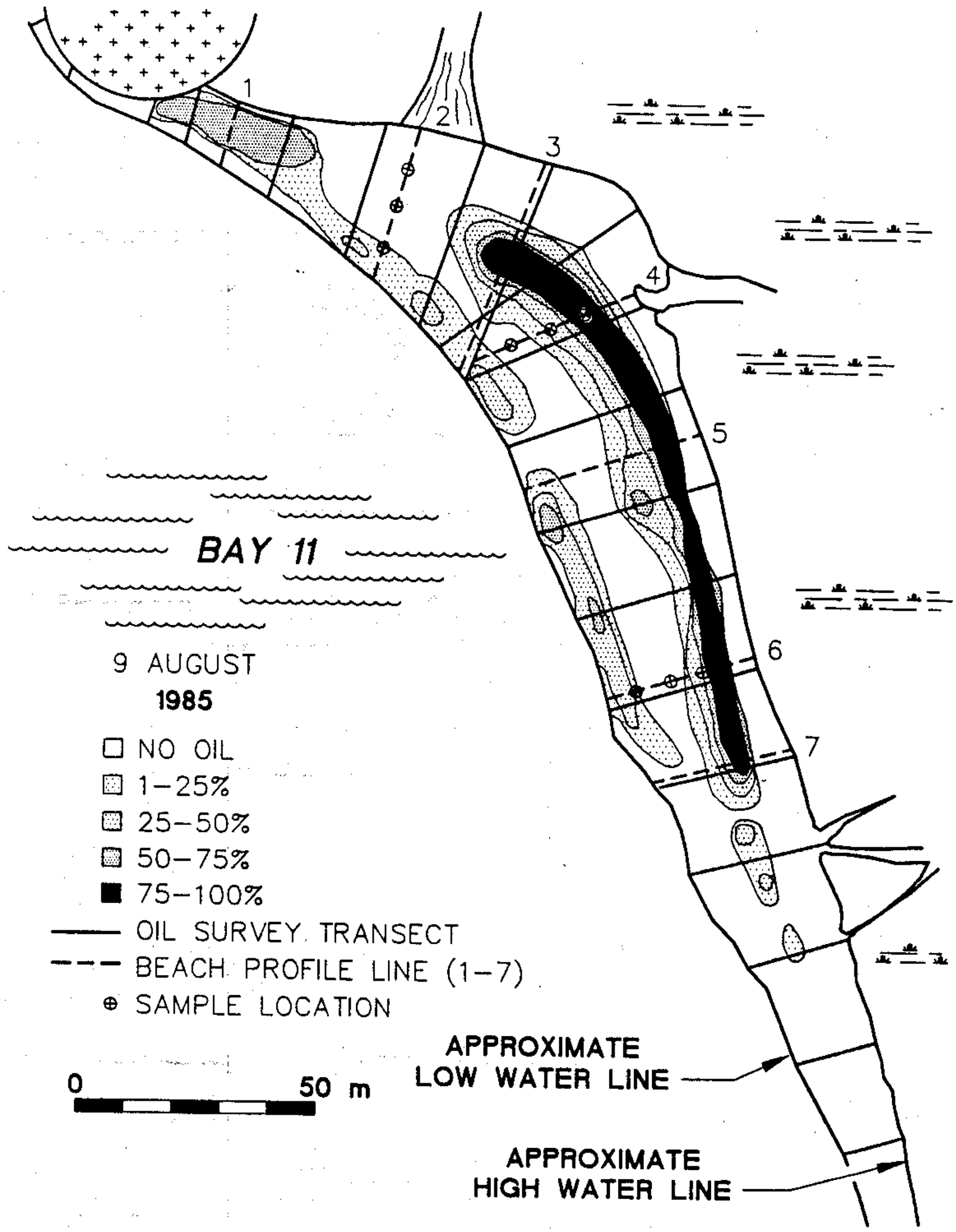
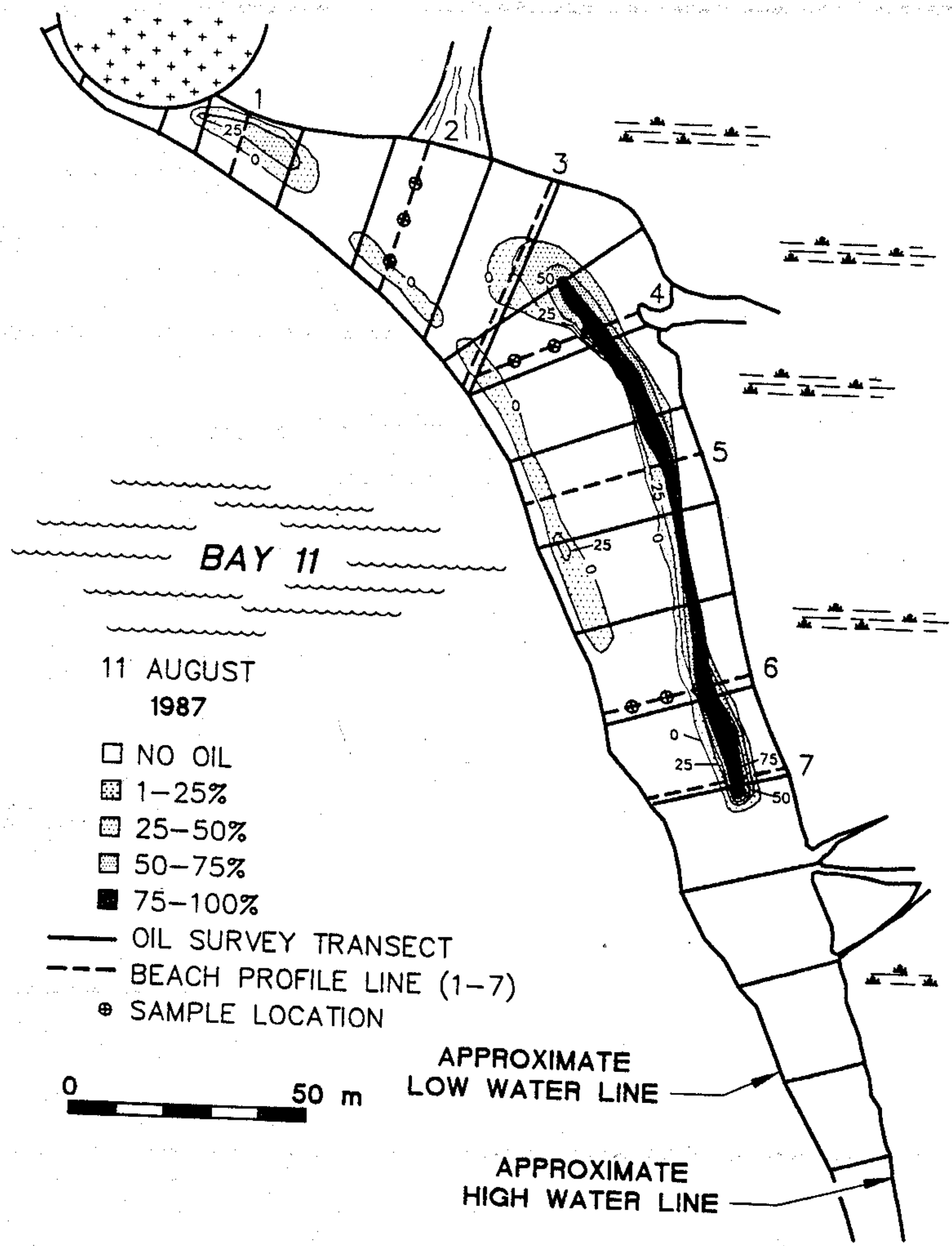


Figure 5.2(e) Bay 11 Surface Oil Distribution, 11 August, 1987.



Visual comparison of the 1985 and 1987 oil distribution maps (Figure 5.2 d and e) indicates that the basic pattern of the oil cover did not change significantly but that the actual cover was significantly reduced in all areas.

The breakdown of the oil cover by category (Table 5.2) indicates a reduction in all of the categories between 1985 and 1987, with the least reduction (of 30%) occurring in the 75-100% range. In 1981 43% of the total oiled area, almost half, had a cover of 75 to 100%, but by 1987 only 16% of the total oiled area was in this category, so that over the time period there has been a major reduction in the proportion of beach with a heavy oil cover. In 1981 24% of the oil cover was in the 0.1 to 24% category, whereas in 1987 this value had increased to 46%, so that the trend of an increasingly lighter oil cover is shown clearly.

The Average Surface Oil Cover has changed little since 1982 (Table 5.3) but the Total Oiled Area, the Equivalent Area of 100% Oil Cover and the Percent of the Beach Area Oiled have all been considerably reduced over that time period and all were reduced significantly between 1985 and 1987. In terms of the area or surface distribution of oil, not only did the total oil cover decrease by 74% over the period 1981 to 1987 but the distribution changed from a heavy to a light oil cover. However, as will be discussed later, Section 5.2.5, in terms of the volume of oil a significant proportion of the remaining oil remains locked in the heavy oil cover category (Table 5.11).

5.2.2 Total Extractable Hydrocarbons

The repetitive intertidal surface sample set (Table 5.4) indicate that the highest oil concentrations remain in the upper Intertidal zone, associated with the area of highest oil cover. [One sample from the lower intertidal zone was destroyed following collection.] The upper intertidal zone samples show high but variable values from 1982 onwards, whereas the middle and lower intertidal zone samples show consistently low relative concentrations. The t-test results show no significant difference between the 1985 and 1987 sample sets nor between the combined 1981 set versus the

1987 sample set. This lack of significant change is most probably due to the similar statistical character of each sample set which has, in all cases, a wide range of values that is often more than one order of magnitude. For example, the combined 1981 data set (48 samples) has a mean of 8,327 $mg{\cdot}kg^{-1}$ and a standard deviation of 8,094 $mg{\cdot}kg^{-1}$, and the same statistics for the 1987 data are 6,793 $mg{\cdot}kg^{-1}$ and 12,363 $mg{\cdot}kg^{-1}$.

The subsurface repetitive sample set are affected by a single anomalous high value (19,000 $mg{\cdot}g^{-1}$) from the upper intertidal zone pavement. If this sample is removed from the set the values are consistent with previous years' data (Table 5.5).

The surface samples that were collected subjectively to illustrate oil concentrations from different segments of the intertidal zone are consistent with previous data (Table 5.6) and show highest values from the beach face pavement (mean 16,200 $mg{\cdot}kg^{-1}$). When the repetitive results are compared with the additional data set (Table 5.7), the mean values are very similar (6,800 and 6,360 $mg{\cdot}kg^{-1}$) and this indicates that the two data sets each are probably representative of the average oil concentrations on the oiled sections of the beach.

5.2.3 Oil Volumes

The computed oil volume, based on the total oiled area and the average total-hydrocarbon concentration method (Section 2.5.1), gives a value of 0.52 m^3 for the 1987 data set. This value compares to an initial volume of 5.3 m^3 and a 1985 volume of 1.3^3. The Equivalent Area calculation, which is based on surface oil distribution only, produces a value of 0.9 m^3 (Table 5.8).

The volume of oil-contaminated sediments that would have had to be removed in 1987, if the beach were to have been cleaned, was on the order of 220 m^3, approximately one-quarter of the original volume of oil-contaminated sediments. The actual volume of contaminated sediments had been reduced to 16 m^3, or about one-sixth of the original total (Table 5.11).

5.2.4 Weathering Ratios

The ratios determined in 1987 follow the patterns set in previous years (Tables 5.9, 5.10). In general, no difference in weathering may be identified. Again, samples with a high t-h exhibit ratios indicative of only moderately weathered oil, whereas samples of low t-h are more weathered.

5.2.5 Asphalt Pavement

The pavement was still very evident in 1987 as a discrete feature of the intertidal zone (Figures 5.2e, 5.3, 5.4, and 5.5) and in terms of the high total-hydrocarbon concentrations (Table 5.6). There was a slight increase in the total area of the pavement compared to 1985 and in the volume of contaminated sediments (Table 5.11). More significant than these minor changes is the proportion of remaining oil and contaminated sediments that are contained in the pavement. This proportional increase is due to natural cleaning of the less contaminated sediments and to the lack of cleaning of the more resistant pavement. The oil in the pavement was considerably softer and more malleable, i.e. it had a lower viscosity, than in 1983 and 1985 although the weathering indices indicate that the samples remain relatively unweathered (Table 5.10). No data are available on the air temperatures prior to the site visit and any explanations for this low viscosity would be purely speculative.

5.2.6 Subtidal Sediments

Four subtidal sediment samples were collected in 1987. The results are summarized in Table 5.15. Applying the same criteria as in 1985 to evaluate the presence or absence of oil, three of the four samples probably contain oil. The fourth, 7135, contains very little hydrocarbon and probably represents natural background material. The pattern of concentrations is similar to the pattern in 1985. A patch of oiled sediment sits below the low tide line, and the oil concentration decreases with depth from that point.

Figure 5.3 Ground view of the heavily oiled area near sample site 401. The upper edge of the heavily oiled area is indicated by arrows and the beach crest by X. Scale is 25 cm. 87-08-12

Figure 5.4 Close view of the sample hole at site 401. Note oil on the water surface. 87-08-12

Figure 5.5 View of the heavily oiled area south of profile 5, which is located by the stake. 87-08-12

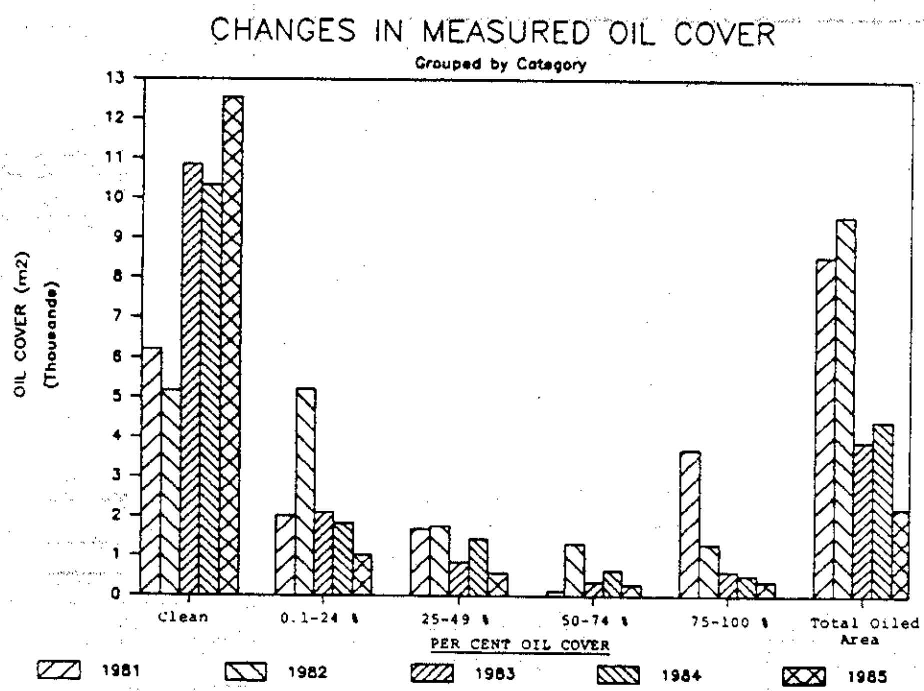


Figure 5.6 Changes in measured oil cover, grouped by category.

5.3 Discussion

The two most significant points to emerge from the 1987 field study are (1): the continued slow reductions in the contaminated area and volume of oil remaining on the intertidal zone (Tables 5.13 and 5.14, Figures 5.6 and 5.7), and (2): the continued presence of the asphalt pavement which contains a high proportion of the remaining oil (Figure 5.8).

Much of the intertidal area has been cleaned naturally and in 1987 85% of the beach was free of visible oil (versus 42% in 1981). The visual estimates of oil cover once again underestimated the actual measured oil cover (Table 5.1). The detailed ground estimates also underestimate the amounts of remaining oil (Figure 5.9). Although the fine grained sediments in the mid-beach trough were visually clean, the sample analyses indicate that they still contain oil (Table 5.6).

The remaining visual oil is concentrated on the beach face pavement, with a secondary concentration on the low-tide ridge (Figure 5.10). On the latter, the oil had a dull brown colour and the distribution was very patchy (Figure 5.11), only one value greater than 25% oil cover was recorded. The pavement oil-in-sediment concentrations remain high, and the highest single value (35,000 $mg \cdot kg^{-1}$) is the same magnitude as the highest concentration (39,000 $mg \cdot kg^{-1}$) from the backshore crude oil control plot (T1). The pavement remains as a narrow but continuous line of relatively unweathered oil in the upper intertidal zone.

Table 5.13 Per Cent Changes in Selected Parameters from Initial Oiling

YEAR	LENGTH OF OILED SHORELINE (>25% Cover)	TOTAL SURFACE AREA OILED	ESTIMATED OIL VOLUME 100%EA Method	Volume Method
1981	<100%>	<100%>	<100%>	<100%>
1982	90	113	67	28
1983	70	45	28	20
1985	67	51	25	24
1987	58	26	16	10

Table 5.14 Changes in Shoreline Contamination Parameters 1981-1987

	Initial (August 1981)	+ 4 Years (August 1985)	% change from 1981	+ 6 Years (August 1987)	% change from 1981
Length of Oiled Beach	275m	180m	67	160m	58
Total Oiled Area	8,570m^2	4,400m^2	51	2,240m^2	26
Average Oil Cover	57%	27%	47	36%	63
Equivalent Area of 100% Cover	4,850m^2	1,200m^2	25	800m^2	16
Volume of Oil on Beach	5.3m^3	1.3m^3	24	0.52m^3	10
Volume of Contaminated Sediments: (a)	97m^3	32m^3	33	16m^3	16
(b)	860m^3	440m^3	51	220m^3	22

(a) Calculated using weighted surface cover values.
(b) Simple length x width x depth calculation.

TABLE 5.15 SUBTIDAL HYDROCARBONS

(a) ALKANES

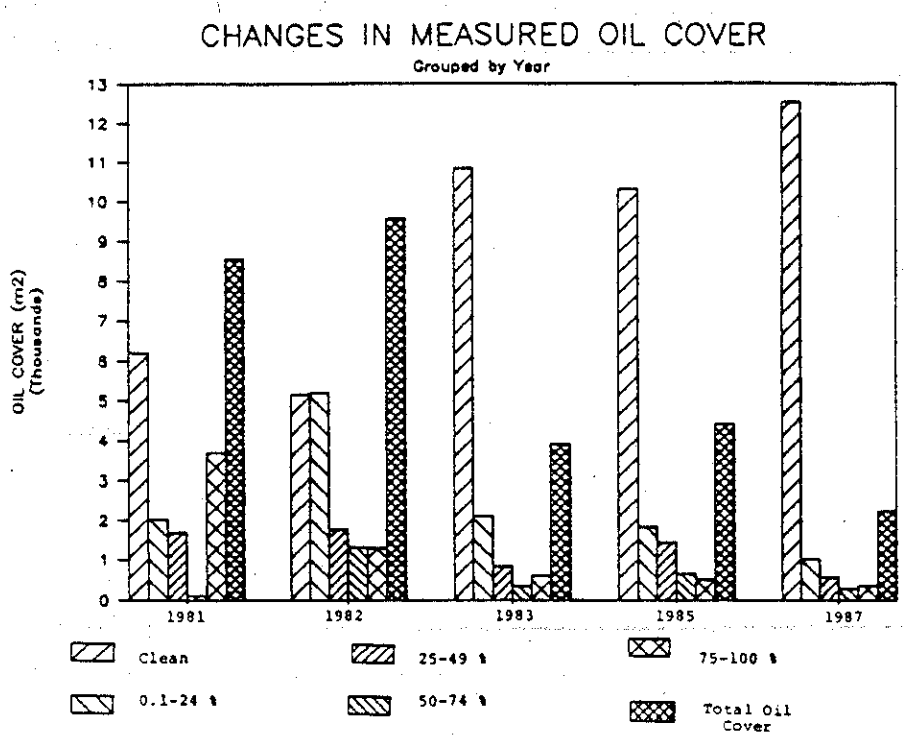
SAMPLE ID	7133	7134	7135	7136
SAMPLE DEPTH AT 1/3 FLOOD	2M	3M	4.6M	4.1M
INDIVIDUAL COMPOUNDS ng/g				
nC10	<0.03	<0.04	<0	<0.02
nC11	<0.03	<0.04	<0	<0.02
nC12	<0.03	<0.04	<0	<0.02
nC13	<0.03	<0.04	<0	<0.02
Farnesane	<0.03	<0.04	<0	<0.02
nC14	<0.03	<0.04	<0	<0.02
Trimethyl-nC13	<0.03	<0.04	<0	<0.02
nC15	<0.03	<0.04	<0	<0.02
nC16	<0.03	<0.04	<0	<0.02
Norpristane	180	2000	0.9	170
nC17	350	1500	6	190
Pristane	390	2400	17	480
nC18	230	1600	4	120
Phytane	710	3100	5	650
nC19	420	400	8	230
nC20	770	730	6	370
nC21	460	3100	36	350
nC22	310	3400	11	250
nC23	770	2800	28	420
nC24	500	3500	18	630
nC25	750	3800	38	1000
nC26	590	1300	24	810
nC27	820	1300	66	990
nC28	490	970	27	580
nC29	880	1300	110	940
nC30	580	1000	26	460
nC31	880	1200	86	770
nC32	470	720	20	300
nC33	550	720	38	350
nC34	480	620	13	270
nC35	450	700	16	270
nC36	300	390	9	170
nC37	250	320	8	110
nC38	180	200	6	82
SUM	1.28E+04	3.91E+04	6.27E+02	1.10E+04
ALK/ISO	1.02	0.70	0.56	0.48
SHWR	1.20	1.04	1.04	1.12
C18/PHYT	0.32	0.52	0.80	0.18
PRIS/PHYT	0.55	0.77	3.40	0.74
CPI	1.58	1.23	3.38	1.59

TABLE 5.15 SUBTIDAL HYDROCARBONS

(b) PAH

SAMPLE ID	7133	7134	7135	7136
SAMPLE DEPTH AT 1/3 FLOOD	2M	3M	4.6M	4.1M
INDIVIDUAL COMPOUNDS ng/g				
C-3 BENZENE	0.8	<12	58	<2
C-4 BENZENE	<3	<12	<0.3	<2
C-5 BENZENE	<3	<12	<0.3	<2
C-6 BENZENE	<3	<12	<0.3	<2
C-0 NAPHTHALENE	1	<6	6	4
C-1 NAPHTHALENE	19	27	7	28
C-2 NAPHTHALENE	60	410	300	120
C-3 NAPHTHALENE	410	1300	310	350
C-4 NAPHTHALENE	340	740	<0.5	200
C-0 FLUORENE	0.2	<5	21	4
C-1 FLUORENE	<2	10	19	8
C-2 FLUORENE	78	94	10	64
C-3 FLUORENE	210	180	14	130
C-0 DIBENZOTHIOPHENE	140	370	33	150
C-1 DIBENZOTHIOPHENE	790	2500	91	850
C-2 DIBENZOTHIOPHENE	4000	7600	230	2200
C-3 DIBENZOTHIOPHENE	3300	7500	230	2700
C-4 DIBENZOTHIOPHENE	730	1200	57	900
C-0 PHENANTHRENE/ANTHRACENE	100	160	110	90
C-1 PHENANTHRENE/ANTHRACENE	740	1400	290	740
C-2 PHENANTHRENE/ANTHRACENE	2700	4600	540	1800
C-3 PHENANTHRENE/ANTHRACENE	1700	4300	690	2100
C-4 PHENANTHRENE/ANTHRACENE	560	400	78	450
SUM	1.59E+04	3.28E+04	3.09E+03	1.29E+04
AMR	1.08	1.09	1.32	1.08
FLUORESCENCE (ug/g)	84	220	9.7	52

Figure 5.7 Changes in measured oil cover, grouped by year.



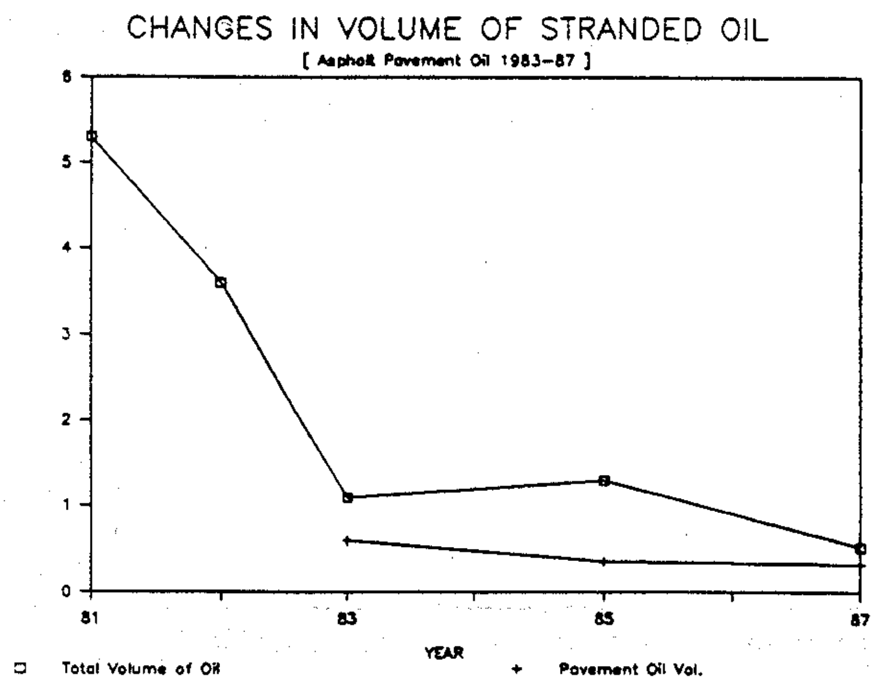
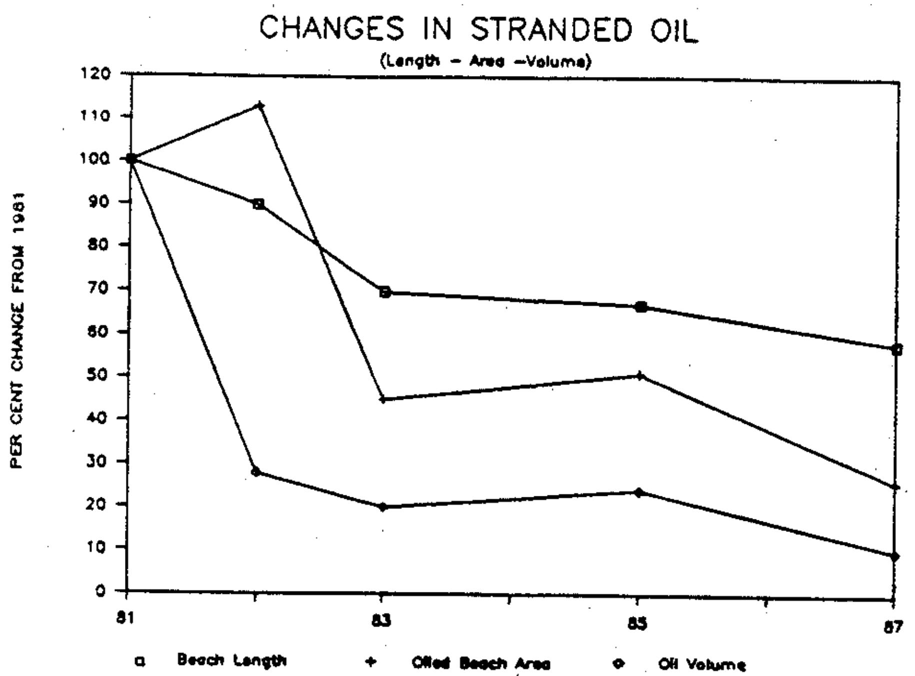


Figure 5.8 Changes in volume of stranded oil; asphalt pavement oil, 1983-1987

Figure 5.9 Changes in stranded oil: length, area, and volume.



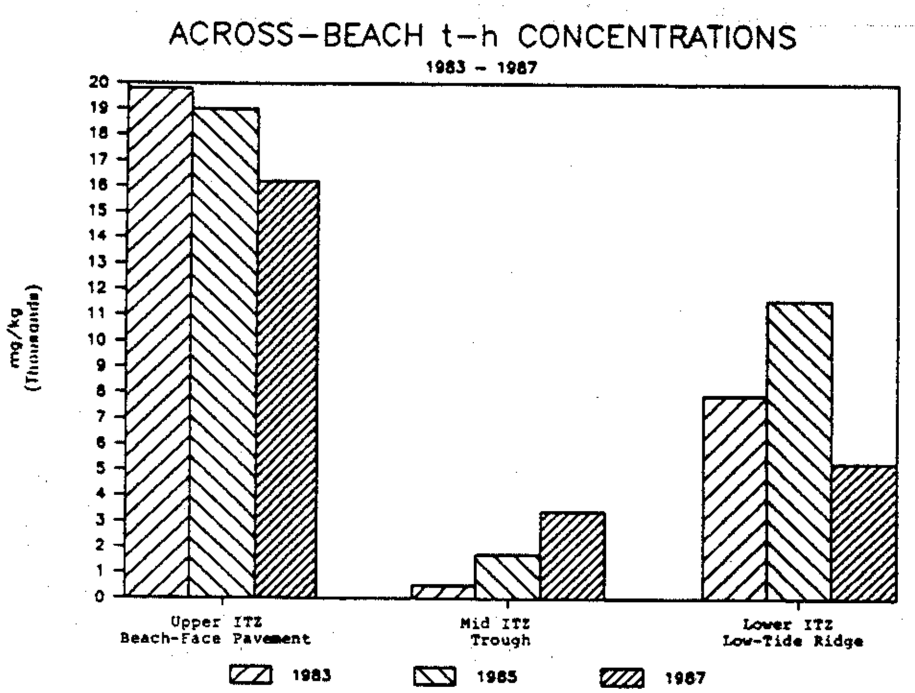


Figure 5.10 Across-beach total hydrocarbon concentrations: 1983-1987.

Figure 5.11 View of the brown oil patch on the low-tide terrace ridge, at sample site 203. 87-08-12

6.0 THE FATE OF STRANDED OILS

6.1 Previous Studies

As part of an on-going program to examine stranded oils, samples were collected from the site of the 1978 Amoco Cadiz spill in 1985 (Owens and Robson 1985) and from the site of the 1974 wreck of the Metula in 1987 (Owens and Robson 1987). The samples from the Amoco Cadiz site were analysed as part of the BIOS project in 1985 (Humphrey and Hope 1986) and samples from the Metula site were analysed as part of this work. All of the samples from the site of the Amoco Cadiz were weathered to a point where no alkanes were resolved. Oil from the spill was recognized by a distinctive hopane cluster in the GC/FID trace.

6.2 Results of the Analyses of Metula Stranded Oil

Total hydrocarbon analyses of the Metula samples indicate that where stranded oil remains in the shore zone in the Strait of Magellan it is present in high concentrations. The highest concentration observed was almost 5% by weight, with most samples containing more than 1% hydrocarbon. Typically, the highest values are associated with sand material, whereas the lower values are associated with sand/cobble material.

The tabulated results of the total hydrocarbon analyses and the compositional analyses, as well as GC/FID traces for each sample, are included in Appendix B.

The samples from the Metula site may be divided into three types, as typified by the traces in Figure 6.1, and are labeled as types A, B, and C.

Type A hydrocarbon compositions (Figure 6.1(a)) are made up of natural n-alkanes and isoprenoids probably derived from the copious amounts of phytoplankton associated with the beach materials, with varying amounts of n-alkanes from n-C23 to about n-C33, which may be from the Metula oil.

Figure 6.1 (a): Natural hydrocarbons

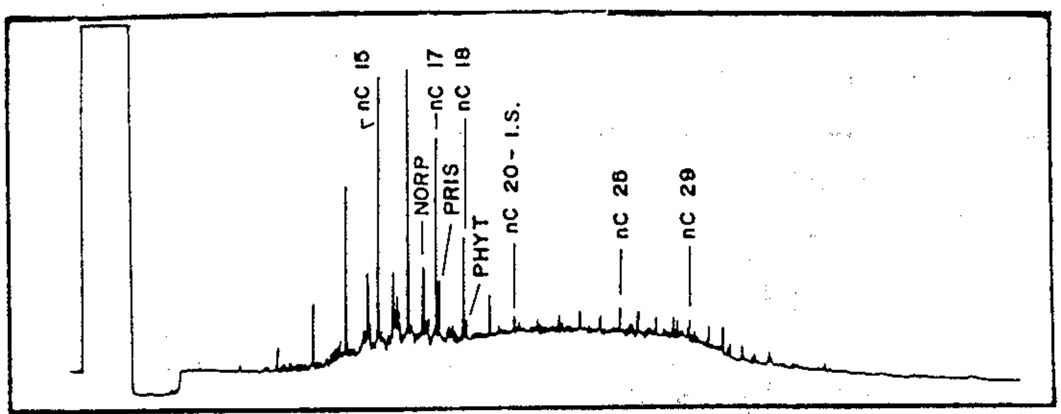


Figure 6.1 (b) Type B: Weathered oil

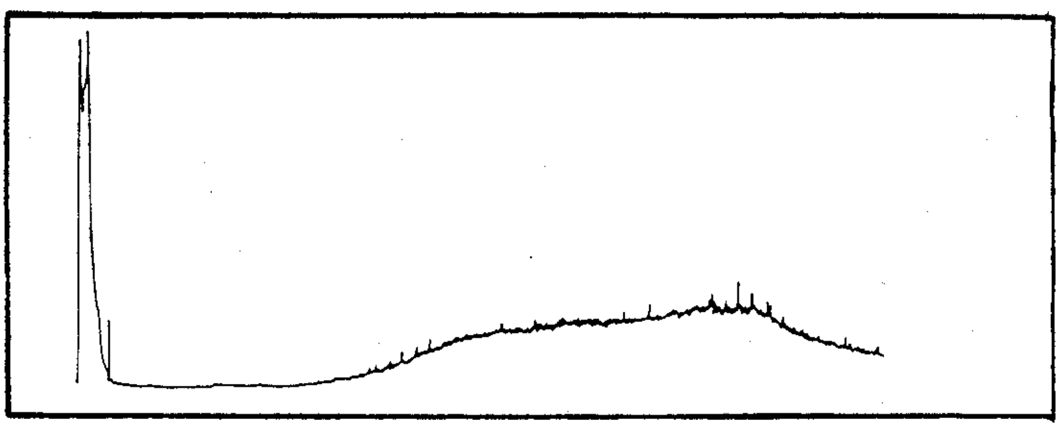
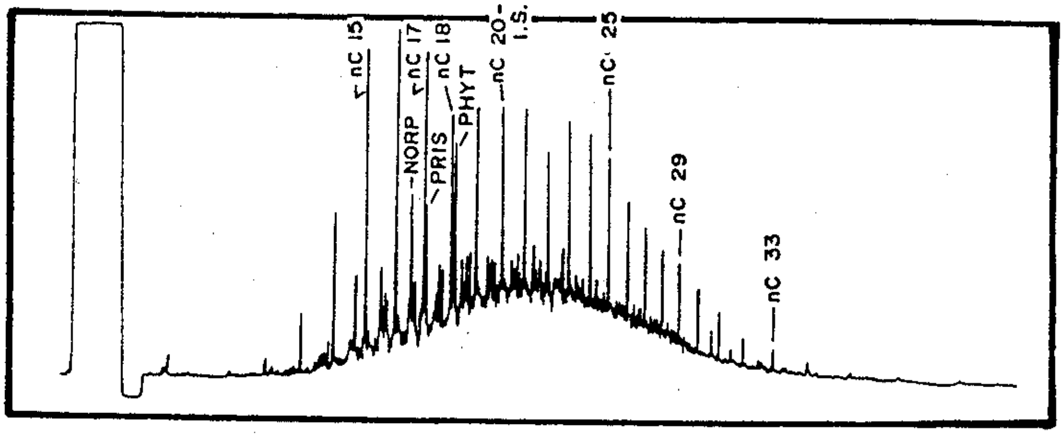


Figure 6.1 (c): Moderately weathered oil



Other areas were exemplified by hydrocarbon compositions made up predominantly of UCM (Type B, Figure 6.1(b)). Some samples, however, were composed of only moderately weathered oil (Type C, Figure 6.1 c). These latter samples include clearly resolved n-alkane components in a typical petroleum related envelope with an underlying UCM.

The suite of samples from Espora Marsh Creek, all from above the spring high water line, included all three of these compositional types, and were also visually different. Sample 52 was a hard, malleable pavement, 53 was soft and oily, whereas 54 was very hard and had to be chipped to collect the sample. The compositional traces differ in a consistent fashion. The soft, oily sample is Type C, only moderately weathered, including n-alkanes from about n-C17 up; the hard, malleable pavement contains resolvable n-alkane from n-C22 up (Type A); and the very hard pavement includes only UCM (Type B).

6.3 Discussion

A comparison of stranded oils collected seven years after the wreck of the Amoco Cadiz in Brittany, and twelve and one-half years after the wreck of the Metula in the Strait of Magellan to the oil spilled experimentally on the beaches at Cape Hatt indicate that, whereas the Cape Hatt oil is weathering slowly, a direct time comparison cannot be made as none of the Amoco Cadiz and few of the Metula samples include marker hydrocarbons.

If it may be assumed that any removal or weathering of the stranded oil will only occur during open water periods, some comparisons may be made. The number of open water months available for removal or weathering of oil at Cape Hatt is estimated as between 12 and 15 by the sampling period in 1987. This estimate is based on calculations from Dickins (1987), who reported open water for 2.5 months after the spill in 1981, 2 months in 1982, and 2 months in 1983. Assuming an average of two months open water per year since that year, the 1985 samples had been subjected to 8.5 open water months, whereas the 1987 samples have been exposed for 12.5 open water months. This figure could be as high as 14.5 months.

By comparison, when the samples were collected from the Amoco Cadiz site, they had been exposed for 84 open water months, and the samples from the Metula site had been exposed for about 150 months.

The BIOS samples collected from the upper ITZ in Bay 11 indicate moderate weathering, whereas those from the mid-ITZ and lower ITZ indicate more advanced weathering. No samples are as weathered as those from the Amoco Cadiz site, which have lost all n-alkane marker compounds and are made up of unresolved complex mixtures (UCM) of alkanes only. The only sample to include any resolved n-alkanes in the range n-C17 and up was a sample from a very low energy area 0.5 m below the spring high water mark (sample AMOCO CADIZ 12, Humphrey and Hope, 1986 page E-4). Unfortunately, no compositional traces made one year after the Amoco Cadiz spill are available for direct comparison.

Most of the samples from the site of the METULA spill are also very weathered. There are, however, a number of samples identified as Type C in composition. These samples appear to be only as weathered as many BIOS samples. All such samples were collected from semi-terrestrial (at or above the spring high water mark) locations in the strait, and should therefore be compared to samples from BIOS plots T1, T2, IMC and IME. Figure 6.2 presents a compositional trace from a site 3 km south of Punta Baxa, above the spring high water line, and a trace from the 1987 sample collected at plot IMC-m. The BIOS sample appears only slightly less weathered than the Metula sample. As the Strait of Magellan is open all year, although the temperature may be at or below freezing, it is likely that the Type C samples are not subjected to marine degradation, but are in fact terrestrial.

7.0 CONCLUSIONS

Several significant points have emerged from the study and these are summarized in point form with cross references to the relevant sections of text in which they are discussed.

1. The oil-in-sediments concentrations on the backshore control plots at Crude Oil Point (T1 and T2) have changed little since 1980 (Section 3.2.1) and little weathering has taken place since 1985 (Section 3.2.2). Changes that have occurred in the total hydrocarbon analytical results from year to year may be considered artifacts of the sampling from sections of the plots with different sediment size distributions (Section 3.2.1).

2. In the event that further samples are collected from Crude Oil Point we recommend that stratified sampling be used, with samples taken from sections of the plots with visually different grain size characteristics, and that grain size determinations be performed along with the chemical analyses (Section 3.3).

3. The oil-in-sediment concentrations on the Bay 106 backshore plots (IMC and IME) had changed little since 1983 (Section 4.2.1) and the weathering ratios had changed little since 1985 (Section 4.2.2). A reduction in the surface and an increase in the subsurface total hydrocarbon values on sections of the berm between 1985 and 1987 likely resulted from sediment reworking by wave action between the two sample intervals (Section 4.3).

4. No pavement has formed on any sections of the the plots at either of the backshore control sites (Crude Oil Point and Bay 106). It can be assumed, therefore, that the processes which control the formation of an asphalt pavement are connected to the interaction of stranded oil with (sea) water, probably through the formation of a hard surface crust (Section 3.3).

5. Oil remains on the Bay 11 intertidal zone, although 85% of the beach is now visually clean after just over one year of cumulative open water conditions (in 1981 only 42% of the intertidal zone was visually clean) (Section 5.2.1). The oil cover and the total volume of remaining oil continued to decrease when compared to previous surveys (Sections 5.2.2 and 5.2.3).

6. The asphalt pavement is the dominant feature of the Bay 11 oil cover and accounts for approximately 60% of the remaining oil, although it has an area of only 220 m^2 out of a total oil cover of 2240 m^2 (Section 5.2.5). The area of the pavement did not decrease between 1985 and 1987 although physically the pavement was soft compared to 1983 and 1985 observations (Section 5.2.5).

7. Total hydrocarbon concentrations remain high in the Bay 11 pavement samples (mean 16,200 $mg \cdot kg^{-1}$)(Section 5.2.2) and those samples with high oil concentrations remain relatively unweathered (Section 5.2.4). Areas that were considered to be visually clean, such as the mid-beach trough, were found to contain oil with oil-in-sediment concentrations of the order of 2000 $mg \cdot kg^{-1}$ to 4,100 $mg \cdot kg^{-1}$ (0.2 to 0.4% by weight) (Section 5.3).

8. Sampling is clearly an important issue when dealing with oil containing sediments. A data set can be skewed by one sample (e.g. Bay 11 subsurface t-h results; Section 5.2.2 and Table 5.5) or by variations in grain size within a plot (e.g. T1 surface t-h results; Section 3.3).

9. It has become evident that the visual and chemical observations generally support each other. This has an important implication as it means that observations and data from other studies, such as the Amoco Cadiz and Metula site visits, can be used with a degree of confidence for comparison with the BIOS results.

The samples from the asphalt pavements of the Metula spill area show that high oil concentrations (up to 50,000 $mg \cdot kg^{-1}$, 5% by weight) remain after 12 1/2 years and there are a range of weathered oil types, with some being relatively unweathered whereas other pavement samples contain predominantly UCMs. Higher oil concentrations are evident from sand sediments whereas lower concentrations are associated with sand-cobble material (Section 6.2).

8.0 ACKNOWLEDGMENTS

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APPENDIX A

BAFFIN ISLAND OIL SPILL

SHORELINE EXPERIMENTS
TOTAL HYDROCARBON
AND
COMPOSITIONAL GC
RESULTS

SUBTIDAL SEDIMENTS
RESULTS

APPENDIX A: SAMPLE LOG AND RESULTS, CAPE HATT

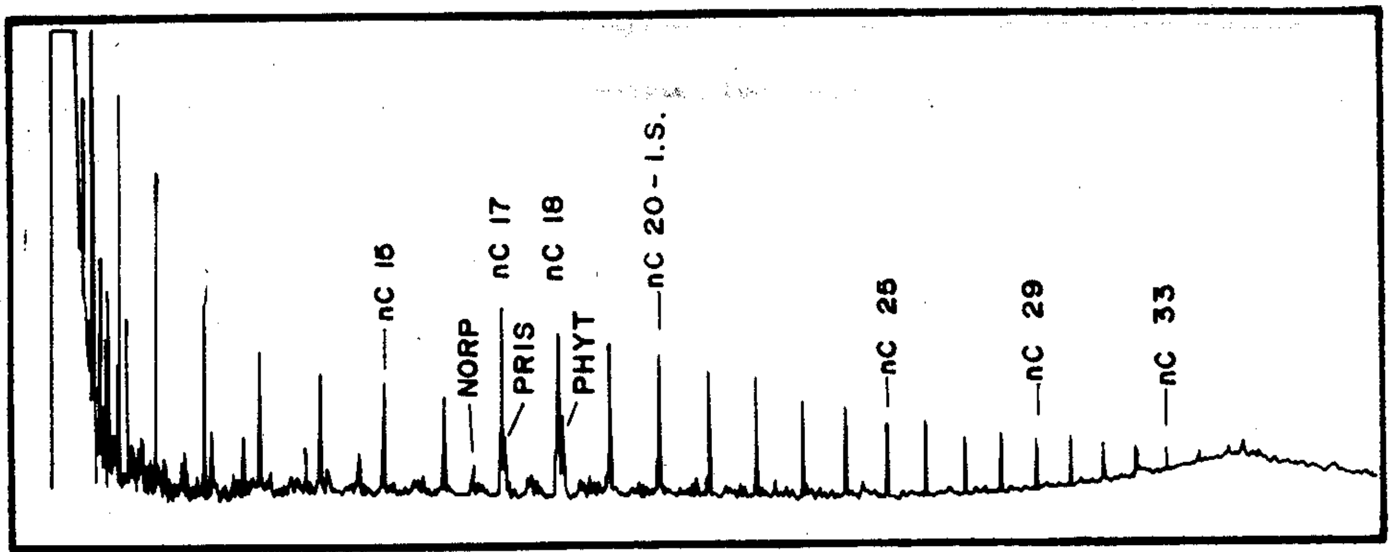
SAMPLE NUMBER	DATE	TIME	PLOT	SITE	STRATUM	ANALYSIS	[OIL] mg kg^{-1}	COMMENT
7001	870811	1435	T1	TOP, EAST	SURF	THC/IR	3.9E+04	
7002	870811	1435	T1	TOP, EAST	SUB	THC/IR	1.1E+04	
7003	870811	1436	T1	BOTTOM, EAST	SURF	THC/IR	2.7E+04	
7004	870811	1436	T1	BOTTOM, EAST	SUB	THC/IR	2.6E+04	
7005	870811	1439	T1	TOP, WEST	SURF	THC/IR	2.3E+04	
7006	870811	1439	T1	TOP, WEST	SUB	THC/IR	1.4E+04	
7007	870811	1442	T1	BOTTOM, WEST	SURF	THC/IR	1.9E+04	
7008	870811	1442	T1	BOTTOM, WEST	SUB	THC/IR	1.8E+04	
7009	870811	1443	T2	TOP, EAST	SURF	THC/IR	2.0E+04	
7010	870811	1444	T2	TOP, EAST	SUB	THC/IR	1.2E+04	
7011	870811	1445	T2	BOTTOM, EAST	SURF	THC/IR	2.6E+04	
7012	870811	1446	T2	BOTTOM, EAST	SUB	THC/IR	1.6E+04	
7013	870811	1447	T2	MID, CENTER	SURF	THC/IR	4.0E+04	
7014	870811	1447	T2	MID, CENTER	SUB	THC/IR	2.4E+04	
7015	870811	1449	T2	BOTTOM, CENTER	SURF	THC/IR	1.9E+04	
7016	870811	1449	T2	BOTTOM, CENTER	SUB	THC/IR	1.4E+04	
7017	870811	1626	IMC-c	BERM	SURF	THC/IR	1.7E+04	
7018	870811	1626	IMC-c	BERM	SUB	THC/IR	2.4E+04	
7019	870811	1626	IMC-c	BACKSHORE	SURF	THC/IR	2.5E+04	
7020	870811	1626	IMC-c	BACKSHORE	SUB	THC/IR	1.2E+03	
7021	870811	1628	IMC-c	BERM	SURF	THC/IR	2.3E+04	
7022	870811	1628	IMC-c	BERM	SUB	THC/IR	1.5E+04	
7023	870811	1629	IMC-c	BACKSHORE	SURF	THC/IR	8.4E+03	
7024	870811	1629	IMC-c	BACKSHORE	SUB	THC/IR	7.8E+02	
7025	870811	1630	IMC-m	BERM	SURF	THC/IR	8.4E+03	
7026	870811	1630	IMC-m	BERM	SUB	THC/IR	3.4E+03	
7027	870811	1631	IMC-m	BACKSHORE	SURF	THC/IR	6.7E+03	
7028	870811	1632	IMC-m	BACKSHORE	SUB	THC/IR	4.2E+03	
7029	870811	1633	IMC-m	BERM	SURF	THC/IR	1.7E+04	
7030	870811	1633	IMC-m	BERM	SUB	THC/IR	2.5E+04	
7031	870811	1634	IMC-m	BACKSHORE	SURF	THC/IR	1.4E+04	
7032	870811	1635	IMC-m	BACKSHORE	SUB	THC/IR	7.0E+03	
7033	870811	1636	IME-m	BERM	SURF	THC/IR	1.0E+04	
7034	870811	1636	IME-m	BERM	SUB	THC/IR	1.1E+04	
7035	870811	1367	IME-m	BACKSHORE	SURF	THC/IR	7.9E+03	
7036	870811	1637	IME-m	BACKSHORE	SUB	THC/IR	4.4E+02	
7037	870811	1638	IME-m	BERM	SURF	THC/IR	7.1E+03	
7038	870811	1639	IME-m	BERM	SUB	THC/IR	5.6E+03	
7039	870811	1640	IME-m	BACKSHORE	SURF	THC/IR	1.4E+04	
7040	870811	1641	IME-m	BACKSHORE	SUB	THC/IR	1.4E+04	
7041	870811	1642	IME-c	BERM	SURF	THC/IR	8.5E+03	
7042	870811	1643	IME-c	BERM	SUB	THC/IR	8.8E+03	
7043	870811	1643	IME-c	BACKSHORE	SURF	THC/IR	1.4E+04	
7044	870811	1644	IME-c	BACKSHORE	SUB	THC/IR	1.2E+03	
7045	870811	1645	IME-c	BERM	SURF	THC/IR	6.3E+03	
7046	870811	1645	IME-c	BERM	SUB	THC/IR	5.7E+03	
7047	870811	1646	IME-c	BACKSHORE	SURF	THC/IR	2.0E+04	
7048	870811	1647	IME-c	BACKSHORE	SUB	THC/IR	6.4E+02	
7049	870811	1004	BAY 11	601	SURF	THC/IR	3.5E+04	PAVEMENT

APPENDIX A: SAMPLE LOG AND RESULTS, CAPE HATT

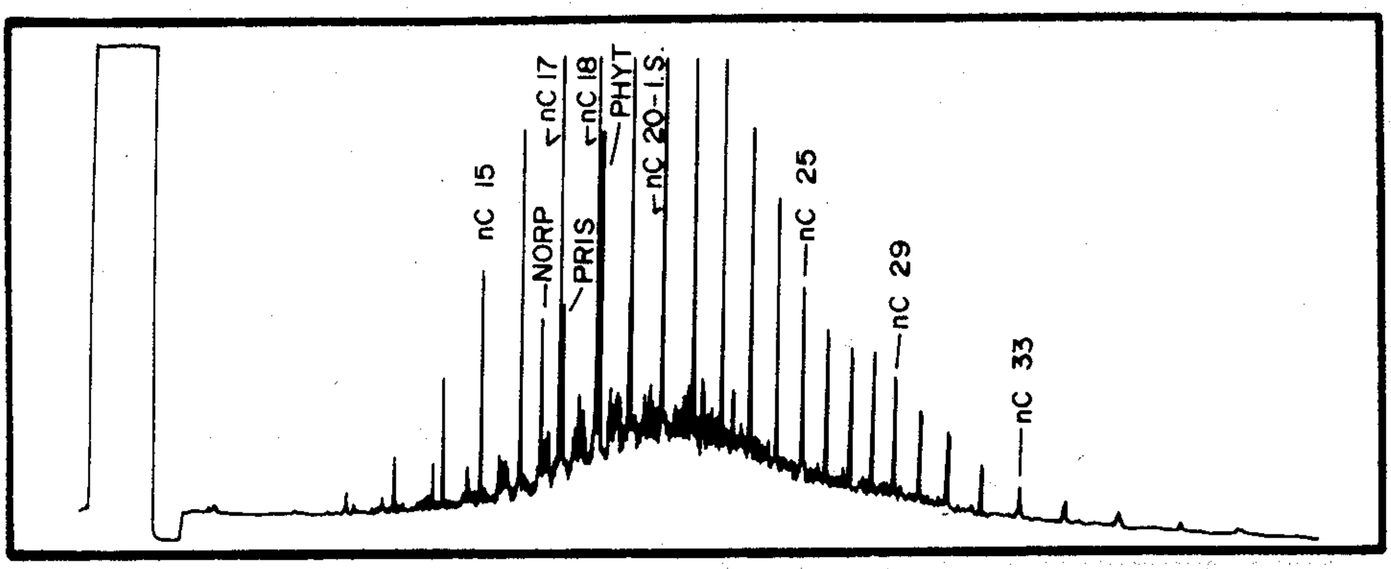
SAMPLE NUMBER	DATE	TIME	PLOT	SITE	STRATUM	ANALYSIS	[OIL] mg kg^{-1}	COMMENT
7050	870812	1005	BAY 11	601	SUB	THC/IR	1.9E+04	PAVEMENT
7051	870812	1003	BAY 11	602	SURF	THC/IR	4.2E+03	SEDS APPEAR CLEAN, BUT ARE OILY
7052	870812	1003	BAY 11	602	SUB	THC/IR	2.2E+03	SEDS APPEAR CLEAN, BUT ARE OILY
7053	870812	1000	BAY 11	603	SURF	THC/IR	3.9E+01	?CLEAN
7054	870812	1001	BAY 11	603	SUB	THC/IR	6.9E+01	?CLEAN
7055	870812	1017	BAY 11	801	SURF	THC/IR	5.0E+01	?CLEAN
7056	870812	1017	BAY 11	801	SUB	THC/IR	2.4E+01	?CLEAN
7057	870812	1014	BAY 11	802	SURF	THC/IR	3.5E+01	NO SHEEN IN HOLE
7058	870812	1015	BAY 11	802	SUB	THC/IR	3.2E+01	NO SHEEN IN HOLE
7059	870812	1012	BAY 11	803	SURF	THC/IR	1.2E+01	?CLEAN
7060	870812	1013	BAY 11	803	SUB	THC/IR	8.8E+00	?CLEAN
7061	870812	1032	BAY 11	201	SURF	THC/IR	2.4E+01	?CLEAN
7062	870812	1033	BAY 11	201	SUB	THC/IR	9.6E+00	?CLEAN
7063	870812	1030	BAY 11	202	SURF	THC/IR	5.9E+02	SOME SHEEN
7064	870812	1028	BAY 11	202	SUB	THC/IR	6.3E+02	SOME SHEEN
7065	870812	1028	BAY 11	203	SURF	THC/IR	3.3E+01	SPECKLED ROCKS
7066	870812	1050	BAY 11	203	SUB	THC/IR	2.9E+01	
7067	870812	1050	BAY 11	401	SURF	THC/IR	1.4E+04	ASPHALT PAVEMENT, NOT SOLID BUT OILY
7068	870812	1051	BAY 11	401	SUB	THC/IR	6.2E+02	ASPHALT PAVEMENT, NOT SOLID BUT OILY
7069	870812	1047	BAY 11	402	SURF	THC/IR	4.6E+02	?CLEAN
7070	870812	1048	BAY 11	402	SUB	THC/IR	5.0E+02	?CLEAN
7071	870812	1044	BAY 11	403	SURF	THC/IR	LOST	?CLEAN
7072	870812	1113	BAY 11	403	SUB	THC/IR	4.8E+01	?CLEAN
7073	870812	1113	BAY 11	NEAR 403	SURF	THC/IR	7.5E+03	LOW TIDE RIDGE, BROWN PATCH
7074	870812	1119	BAY 11	NEAR 403	SUB	THC/IR	1.4E+03	LOW TIDE RIDGE, BROWN PATCH
7075	870812	1117	BAY 11	NEAR 401	SURF	THC/IR	2.4E+04	ASPHALT PAVEMENT
7076	870812	1120	BAY 11	302	SURF	THC/IR	5.5E+03	SLIGHT SHEEN, MID ITZ
7077	870812	1122	BAY 11	NEAR 203	SURF	THC/IR	9.2E+02	LOW TIDE RIDGE, COARSE SEDIMENTS
7078	870812	1124	BAY 11	NEAR 203	SURF	THC/IR	4.0E+03	LOW TIDE RIDGE, FINE & COARSE SEDIMENTS
7079	870812	1138	BAY 11	NEAR 301	SURF	THC/IR	1.3E+04	ASPHALT PAVEMENT
7080	870812	1148	BAY 11	NEAR 501	SURF	THC/IR	6.8E+03	ASPHALT PAVEMENT
7081	870812	1202	BAY 11	NEAR 701	SURF	THC/IR	4.5E+03	ASPHALT PAVEMENT
7082	870812	1205	BAY 11	(503+603)/2	SURF	THC/IR	7.3E+03	LOW TIDE RIDGE, FINE & COARSE SEDIMENTS
7083	870812	1207	BAY 11	NEAR 503	SURF	THC/IR	1.2E+04	LOW TIDE RIDGE, BROWN PATCH

APPENDIX A: SAMPLE LOG AND RESULTS, CAPE HATT

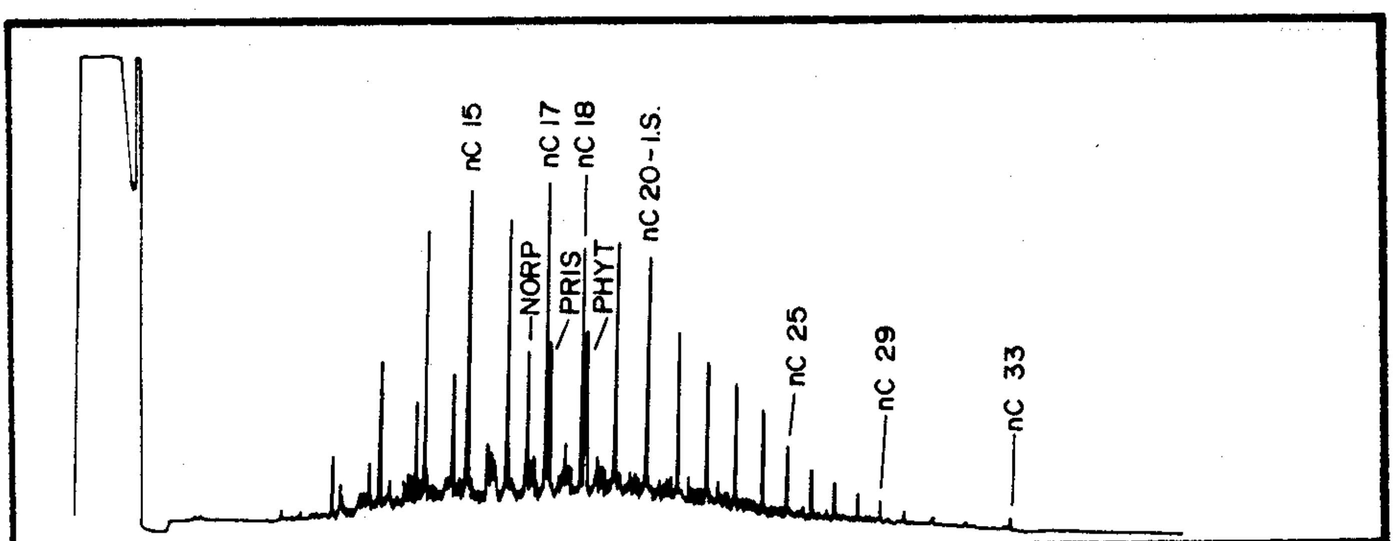
SAMPLE NUMBER	DATE	TIME	PLOT	SITE	STRATUM	ANALYSIS	
7101	870811	1423	T1	TOP	SURF	GC COMPO	
7102	870811	1424	T1	TOP	SUB	GC COMPO	
7103	870811	1426	T1	BOTTOM	SURF	GC COMPO	
7104	870811	1427	T1	BOTTOM	SUB	GC COMPO	
7105	870811	1428	T2	TOP	SURF	GC COMPO	
7106	870811	1428	T2	TOP	SUB	GC COMPO	
7107	870811	1429	T2	BOTTOM	SURF	GC COMPO	
7108	870811	1430	T2	BOTTOM	SUB	GC COMPO	
7109	870811	1616	IMC-c		SURF	GC COMPO	
7110	870811	1616	IMC-c		SUB	GC COMPO	
7111	870811	1617	IMC-m		SURF	GC COMPO	
7112	870811	1617	IMC-m		SUB	GC COMPO	
7113	870811	1618	IME-m		SURF	GC COMPO	
7114	870811	1618	IME-m		SUB	GC COMPO	
7115	870811	1619	IME-c		SURF	GC COMPO	
7116	870811	1619	IME-c		SUB	GC COMPO	
7117	870812	955	BAY 11	601	SURF	GC COMPO	FRESH
7118	870812	955	BAY 11	602	SURF	GC COMPO	
7119	870812	957	BAY 11	603	SURF	GC COMPO	
7120	870812	1009	BAY 11	801	SURF	GC COMPO	
7121	870812	1010	BAY 11	802	SURF	GC COMPO	
7122	870812	1011	BAY 11	803	SURF	GC COMPO	
7123	870812	1040	BAY 11	401	SURF	GC COMPO	NOT ASPHALT PAVEMENT, BUT VERY OILY
7124	870812	1041	BAY 11	402	SURF	GC COMPO	SHEEN
7125	870812	1043	BAY 11	403	SURF	GC COMPO	
7126	870812	1023	BAY 11	201	SURF	GC COMPO	NO SHEEN
7127	870812	1024	BAY 11	202	SURF	GC COMPO	OIL COATED?
7128	870812	1026	BAY 11	203	SURF	GC COMPO	OIL COATED?
7129	870812	1112	BAY 11	NEAR 403	SURF	GC COMPO	LOW TIDE RIDGE, BROWN PATCH
7130	870812	1116	BAY 11	NEAR 401	SURF	GC COMPO	SOLID BUT CRUMBLY PAVEMENT
7131	870812	1110	BAY 11	NEAR 401	SURF	GC COMPO	CREEK EDGE, FRESH
7132	870812	1147	BAY 11	NEAR 501	SURF	GC COMPO	PAVEMENT
7133	870812	1100	BAY 11		SUBTIDAL	GC/GCMS/UV	2M AT 1/3 FLOOD
7134	870812	1100	BAY 11		SUBTIDAL	GC/GCMS/UV	3M AT 1/3 FLOOD
7135	870812	1100	BAY 11		SUBTIDAL	GC/GCMS/UV	4.6M AT 1/3 FLOOD
7136	870812	1100	BAY 11		SUBTIDAL	GC/GCMS/UV	4.1M AT 1/3 FLOOD



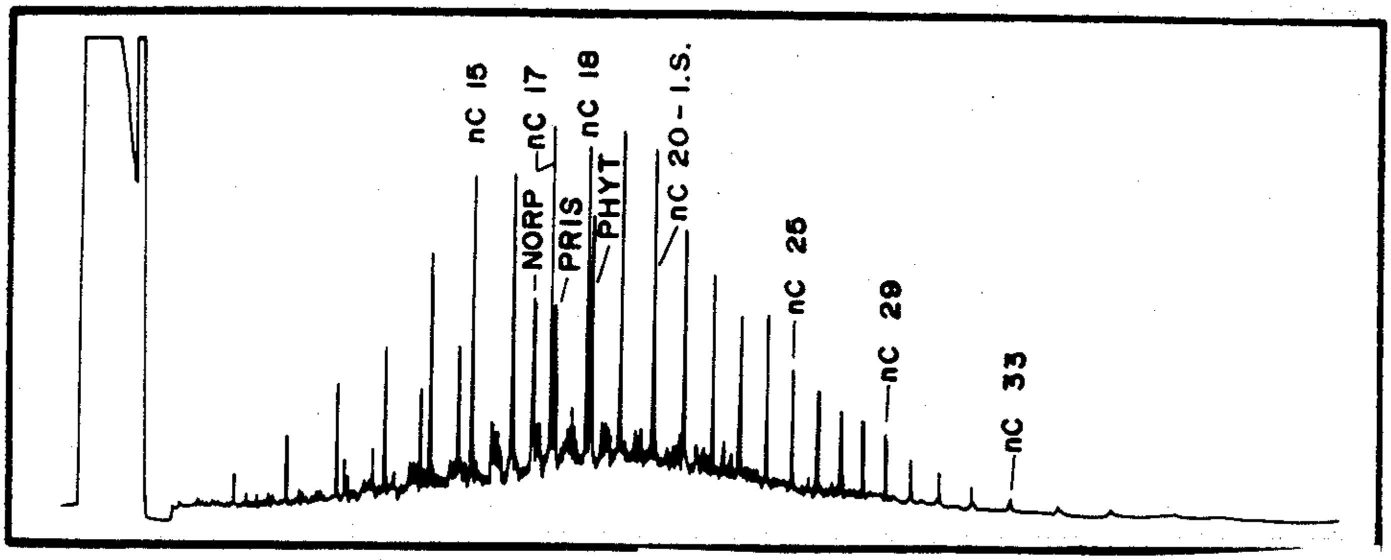
Lago Medio Crude Oil



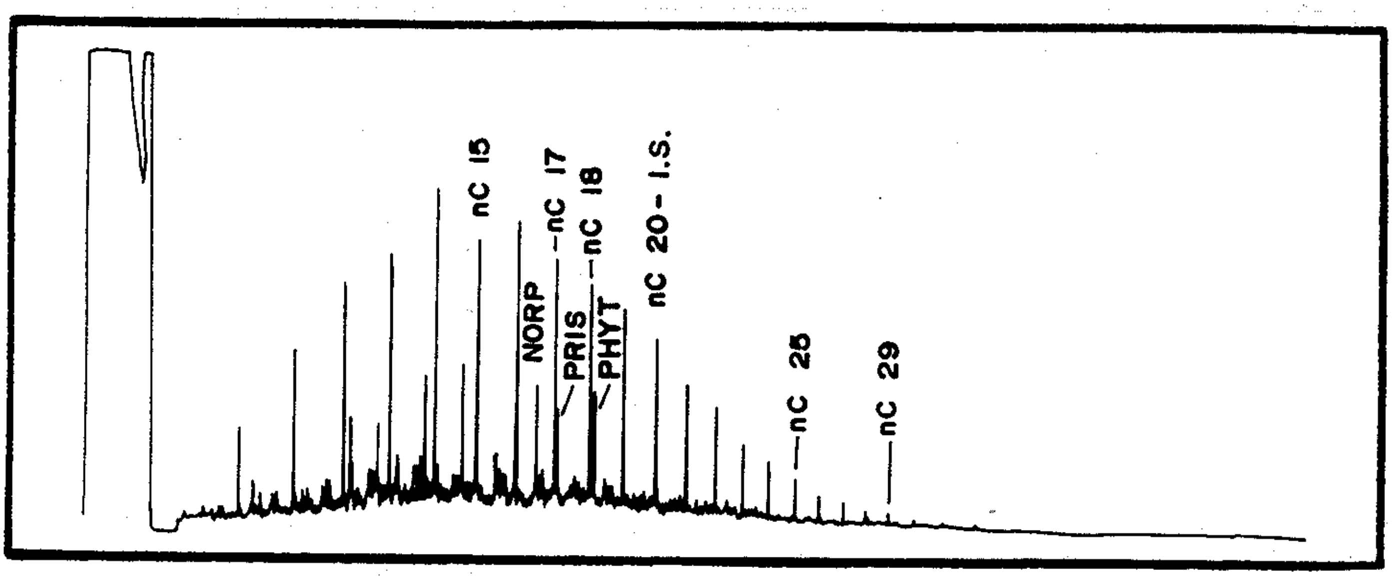
T1 TOP, EAST surf 7101



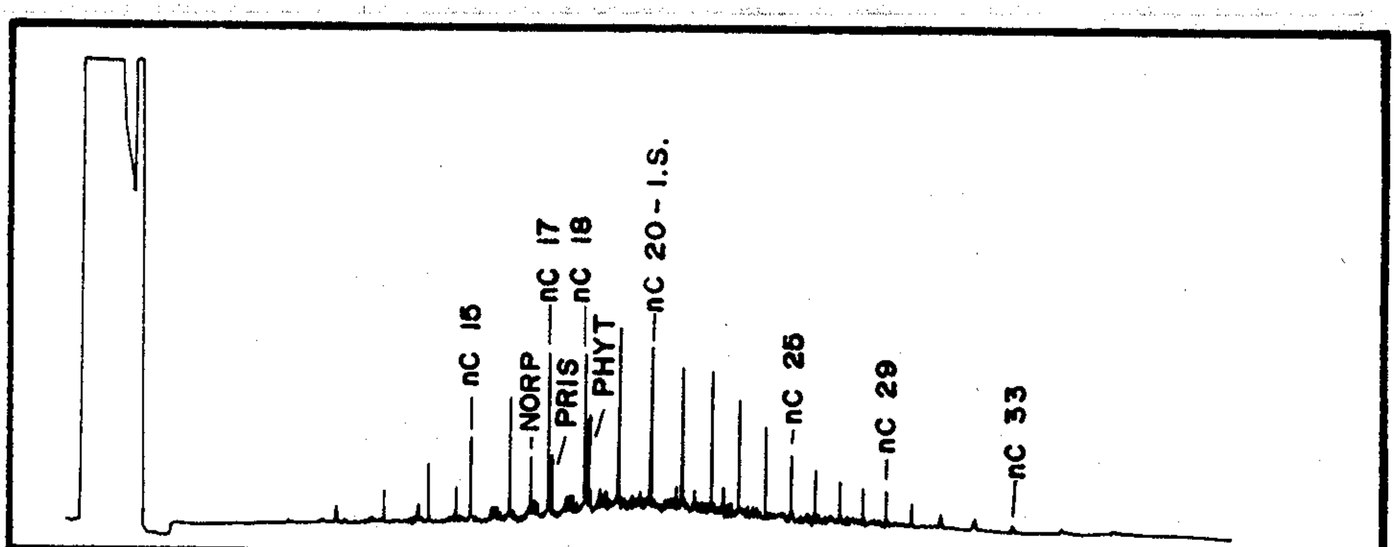
T1 TOP, EAST sub 7102



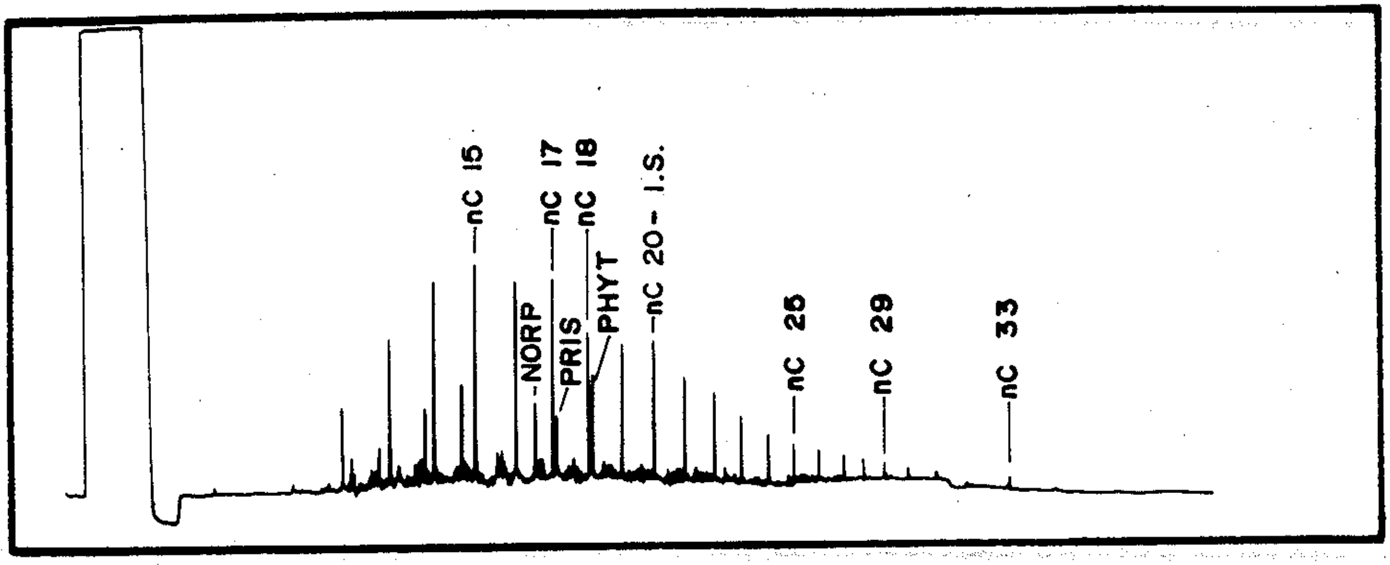
T1 TOP,WEST surf 7103



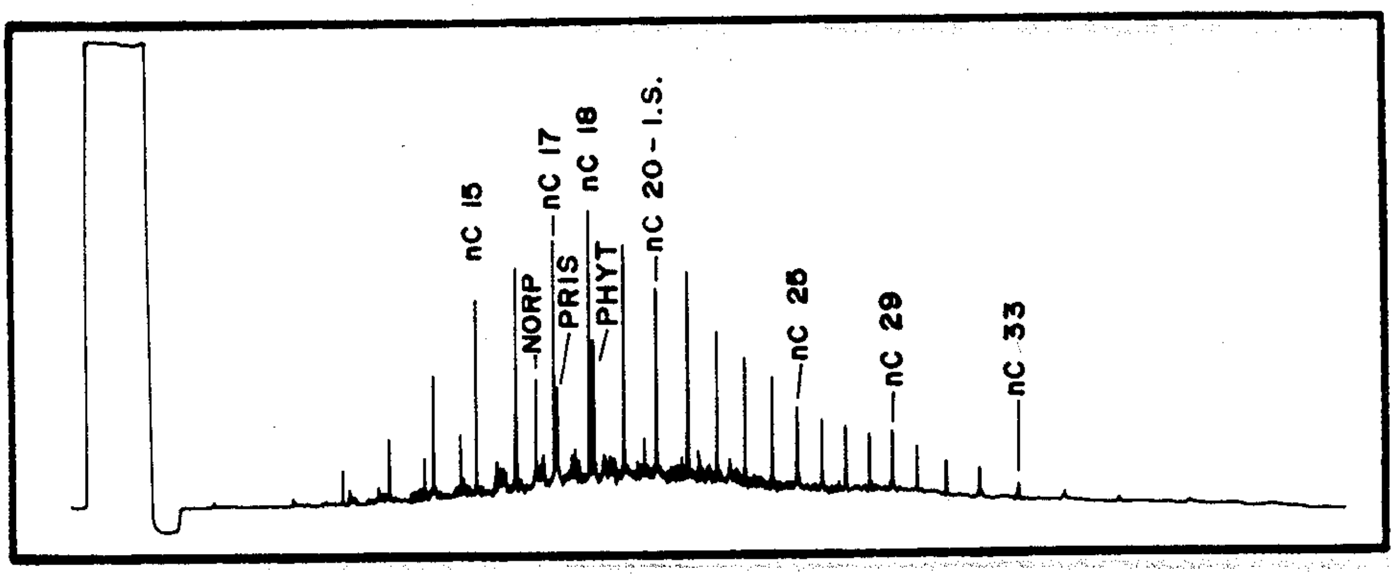
T1 TOP,WEST sub 7104



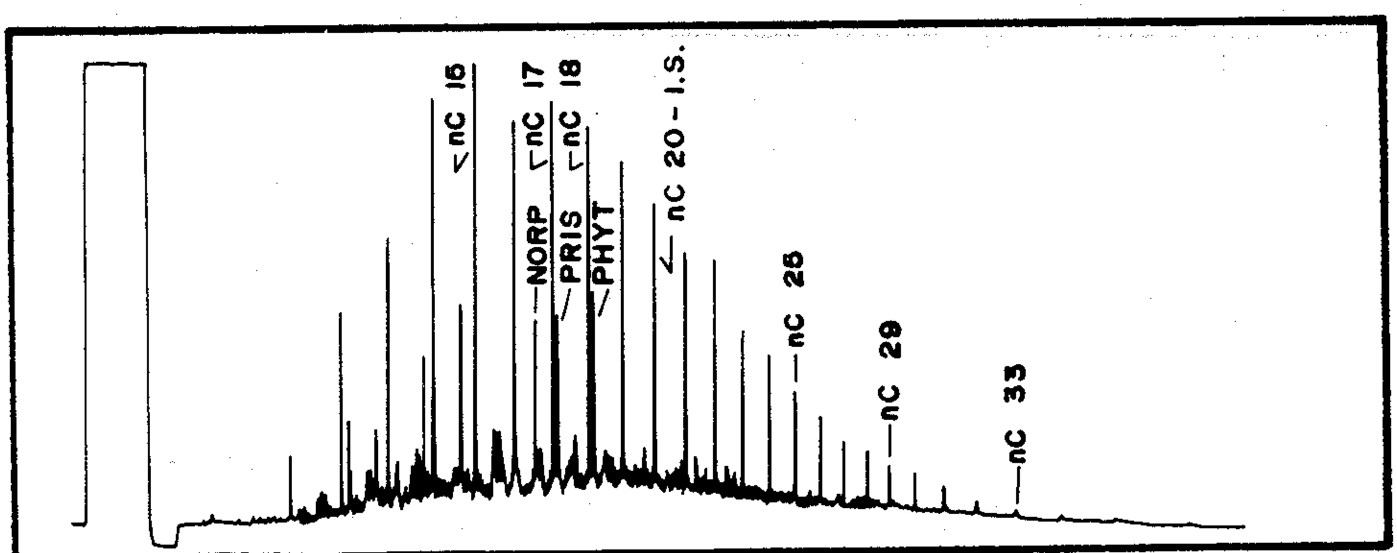
T2 TOP,EAST surf 7105



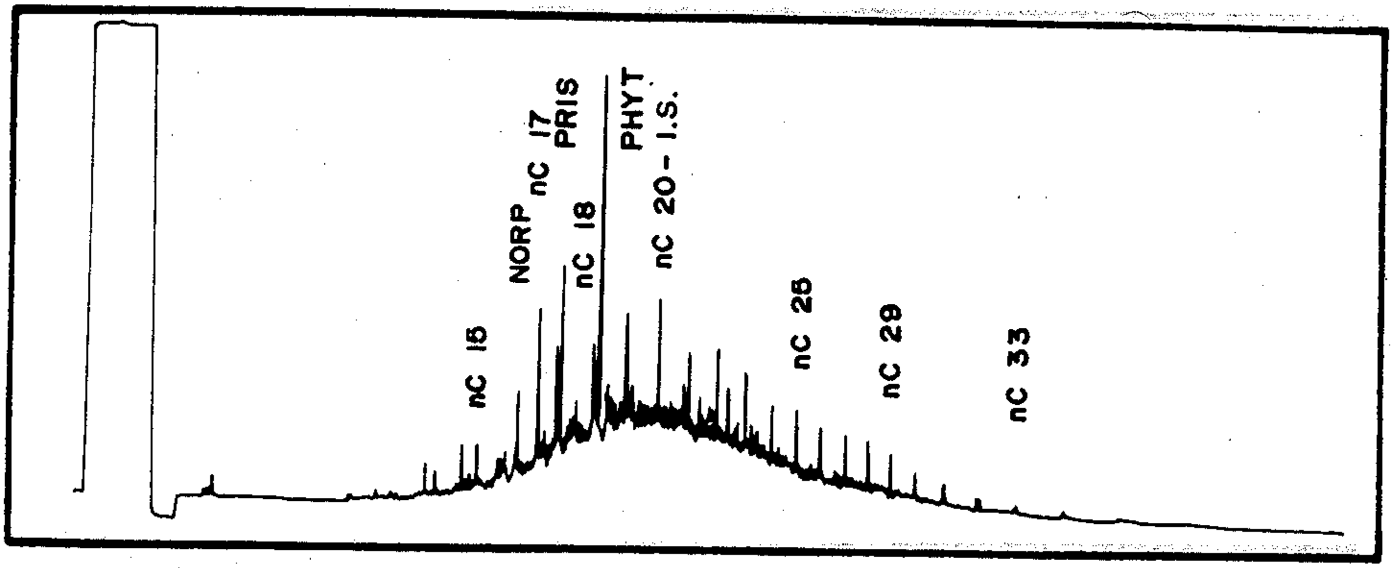
T2 TOP,EAST sub 7106



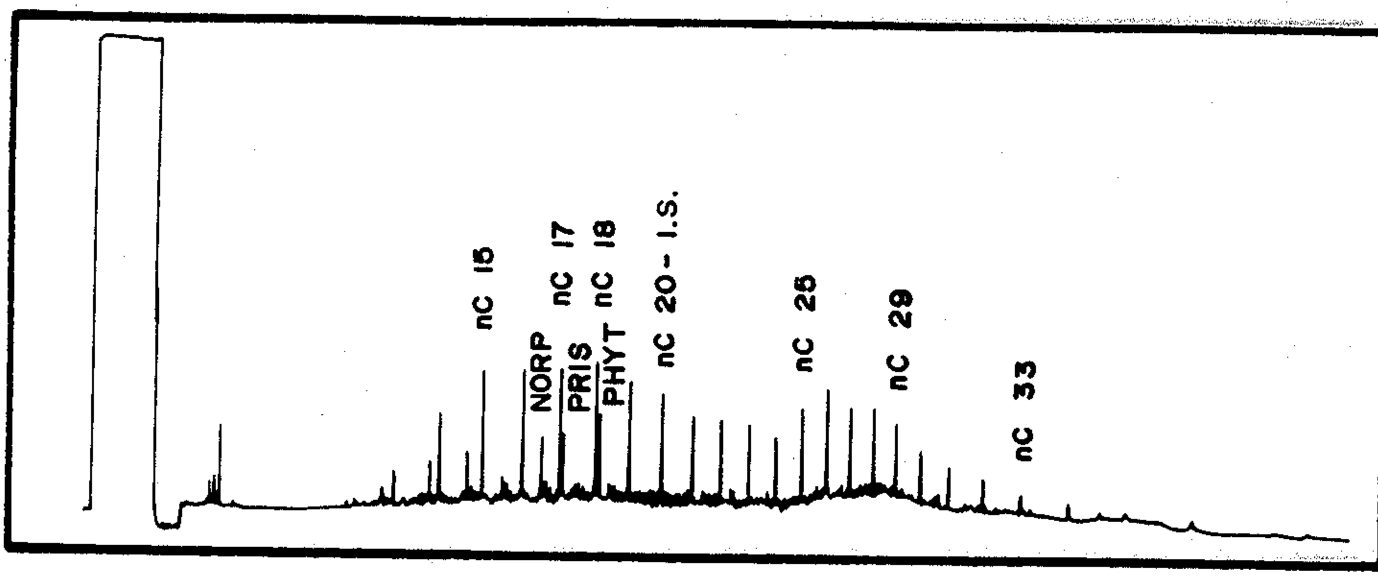
T2 TOP,WEST surf 7107



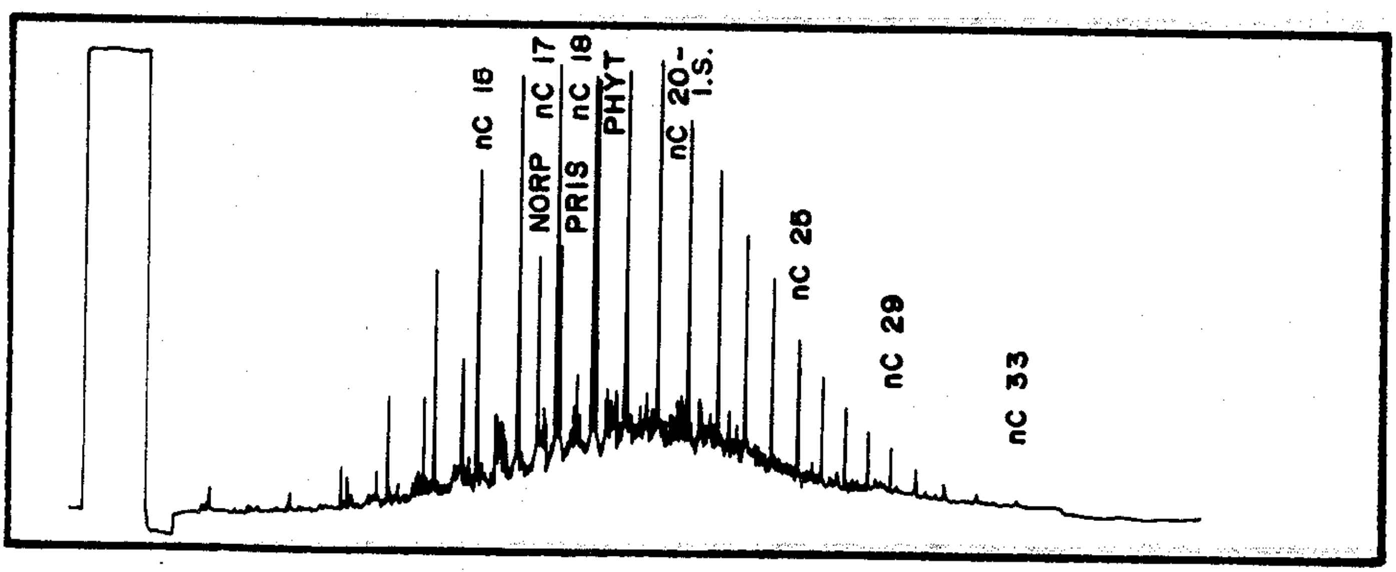
T2 TOP,WEST sub 7108



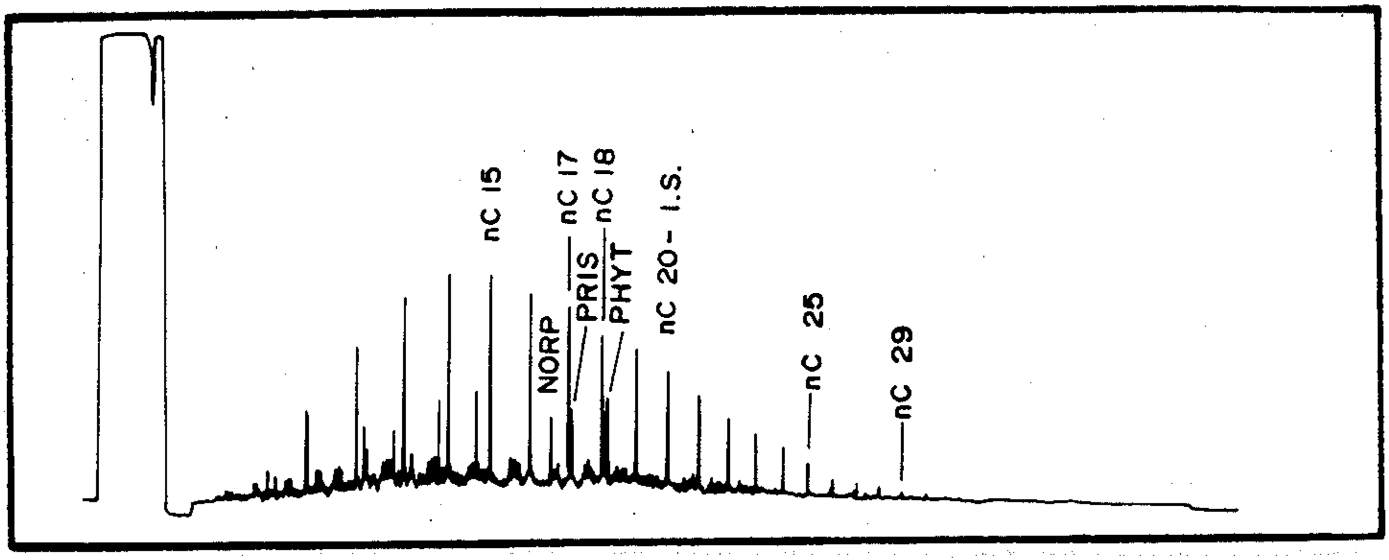
IMC-Co BERM surf 7109



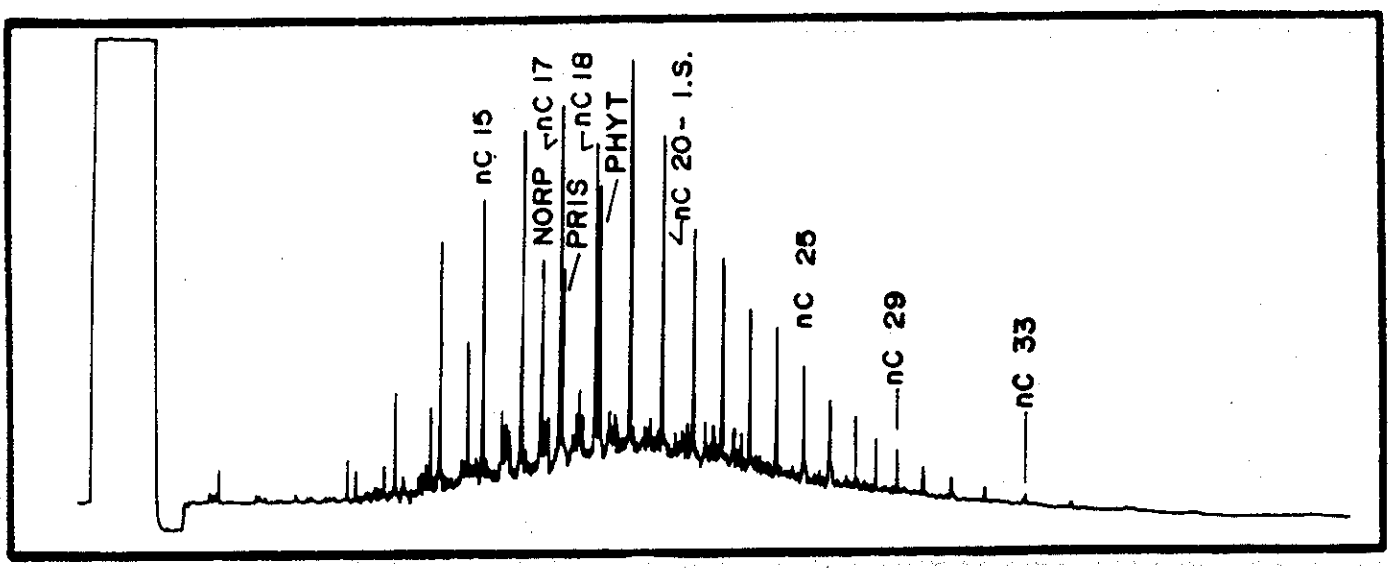
IMC-Co BERM sub 7110



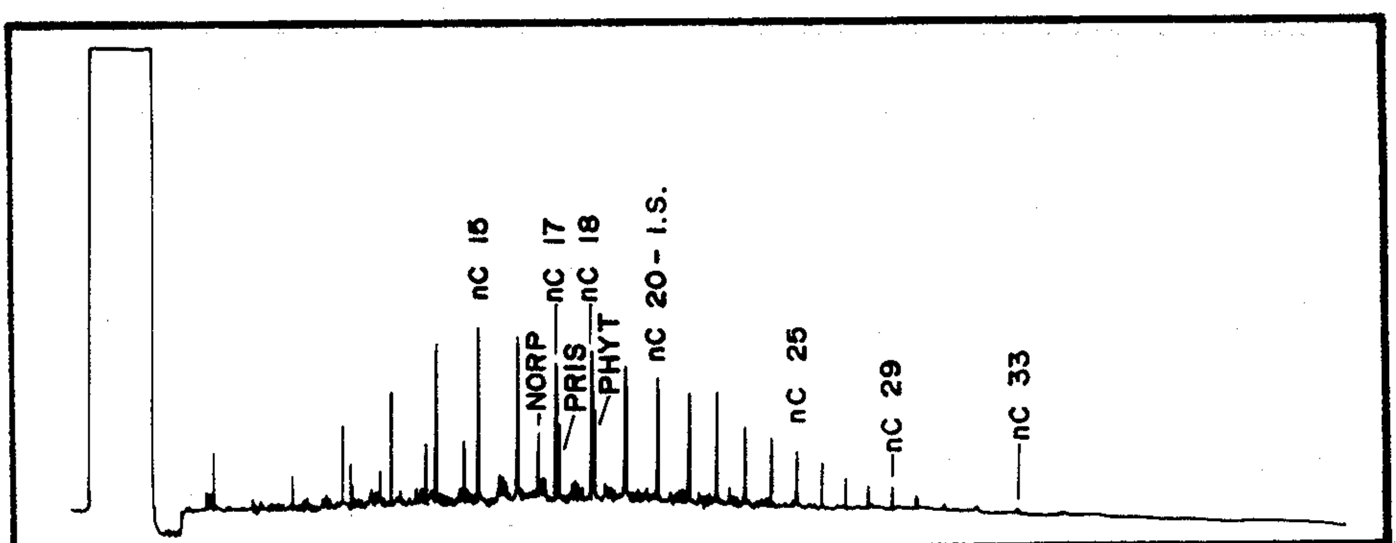
IMC-Mix BERM surf 7111



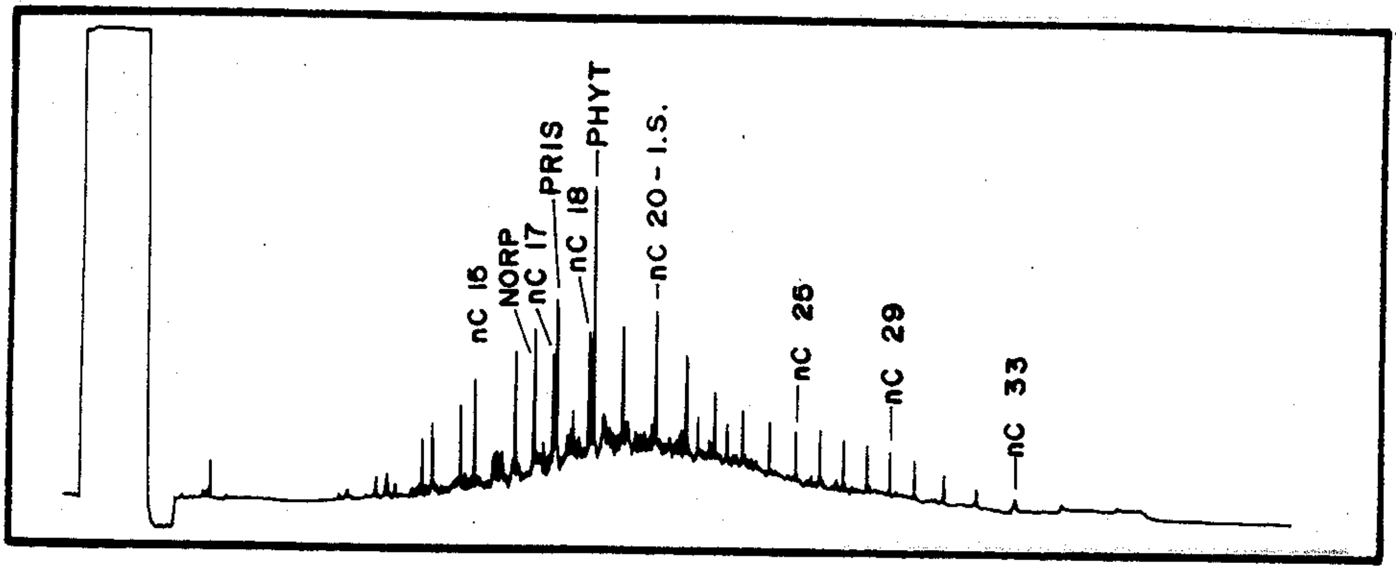
IMC-Mix BERM sub 7112



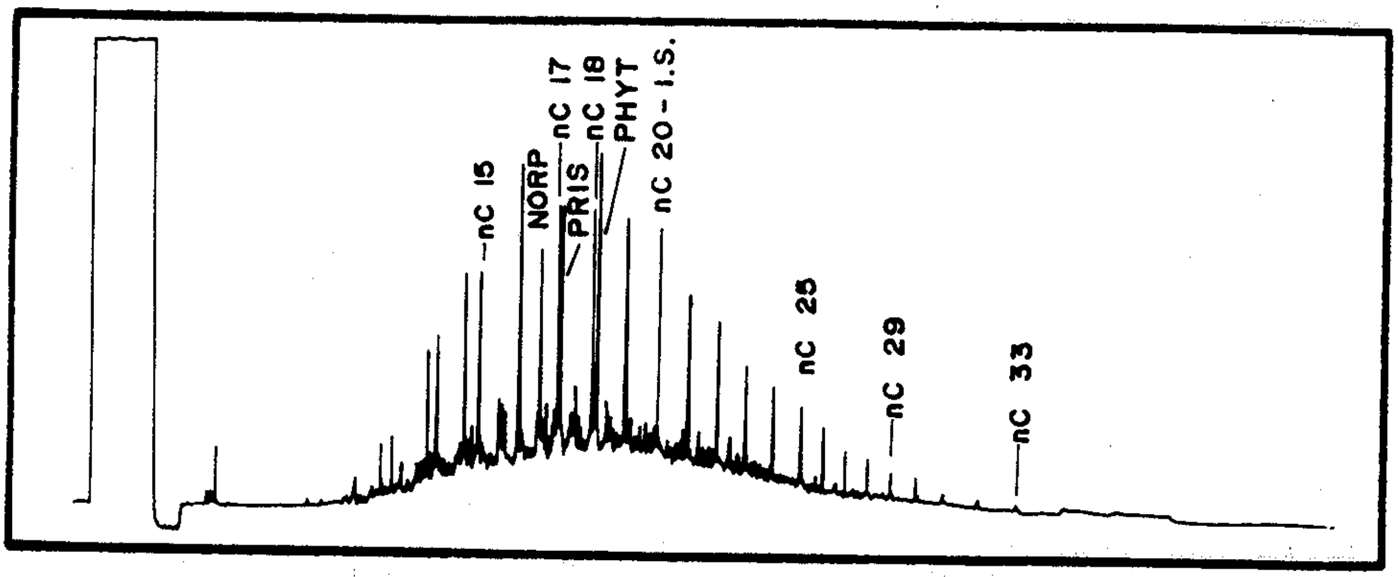
IME-Mix BERM surf 7113



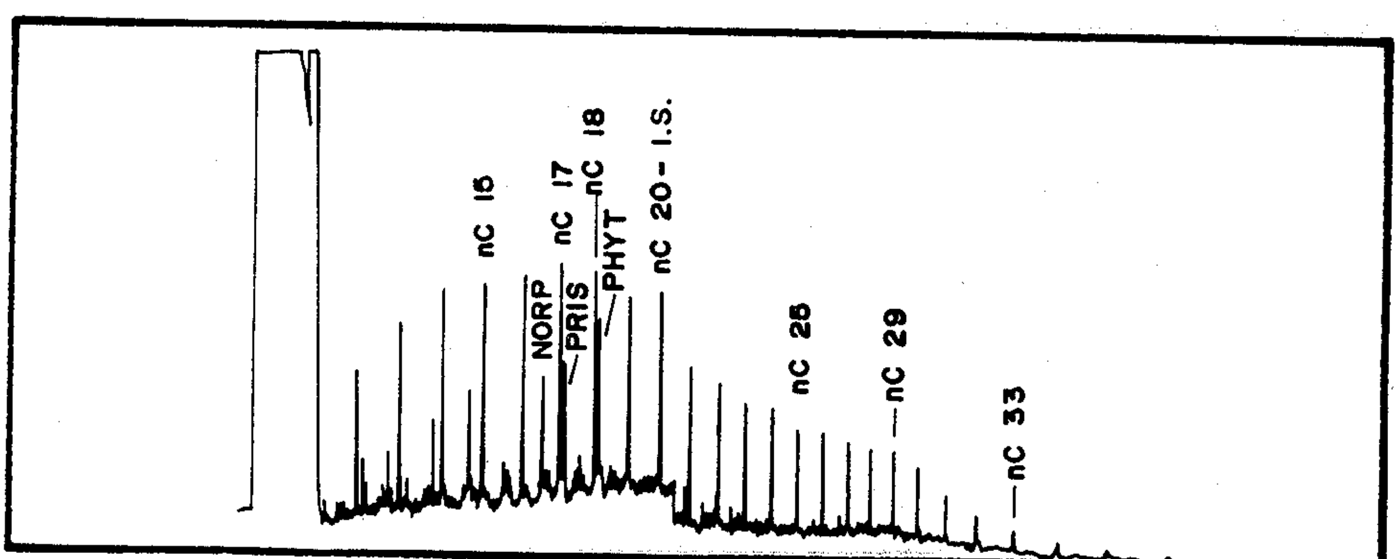
IME-Mix BERM sub 7114



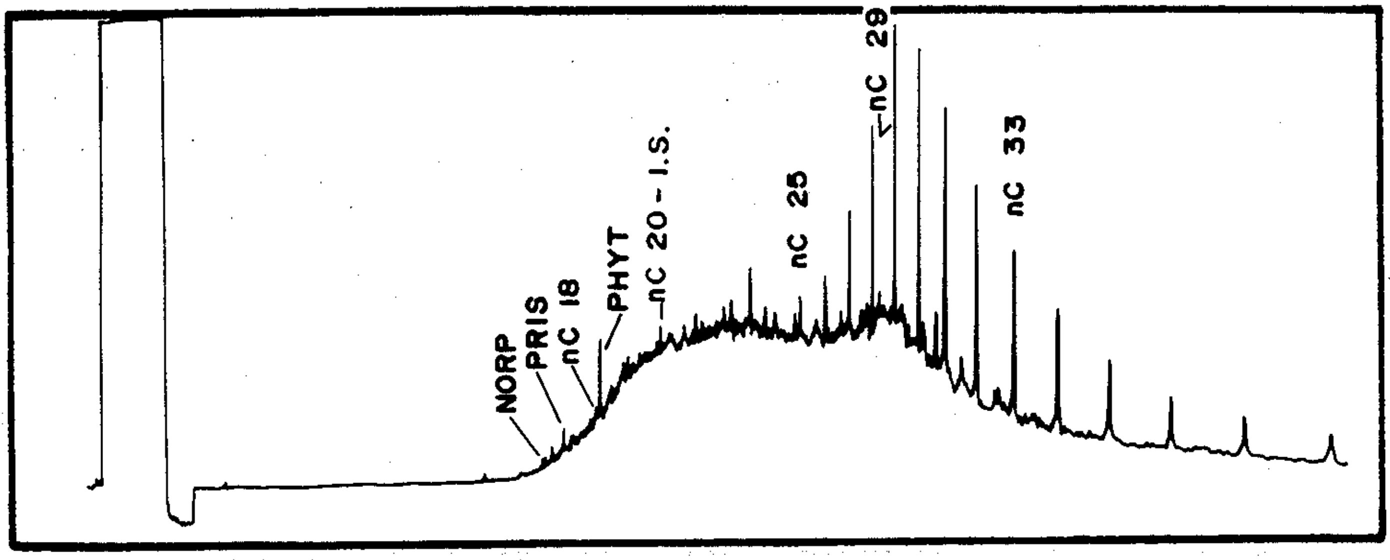
IME-Co BERM surf 7115



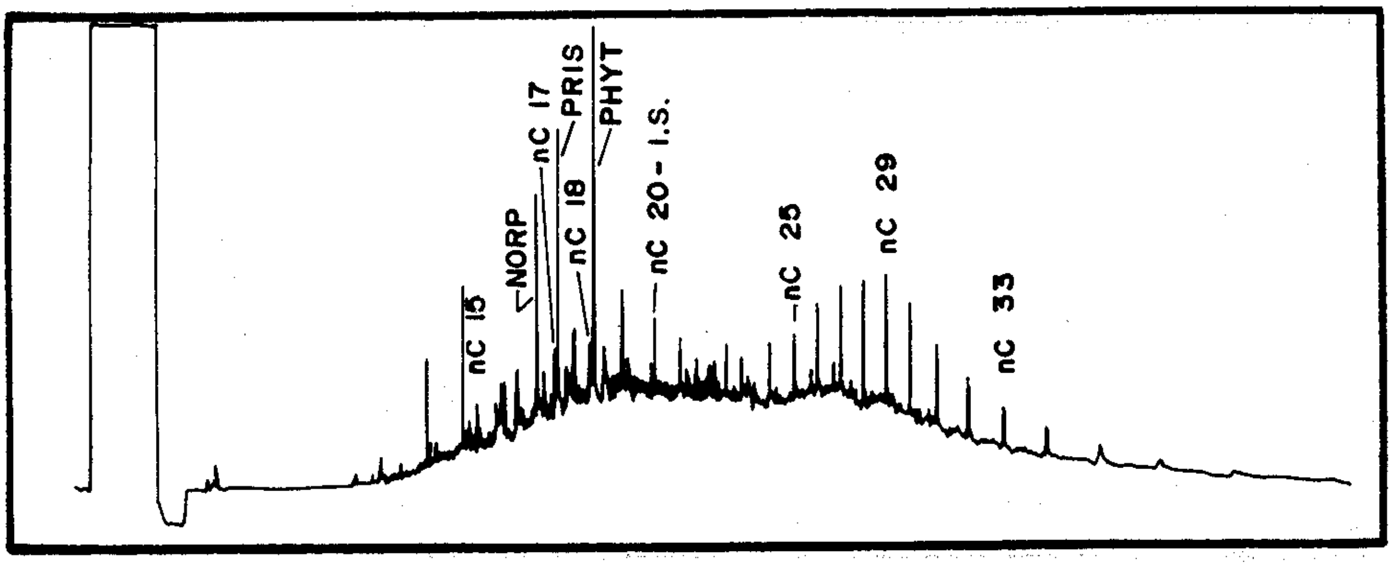
IME-Co BERM sub 7116



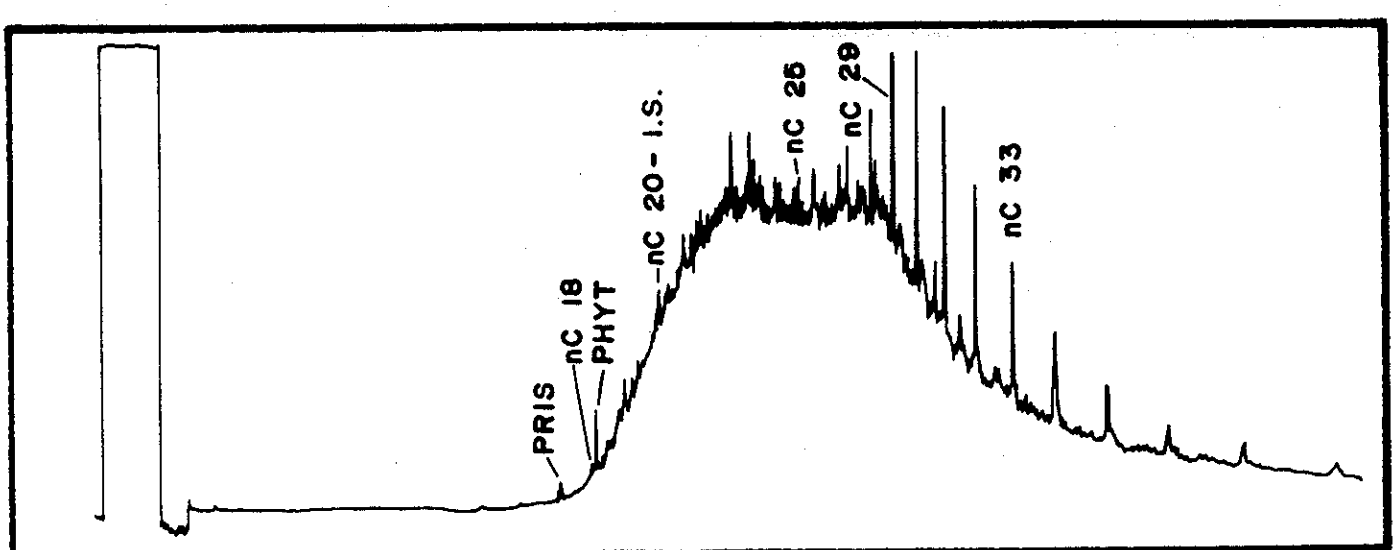
BAY 11 601 surf 7117



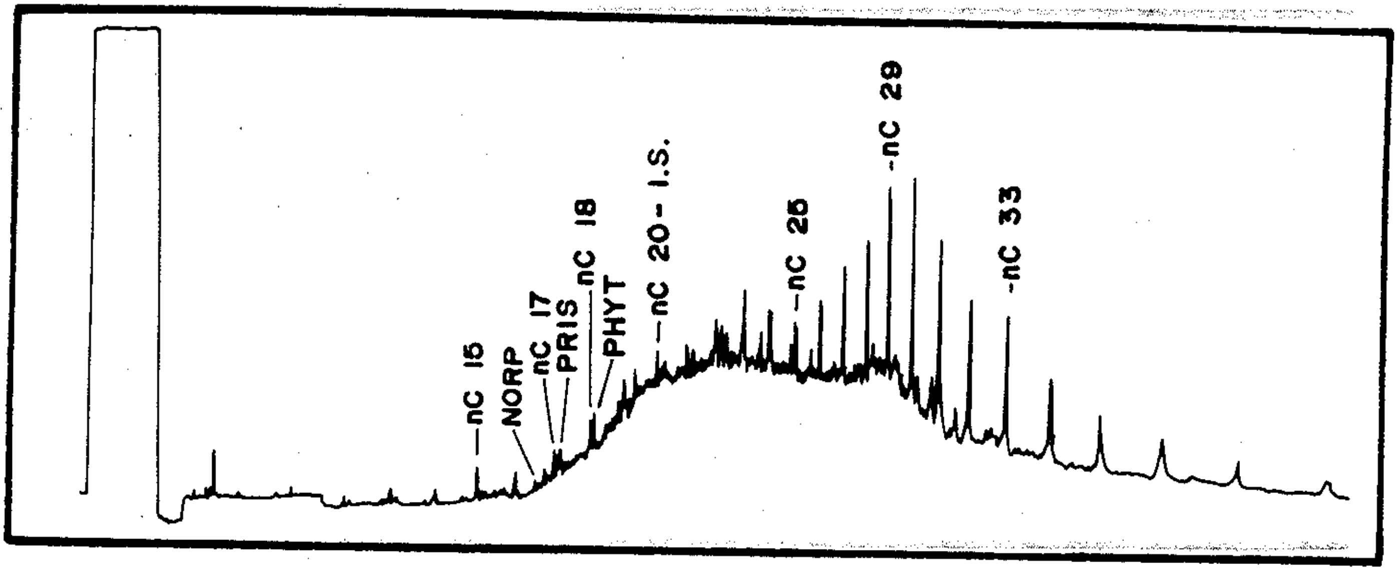
BAY 11 602 surf 7118



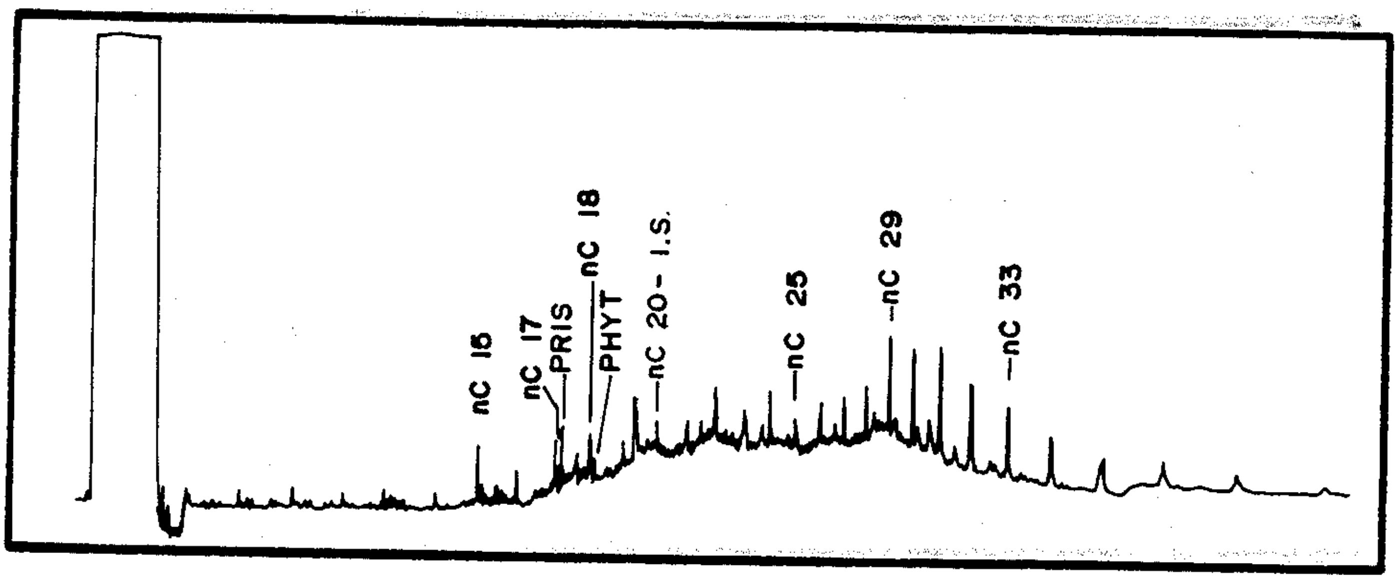
BAY 11 603 surf 7119



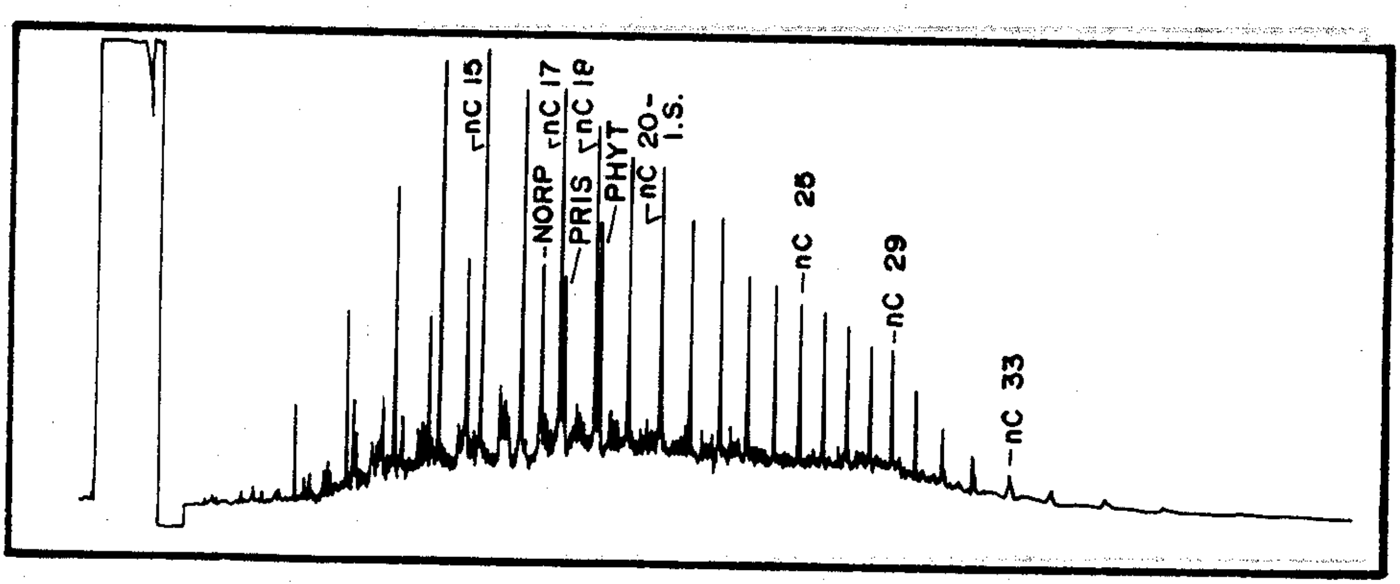
BAY 11 801 surf 7120



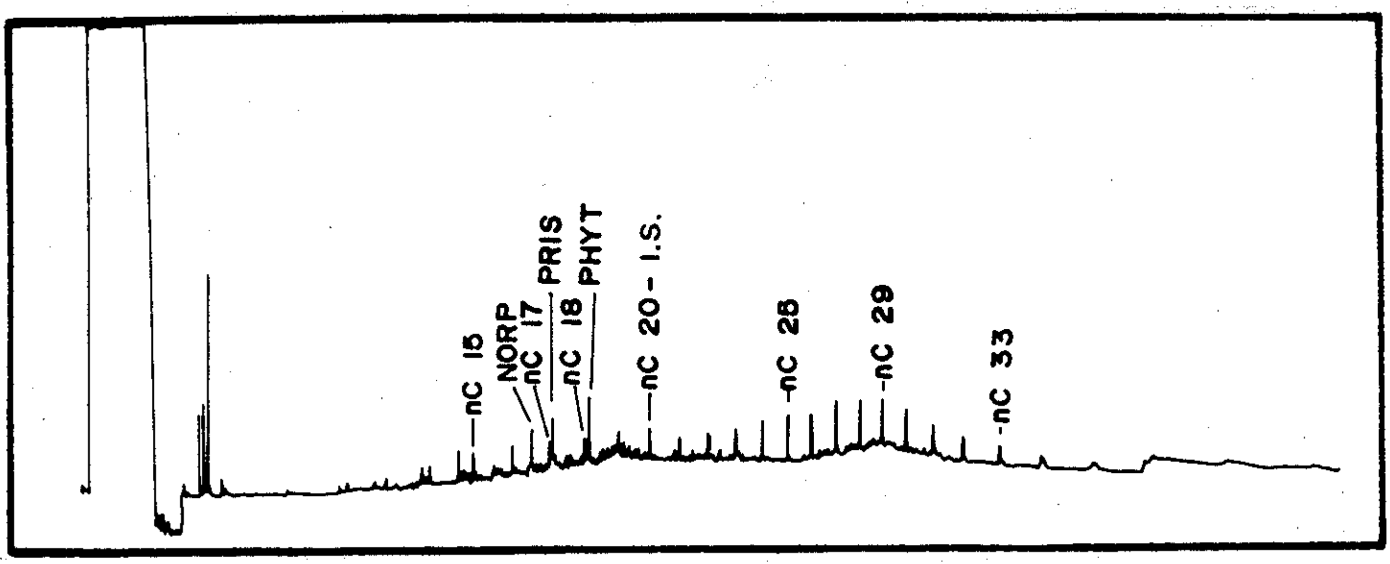
BAY 11 802 surf 7121



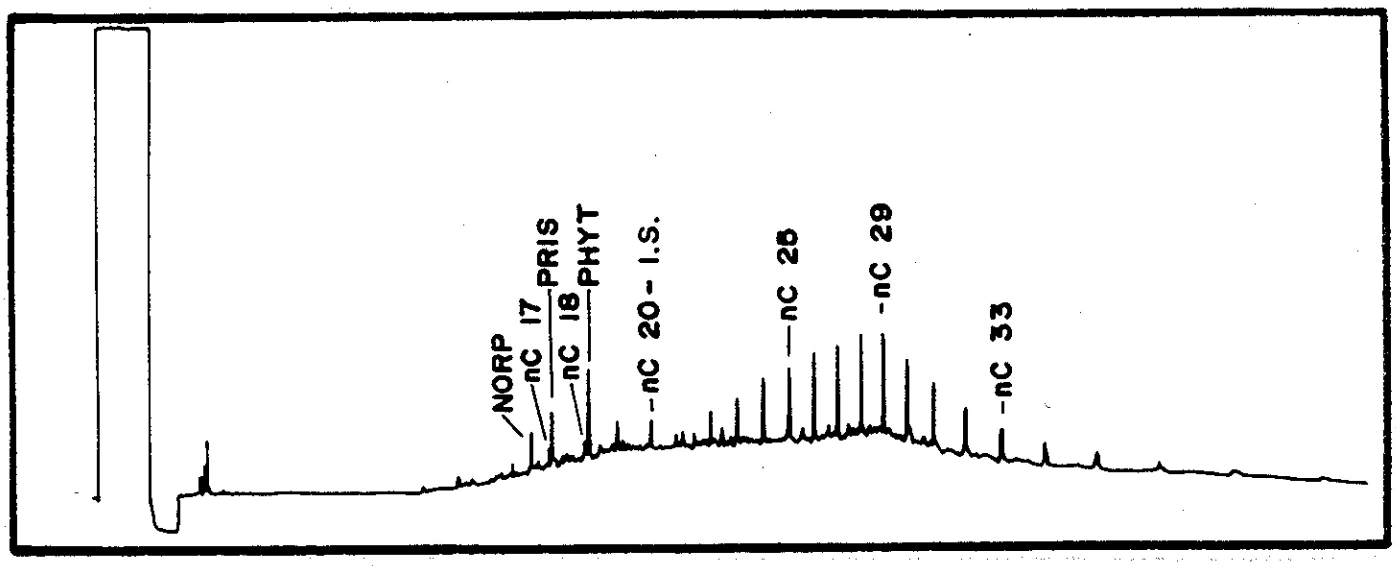
BAY 11 803 surf 7122



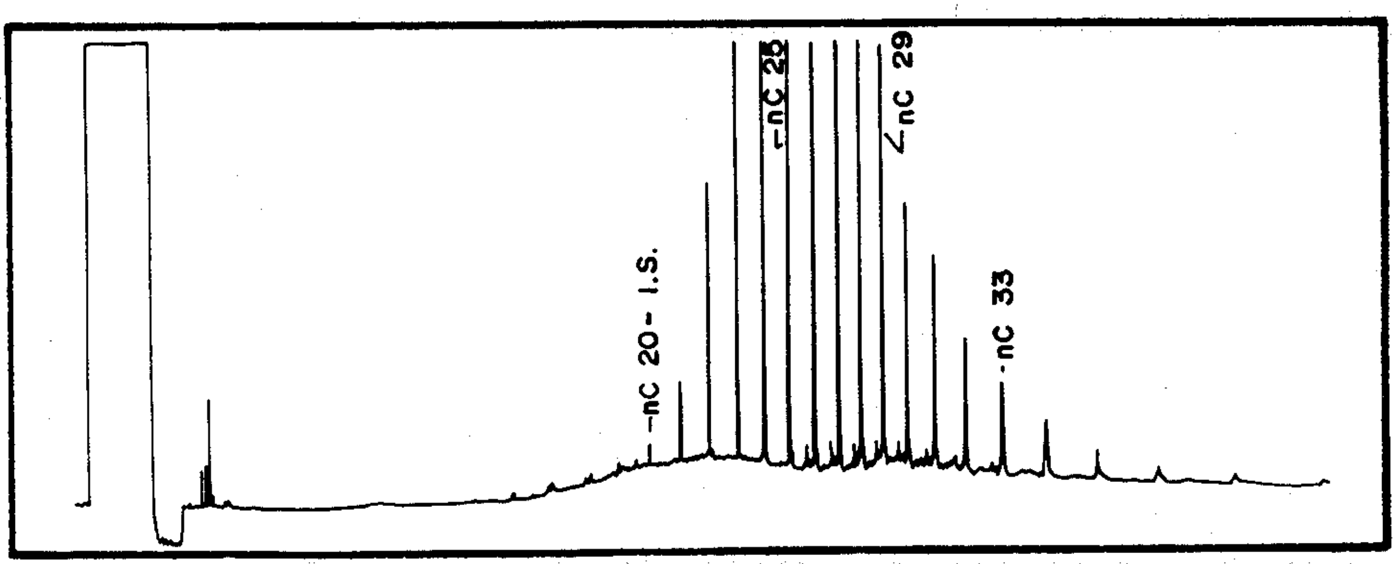
BAY 11 401 surf 7123



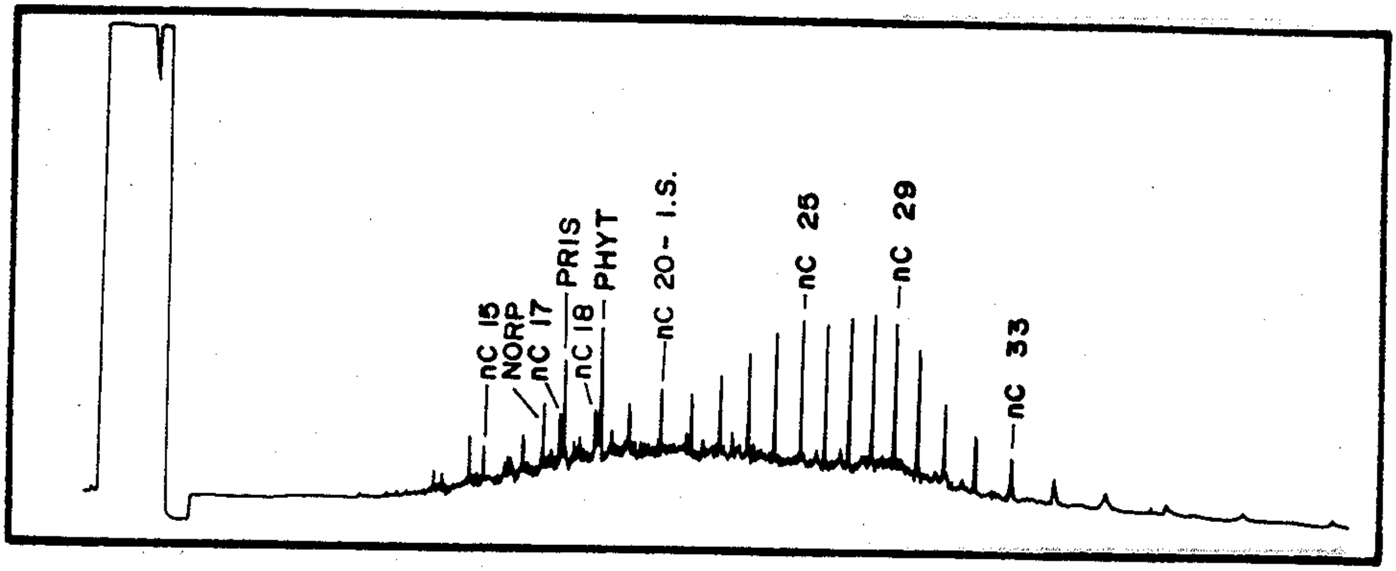
BAY 11 402 surf 7124



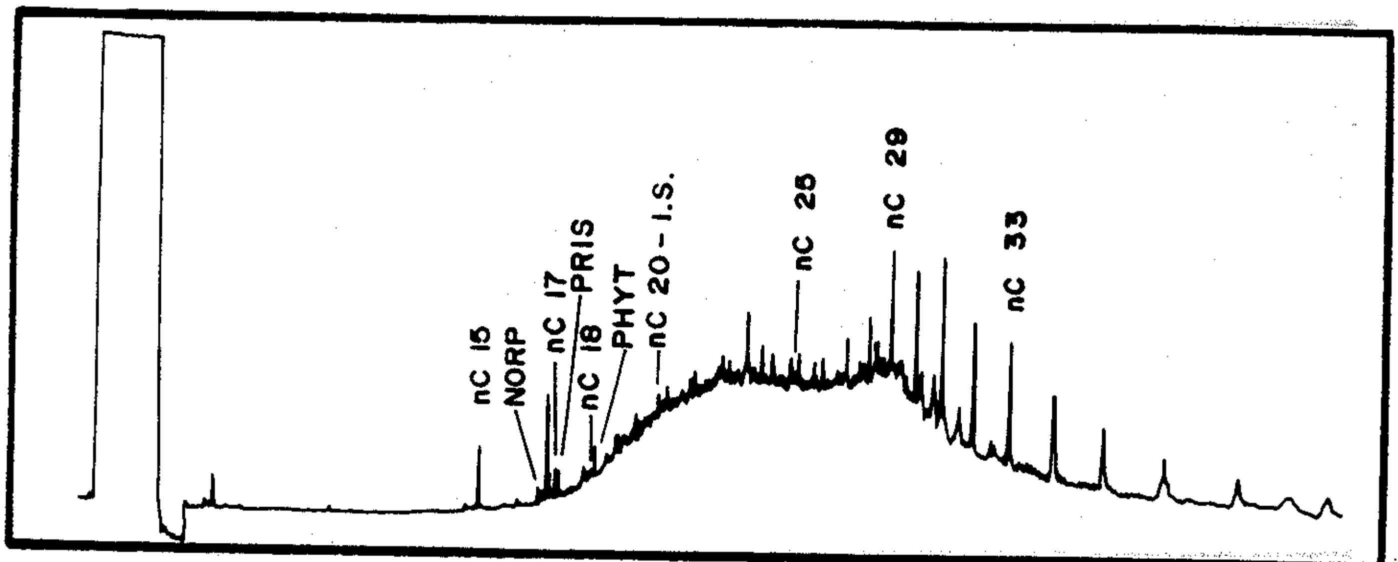
BAY 11 403 surf 7125



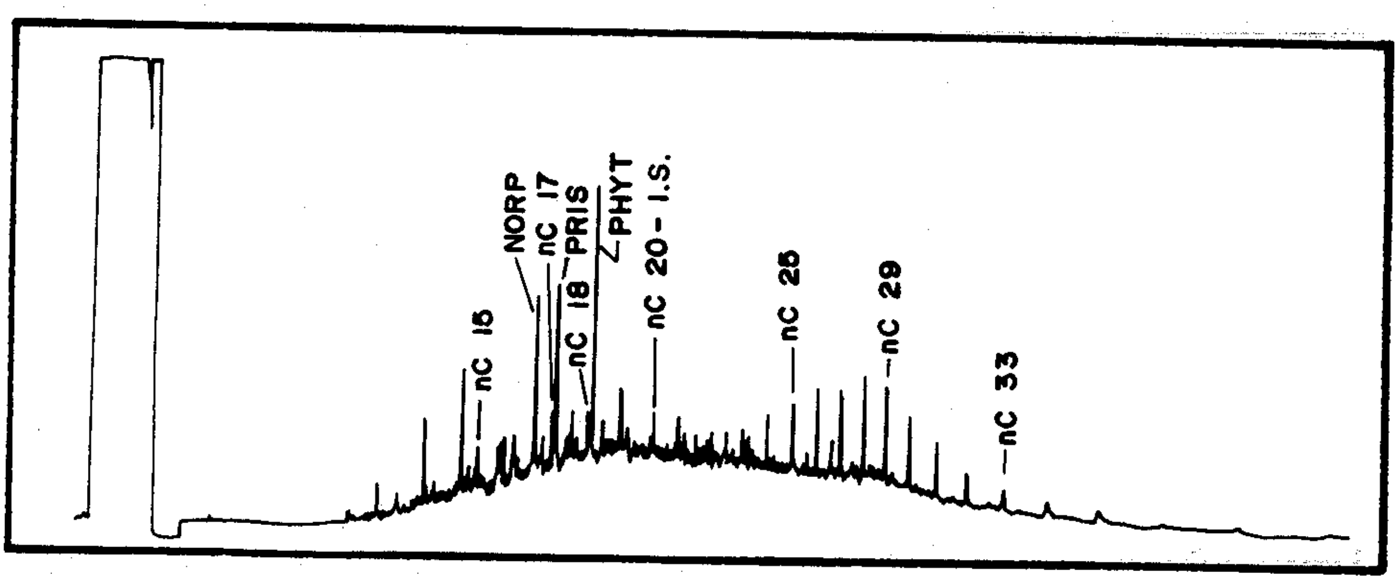
BAY 11 201 surf 7126



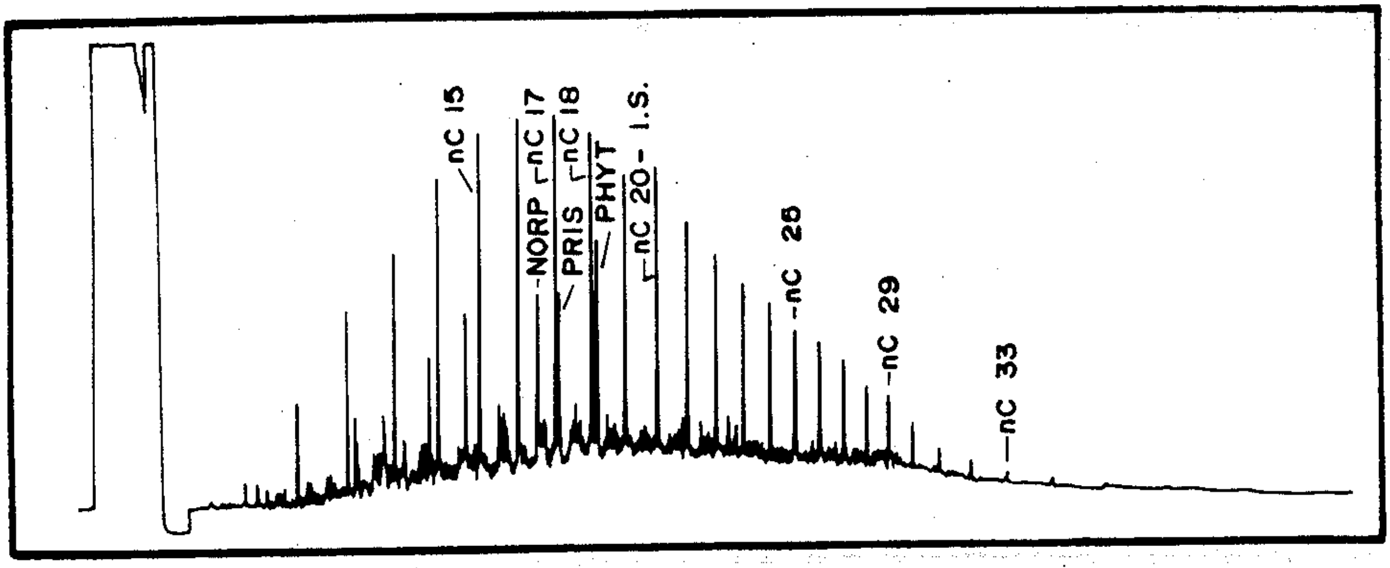
BAY 11 202 surf 7127



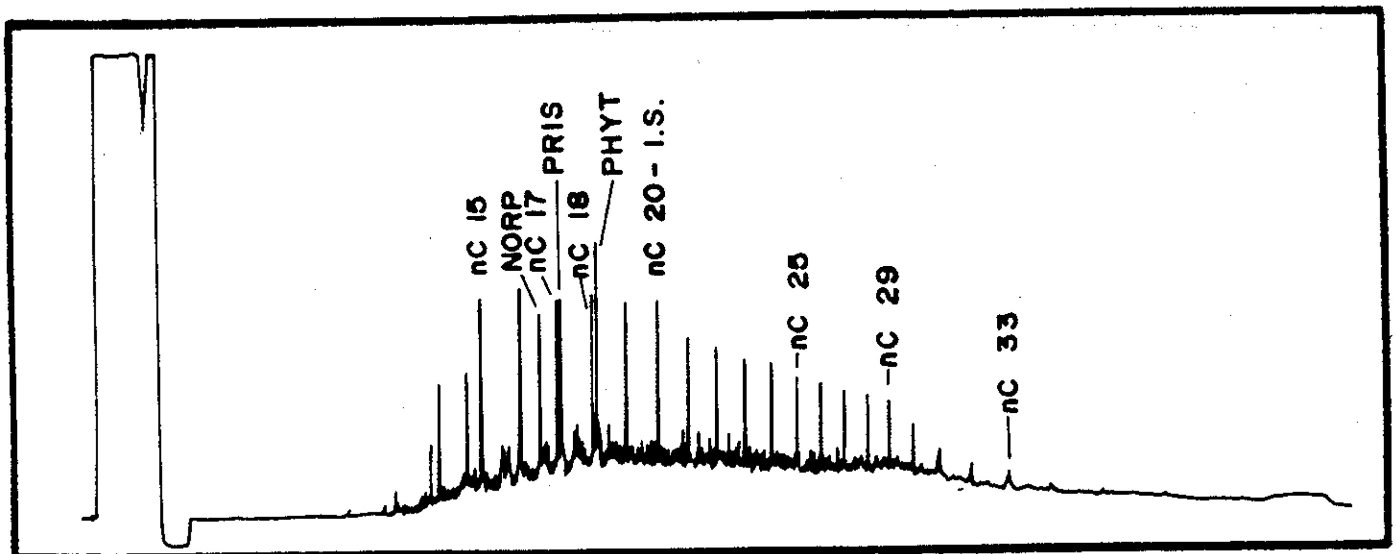
BAY 11 203 surf 7128



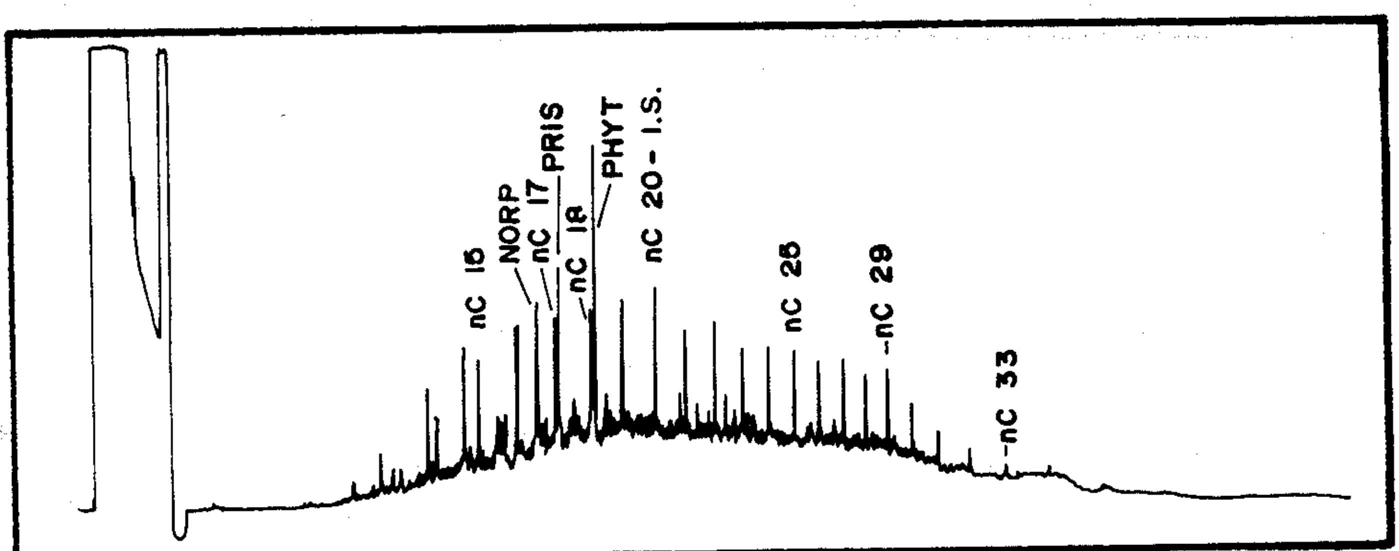
BAY 11 N403 surf 7129



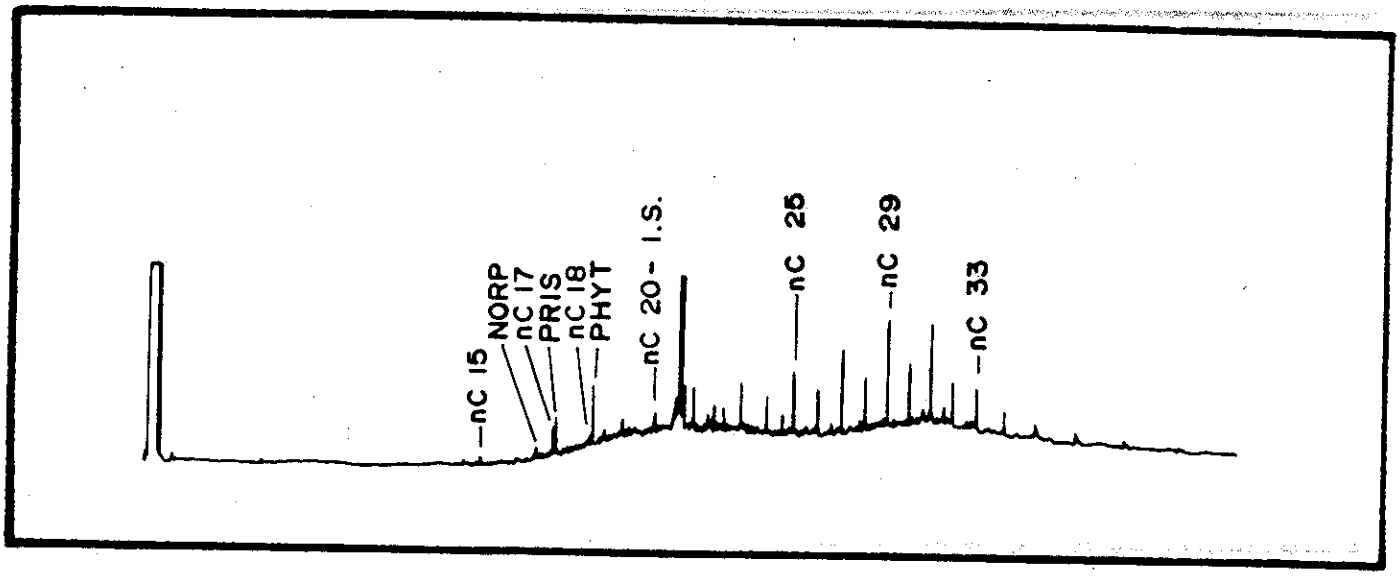
BAY 11 N401 surf 7130



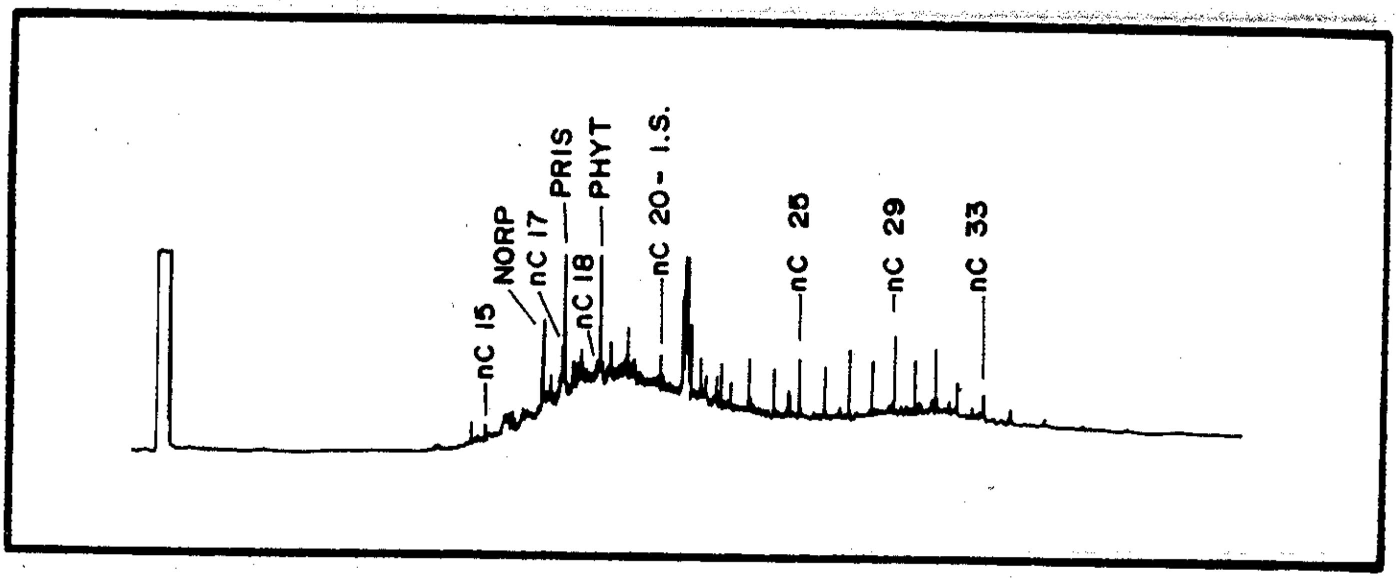
BAY 11 N401 surf 7131



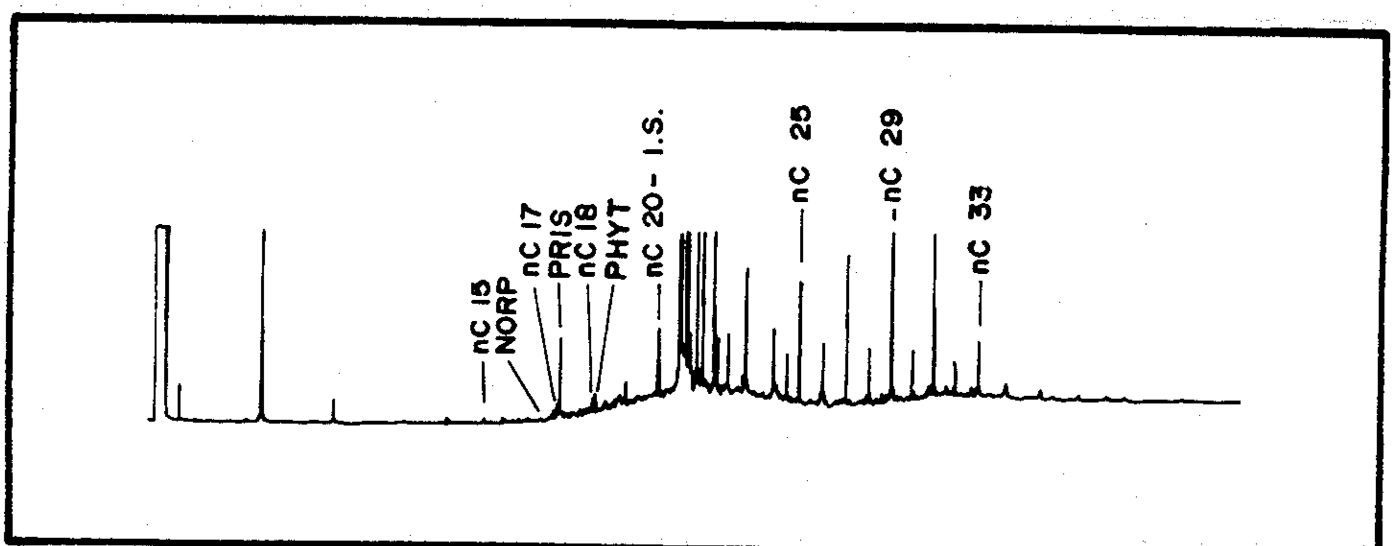
BAY 11 N501 surf 7132



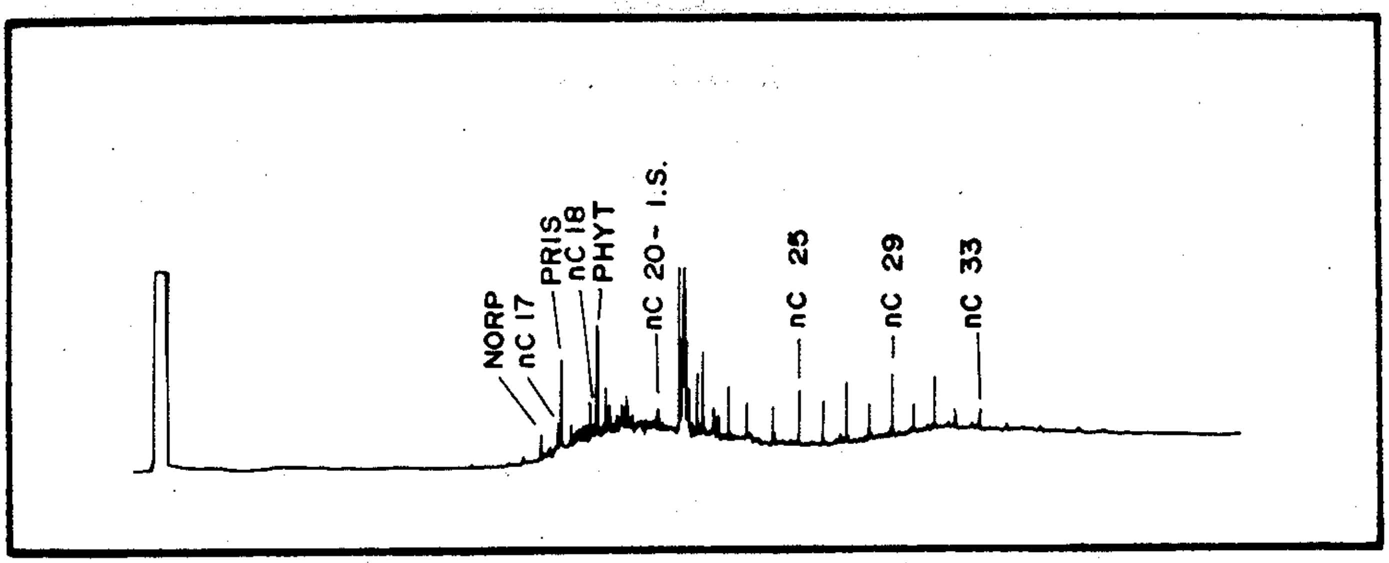
BAY 11 SUBTIDAL 7133



BAY 11 SUBTIDAL 7134



BAY 11 SUBTIDAL 7135



BAY 11 SUBTIDAL 7136

APPENDIX B

METULA SPILL

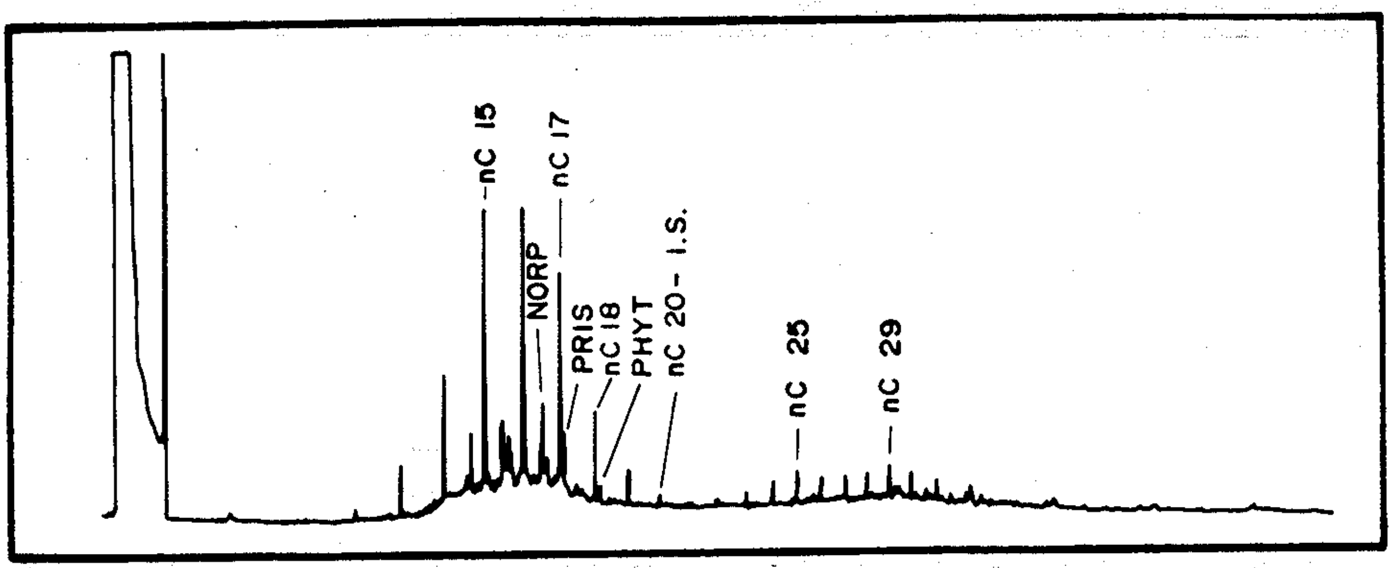
TOTAL HYDROCARBON AND COMPOSITIONAL GC RESULTS

COMPOSITIONAL ANALYSIS BY GC/FID; GC/MS

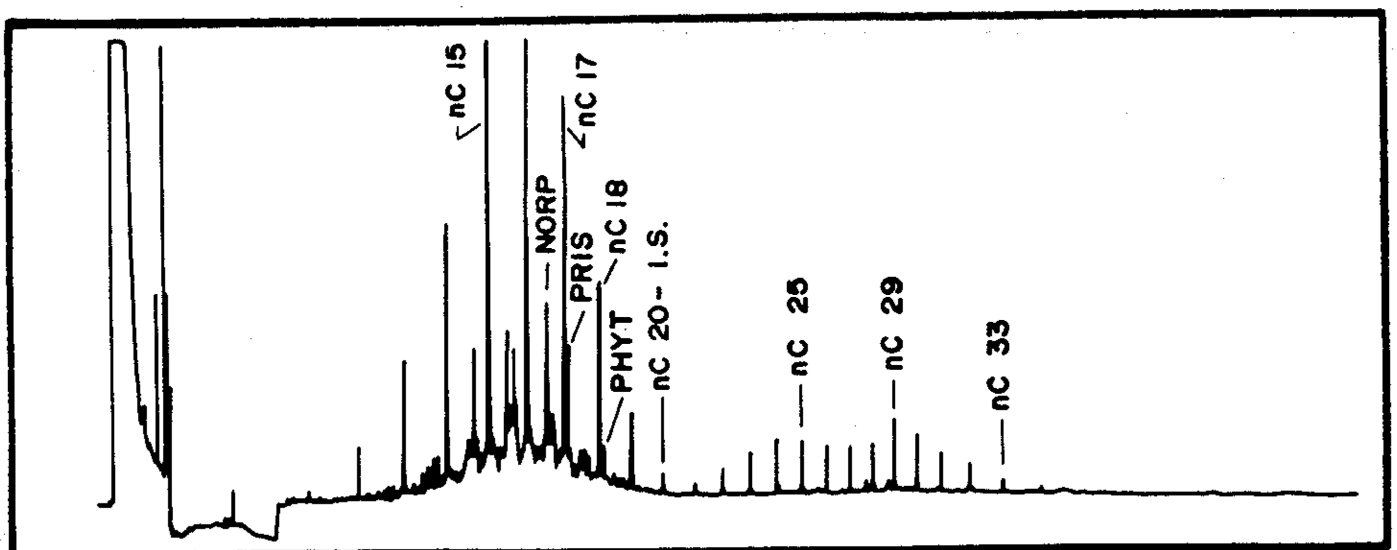
SAMPLE NUMBER	DATE	TIME	LOCATION	TIDE	[OIL] (MG KG^{-1})	SHWR	ALK/ISO	AWR
SKW102-1	870120	1650	BANCO ORANGE	HHSW		na	na	2.0
SKW102-2	870120	1650	BANCO ORANGE	LTT		3.3	3.9	27.0
SKW102-3	870120	1800	ESPORA MARSH	+NHWM		na	na	1.0
SKW102-4	870120	1810	ESPORA MARSH	+HSWM		1.2	3.1	1.1
SKW102-5	870120	1820	ESPORA MARSH (CREEK)	+HSWM		2.4	3.8	1.3
SKW102-6	870120	1830	ESPORA SPIT	MID-ITZ		na	na	1.0
SKW102-7	870120	1835	ESPORA SPIT			2.8	6.1	1.2
SKW102-8	870120	1840	ESPORA SPIT	MHWM		na	na	2.0
SKW102-9	870120	1845	ESPORA SPIT			2.7	4.4	2.8
SKW102-10	870120	1850	ESPORA SPIT	+HHWM		1.1	5.2	1.3
SKW102-11	870120	1850	ESPORA SPIT	+HHWM		1.5	3.2	1.0
SKW102-12	870120	1245	ESPORA SPIT	+MHWM		2.9	5.4	1.1
SKW102-13	870120	1830	ESPORA SPIT	MHWS		1.1	na	1.1
SKW102-14	870120	1830	ESPORA SPIT	MHWS		1	na	1.2
SKW102-15	870121	1530	DANIEL ESTE 85.6			na	na	1.9
SKW102-16	870122	1500	RIO OSCAR	HHWS		1.1	3	188.0
SKW102-17	870122	1500	RIO OSCAR	HHWS		1	2.6	1.2
SKW102-18	870122	1645	3 KM S PUNTA BAYA	HHWS		1.1	2.8	1.4
SKW102-19	870122	1650	3 KM S PUNTA BAYA	HHWS		1	na	1.8
SKW102-20	870122	1120	PUNTA MALVINAS	HHSW		1	0.5	1.2
SKW102-21	870122	1120	PUNTA MALVINAS	HHSW		1	0.3	1.2
SKW102-22	870123	1040	PUNTA ESPORA	LTT		1	na	1.2
SKW102-23	870123	1045	PUNTA ESPORA	LTT		na	na	1.0
SKW102-24	870123	1200	PUNTA ESPORA	BFSLOPE		na	na	1.0
SKW102-48	870123	1145	PUNTA ESPORA	LTT	17000	na	na	1.0
SKW102-52	870123	1230	ESPORA MARSH (CREEK)	SUPRATIDA	32000	1	0.6	1.2
SKW102-53	870123	1230	ESPORA MARSH (CREEK)	SUPRATIDA	48000	1	0.9	1.2
SKW102-54	870123	1230	ESPORA MARSH (CREEK)	SUPRATIDA	7300	1.2	3.5	1.4
SKW102-55			ORIGINAL OIL					3.6

TOTAL HYDROCARBON CONCENTRATION BY IR

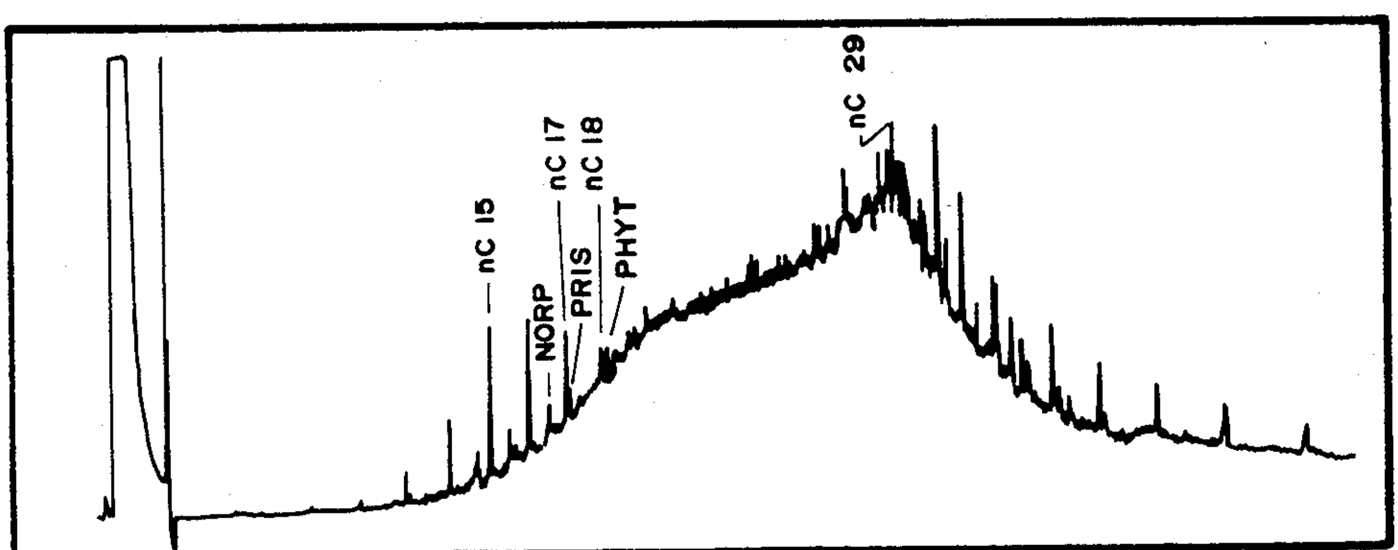
SAMPLE NUMBER	DATE	TIME	LOCATION	TIDE	[OIL] (MG KG^{-1})
SKW102-25	870120	1650	BANCO ORANGE	HHSW	10000
SKW102-26	870120	1810	ESPORA MARSH	+HSWM	30000
SKW102-27	870120	1820	ESPORA MARSH (CREEK)	HSWM	22000
SKW102-28	870120	1830	ESPORA SPIT	MHWS	12000
SKW102-29	870120	1830	ESPORA SPIT	MHWS	9300
SKW102-30	870120	1835	ESPORA SPIT		23000
SKW102-31	870120	1840	ESPORA SPIT	MHWM	18000
SKW102-32	870120	1850	ESPORA SPIT	MHWM	13000
SKW102-33	870120	1855	ESPORA SPIT	MHWM	280
SKW102-34	870120	1900	ESPORA SPIT	+MHWM	9200
SKW102-35	870120	1900	ESPORA SPIT	+MHWM	13000
SKW102-36	870121	1530	DANIEL ESTE 85.6		24000
SKW102-37	870121	1115	PUNTA MALVINAS	HHWS	11000
SKW102-38	870122	1120	PUNTA MALVINAS	HHSW	24000
SKW102-39	870122	1120	PUNTA MALVINAS	HHSW	36000
SKW102-40	870122	1500	RIO OSCAR	HHWS	12000
SKW102-41	870122	1500	RIO OSCAR	HHWS	10000
SKW102-42	870122	1645	3 KM S PUNTA BAYA	HHWS	50000
SKW102-43	870123	1045	PUNTA ESPORA	LTT	53000
SKW102-44	870123	1100	PUNTA ESPORA	LTT	32000
SKW102-45	870123	1110	PUNTA ESPORA	LTT	14000
SKW102-46	870123	1115	PUNTA ESPORA	LTT	9100
SKW102-47	870123	1130	PUNTA ESPORA	LTT	9800
SKW102-48	870123	1145	PUNTA ESPORA	LTT	17000
SKW102-49	870123	1145	PUNTA ESPORA	LOW BF SL	16000
SKW102-50	870123	1145	PUNTA ESPORA	MID BF SL	47000
SKW102-51	870123	1145	PUNTA ESPORA	MID BF SL	25000
SKW102-52	870123	1230	ESPORA MARSH (CREEK)	SUPRATIDA	32000
SKW102-53	870123	1230	ESPORA MARSH (CREEK)	SUPRATIDA	48000
SKW102-54	870123	1230	ESPORA MARSH (CREEK)	SUPRATIDA	7300



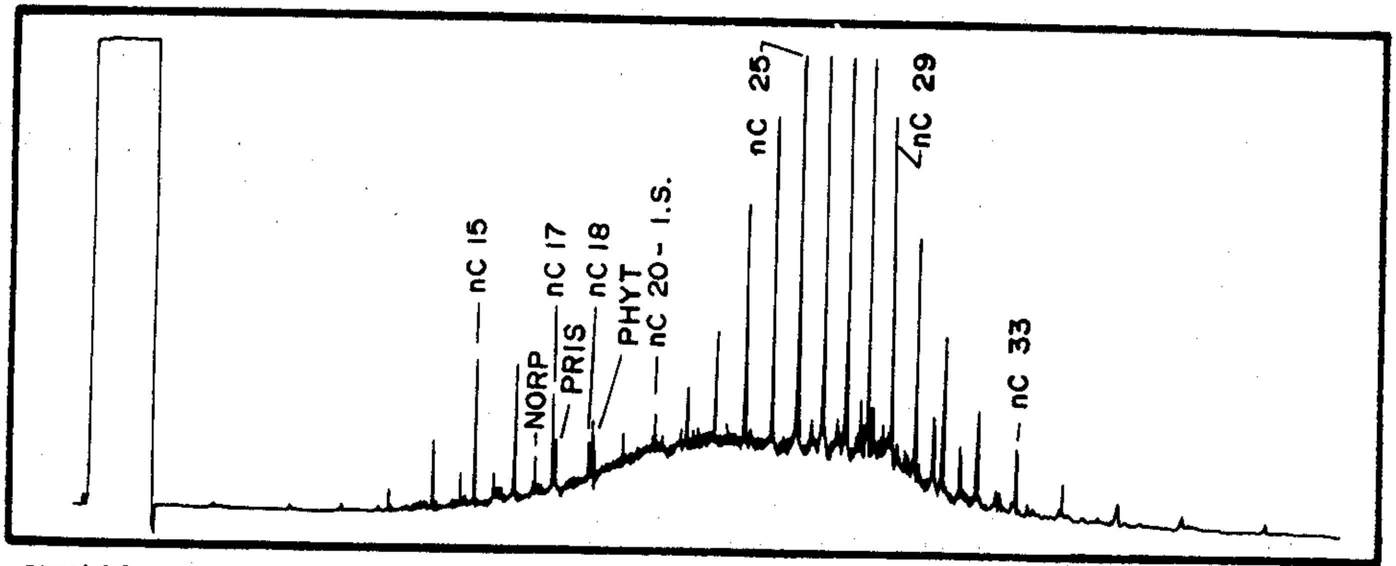
SKW102-1 BANCO ORANGE HHSW



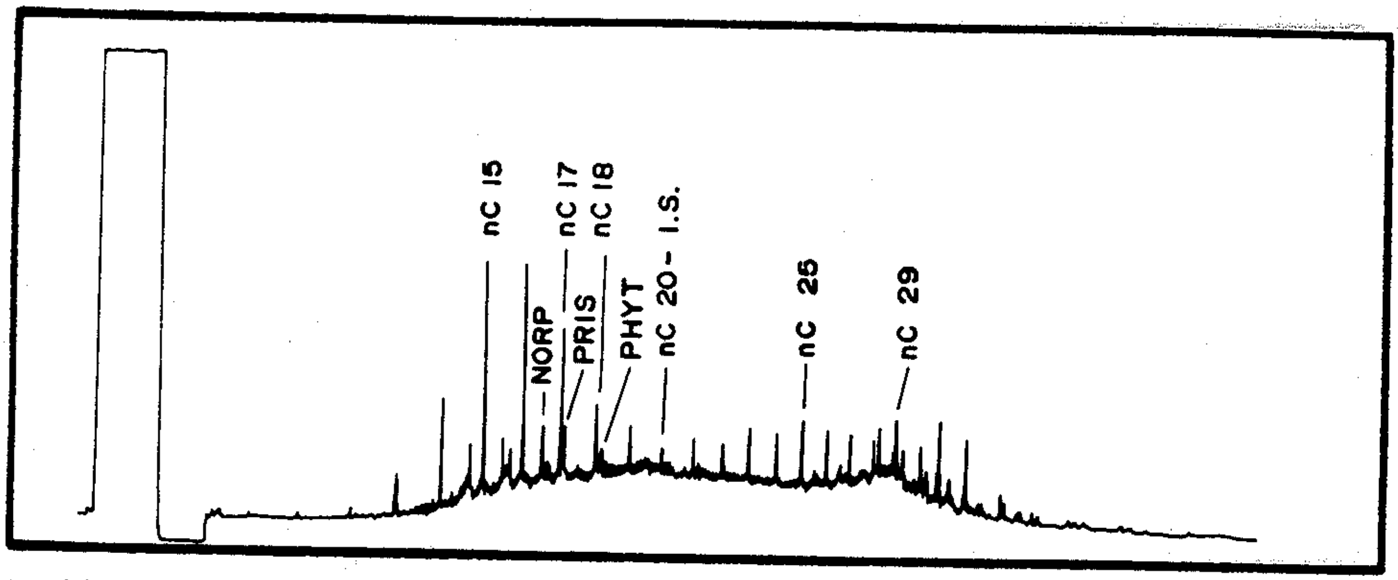
SKW102-2 BANCO ORANGE LTT



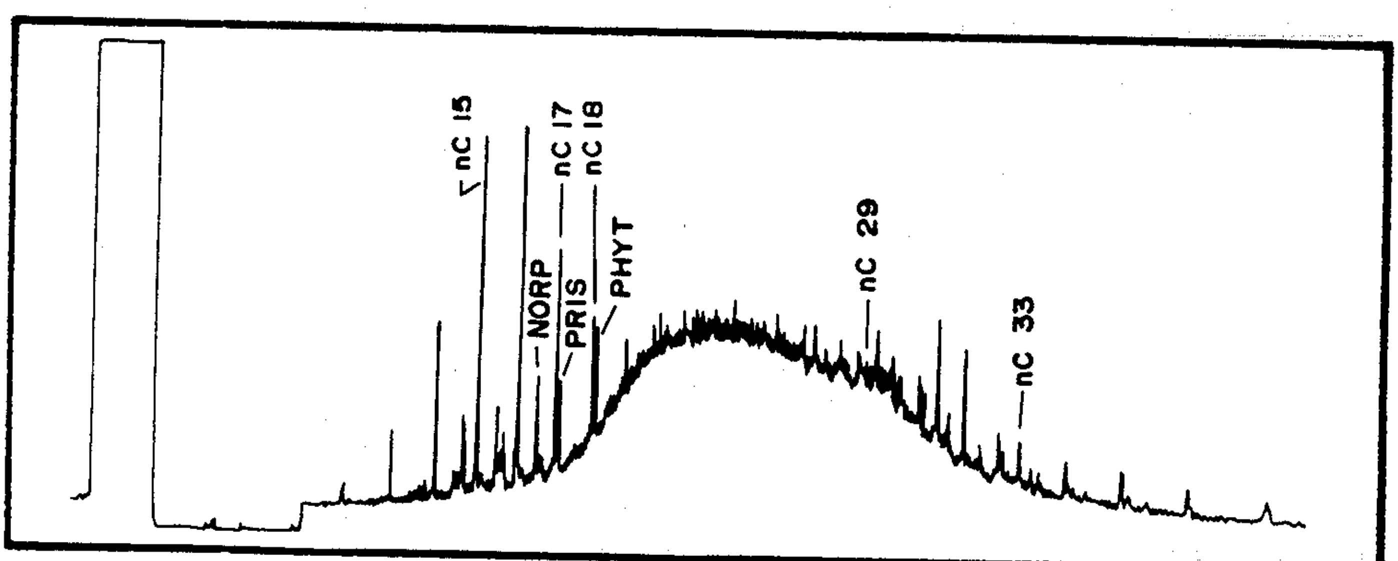
SKW102-3 ESPORA MARSH +NHWM



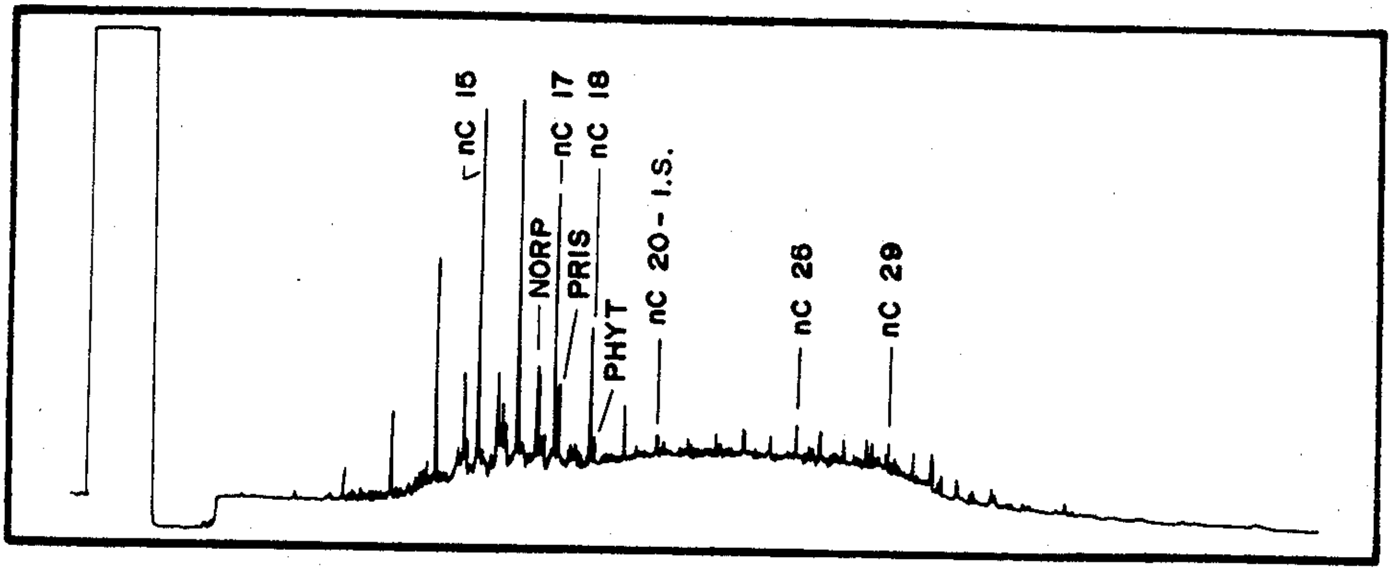
SKW102-4 ESPORA MARSH +HSWM



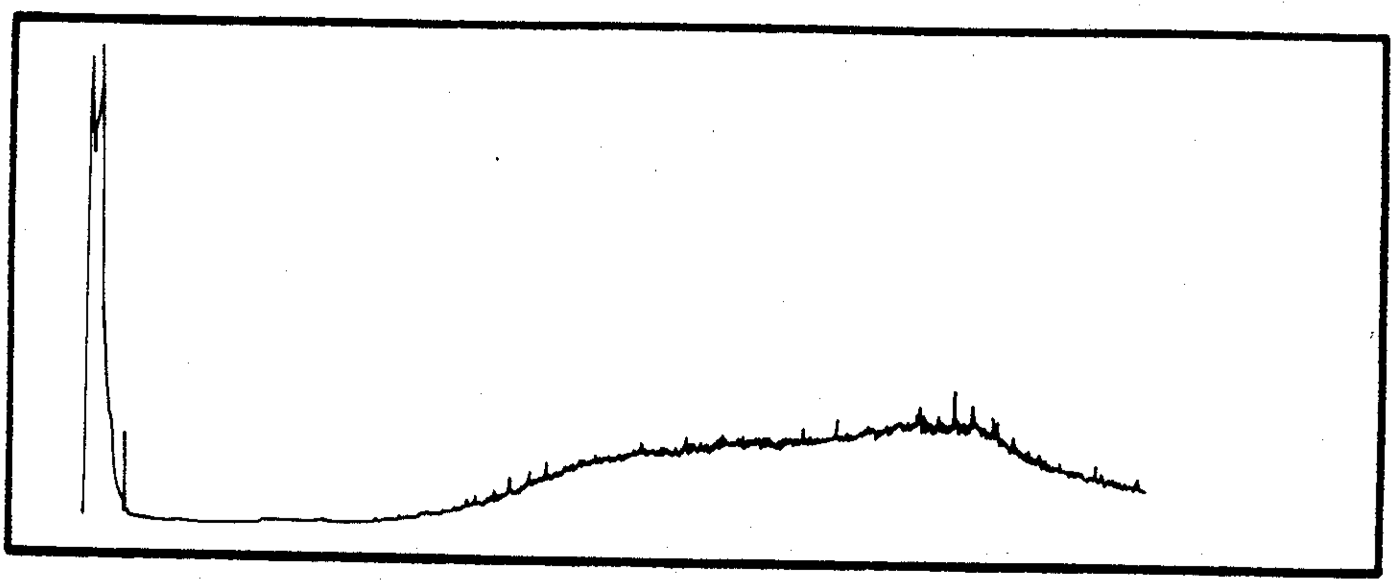
SKW102-5 ESPORA MARSH (CREEK) +HSWM



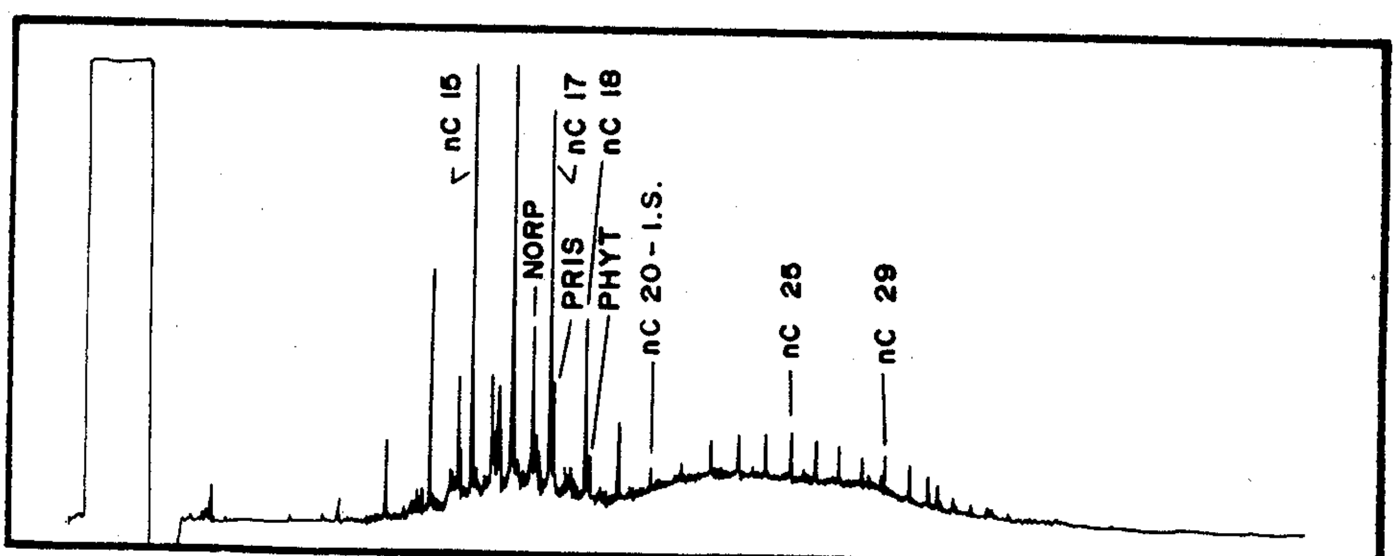
SKW102-6 ESPORA SPIT MID-ITZ



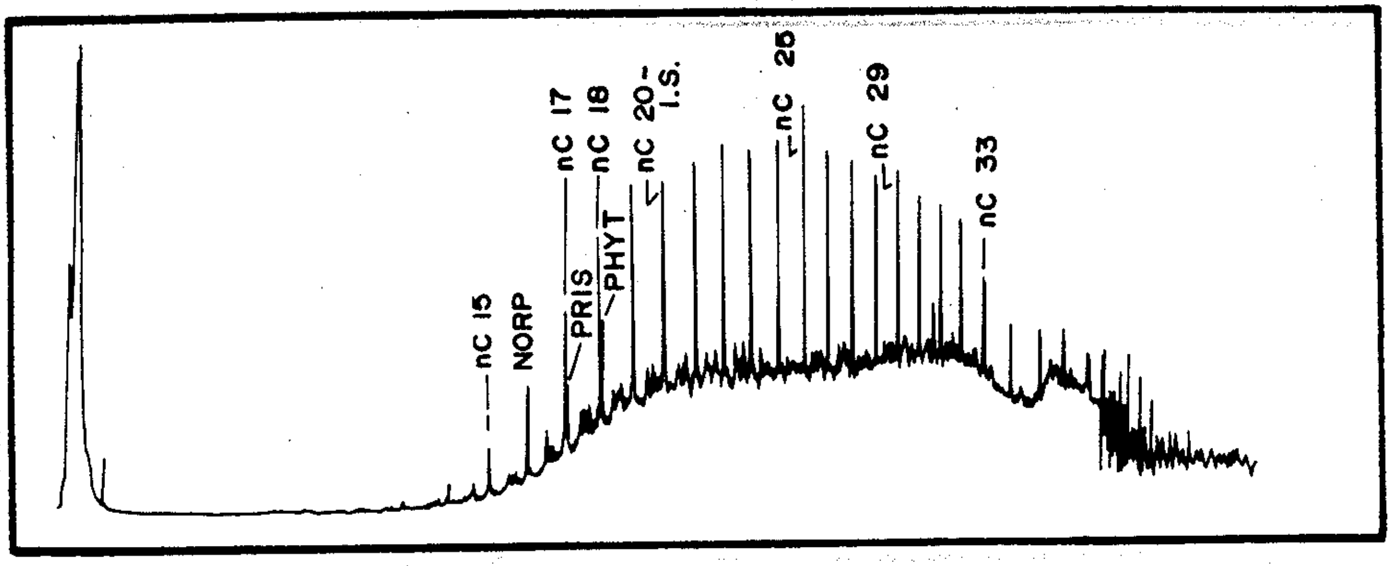
SKW102-7 ESPORA SPIT



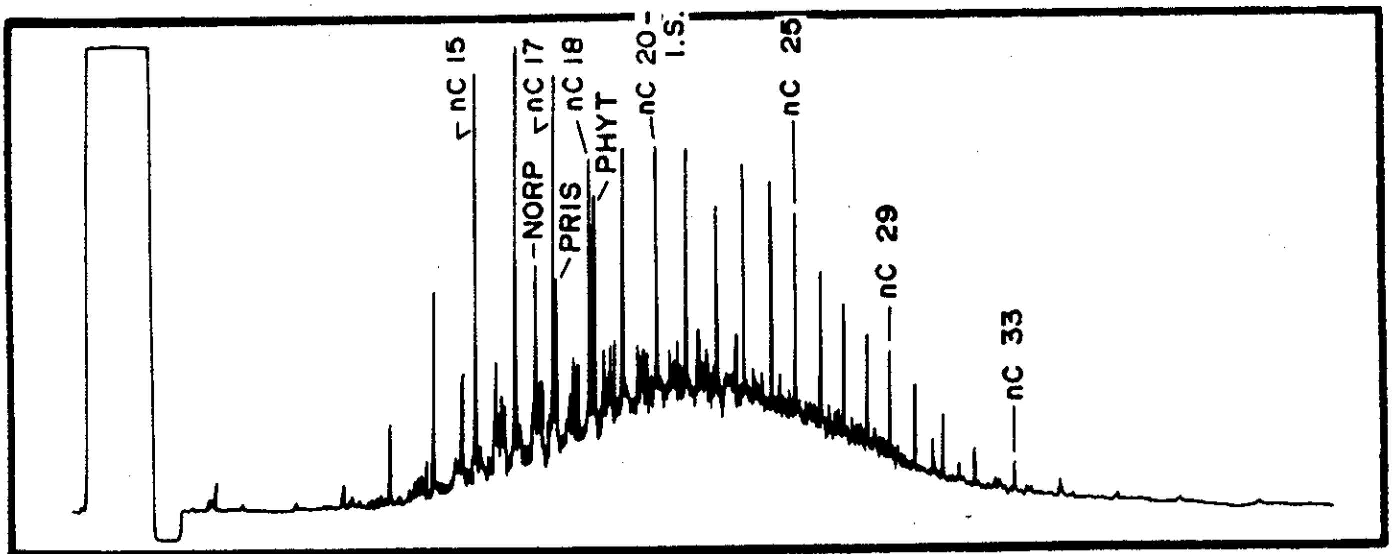
SKW102-8 ESPORA SPIT MHWM



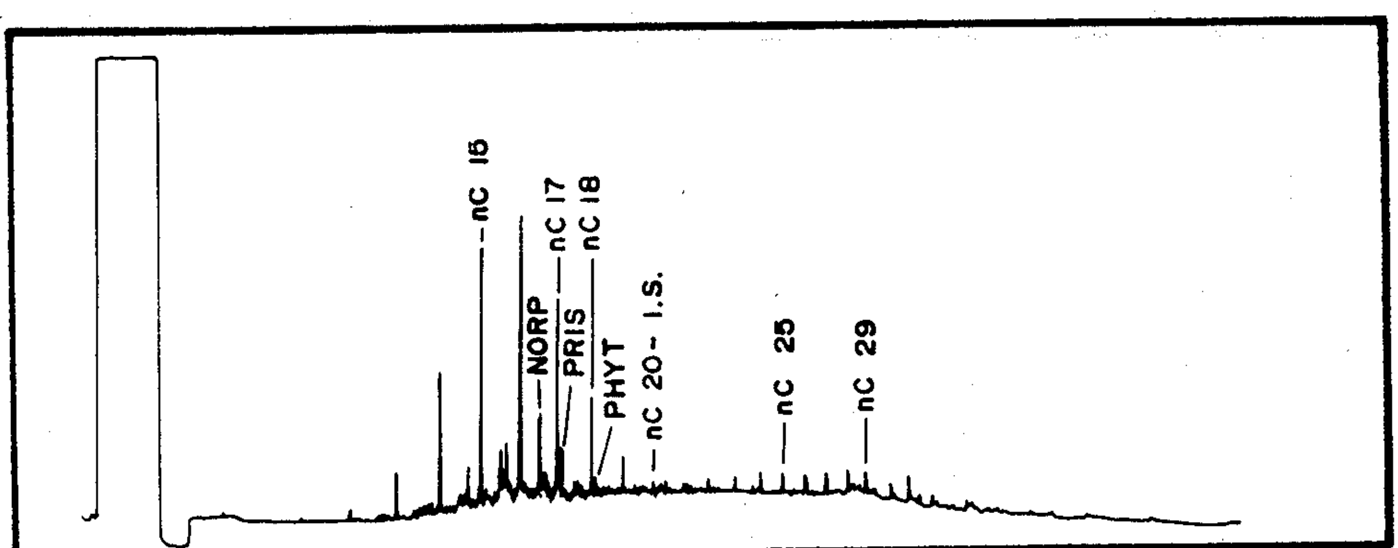
SKW102-9 ESPORA SPIT



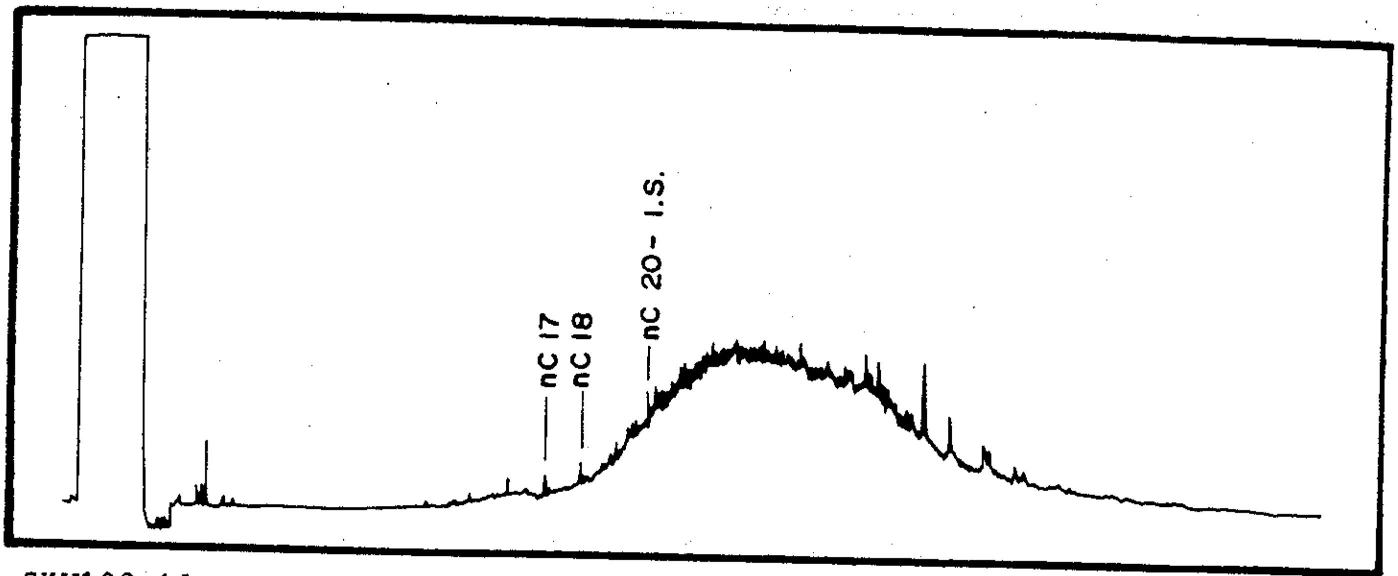
SKW102-10 ESPORA SPIT +HHWM



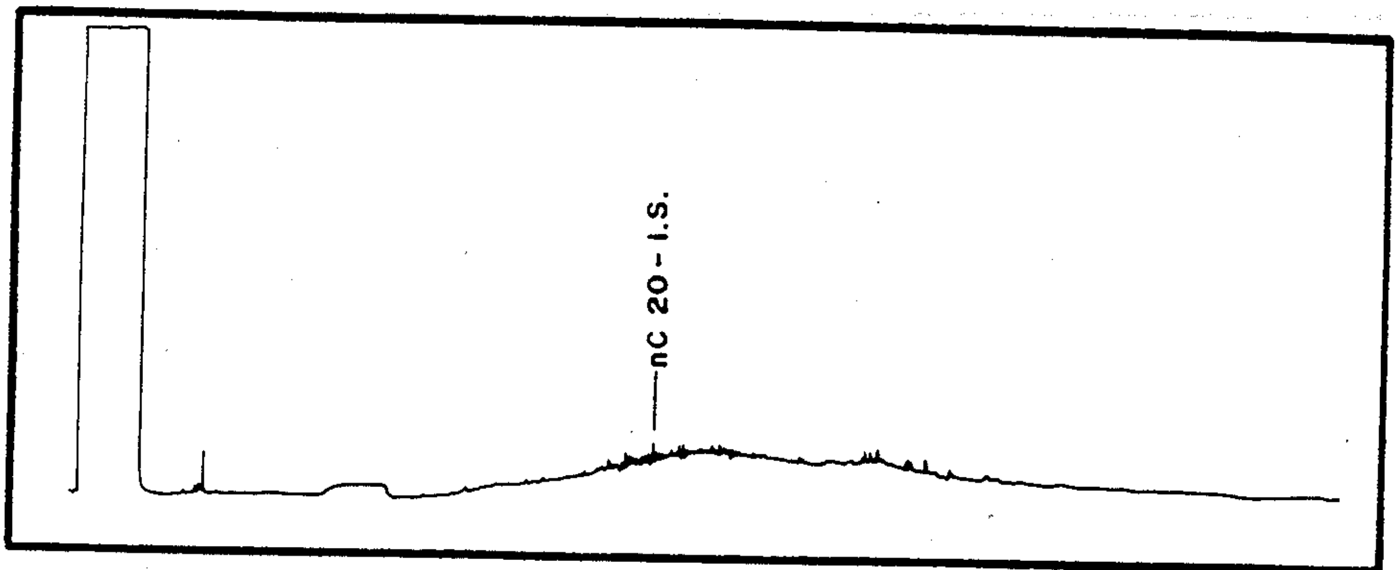
SKW102-11 ESPORA SPIT +HHWM



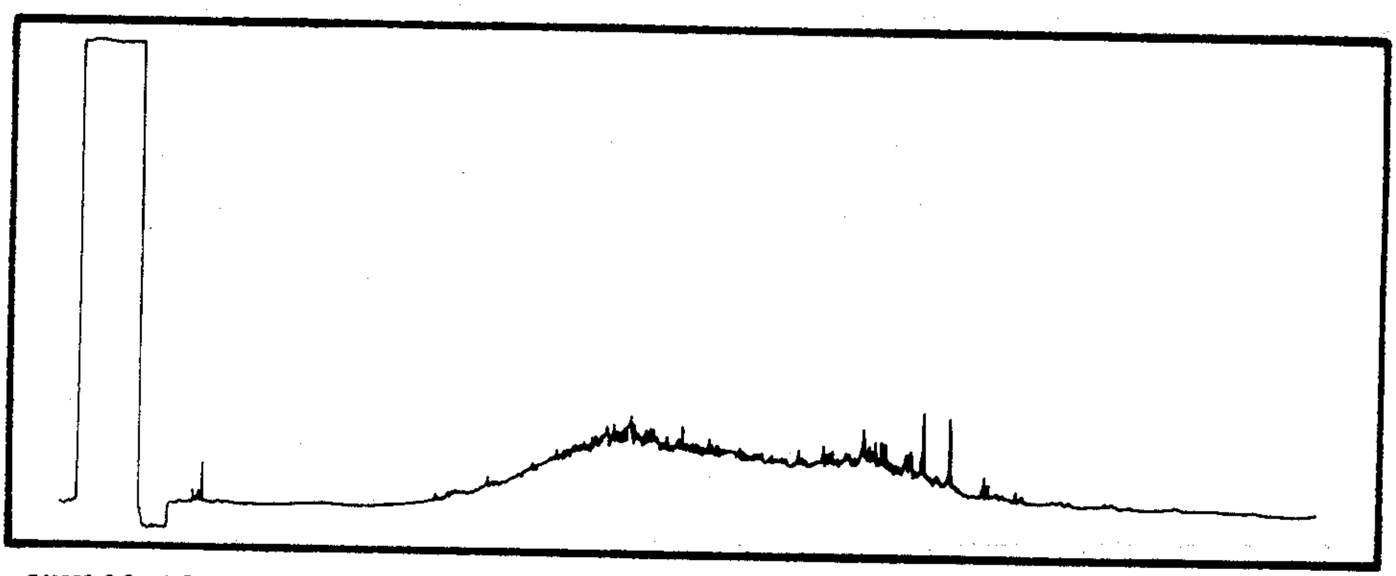
SKW102-12 ESPORA SPIT +MHWM



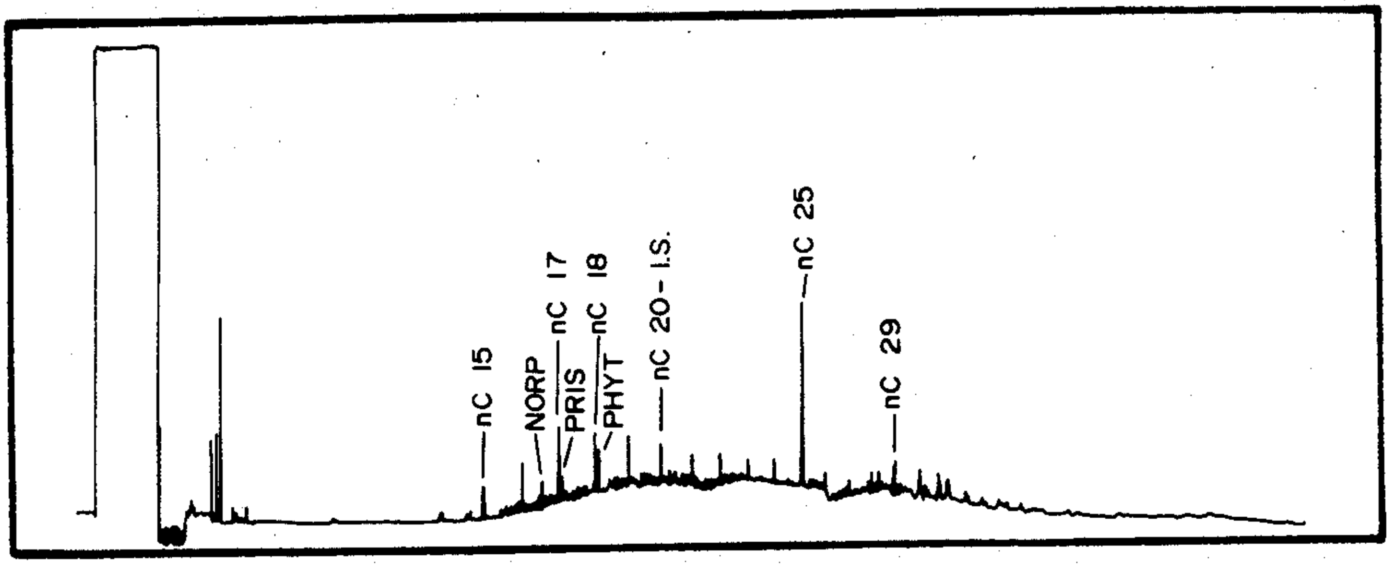
SKW102-13 ESPORA SPIT MHWS



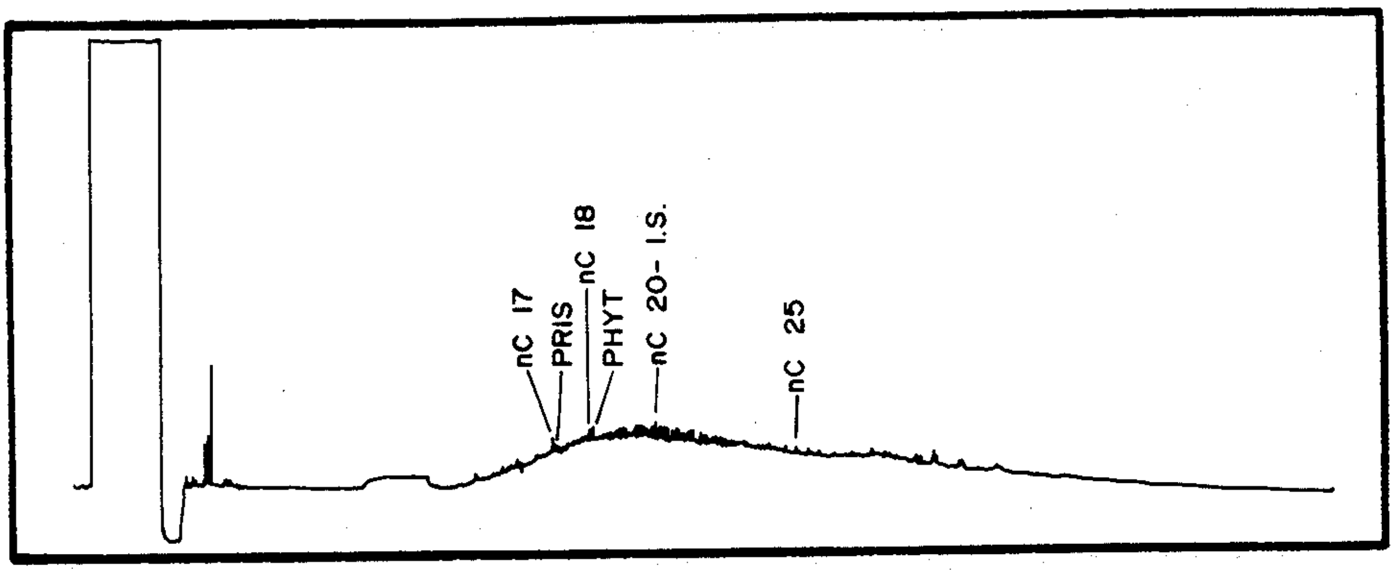
SKW102-14 ESPORA SPIT MHWS



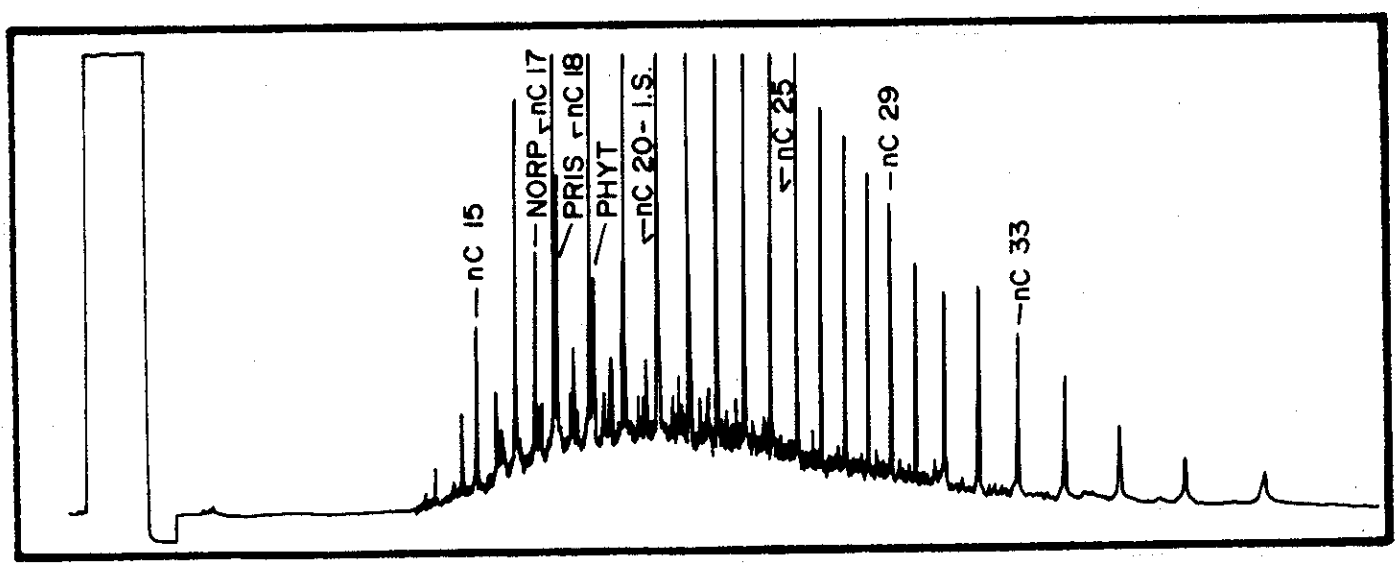
SKW102-15 DANIEL ESTE 85.6



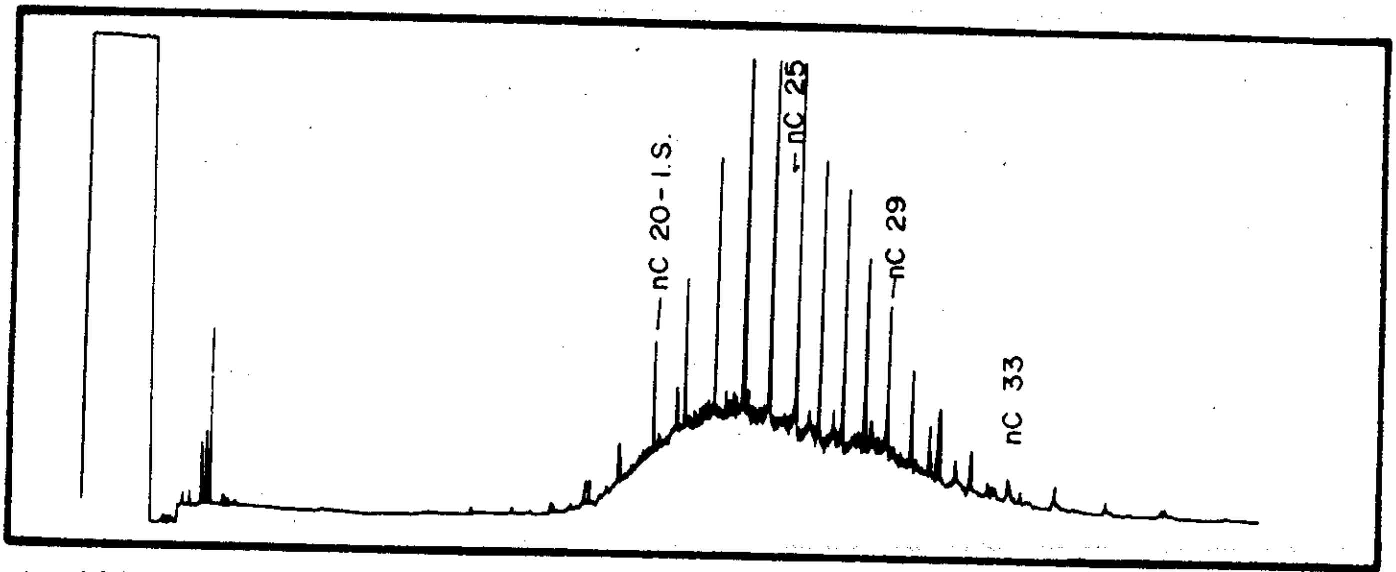
SKW102-16 RIO OSCAR HHWS



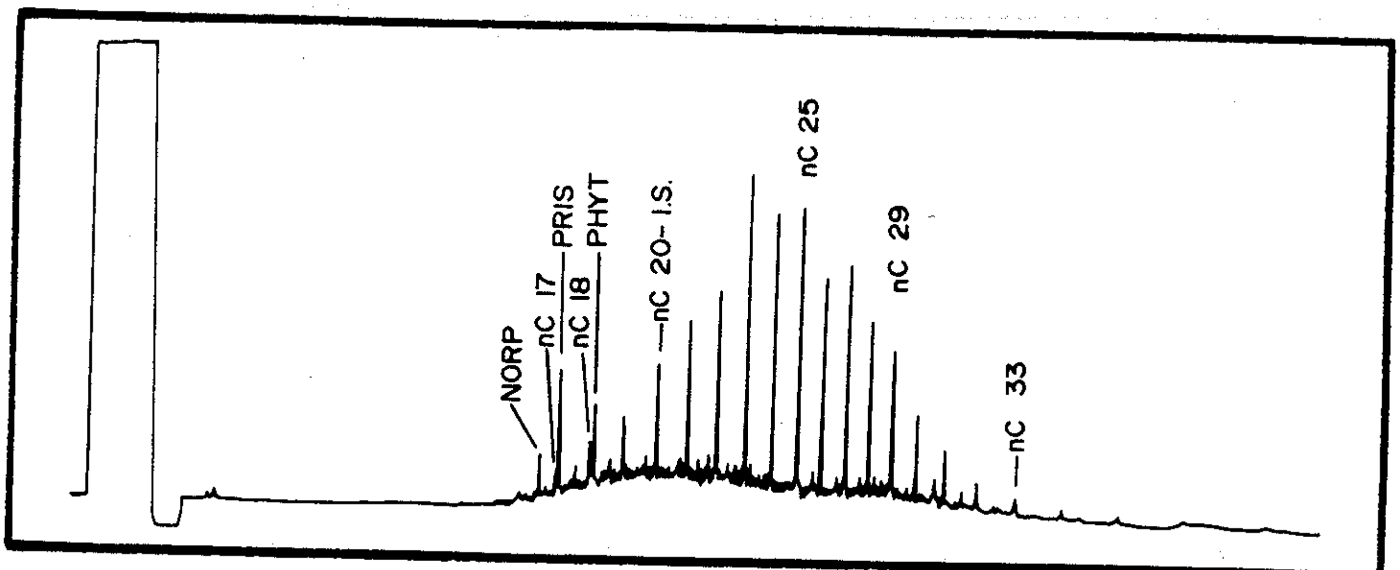
SKW102-17 RIO OSCAR HHWS



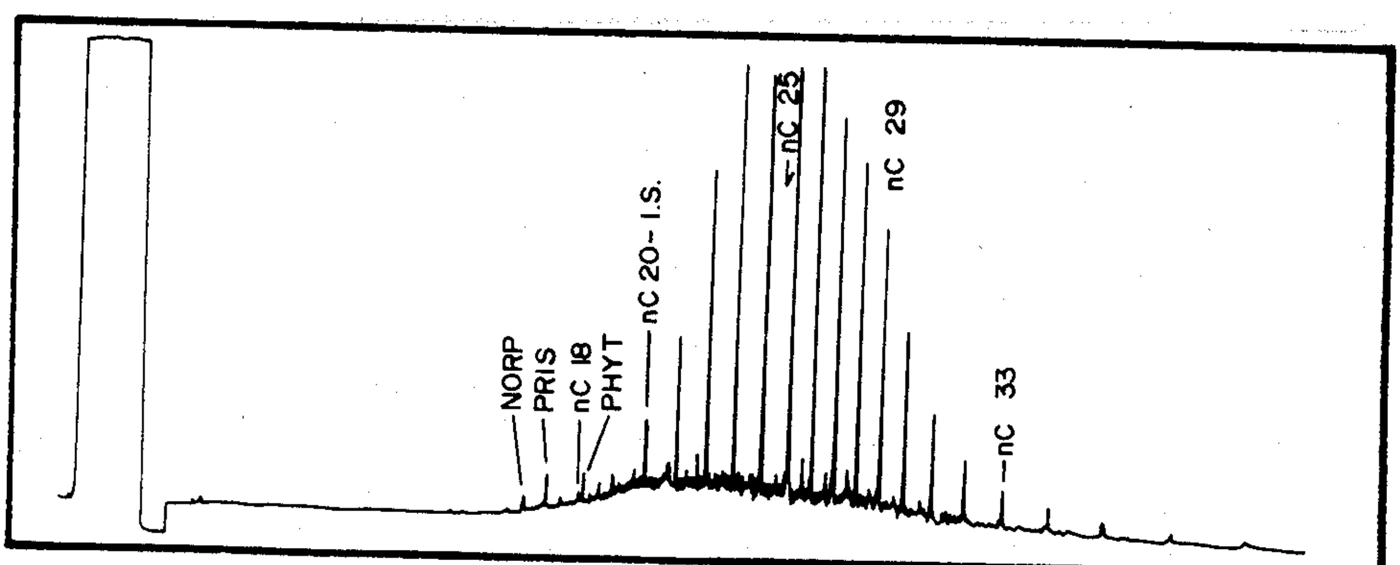
SKW102-18 3 KM S PUNTA BAYA HHWS



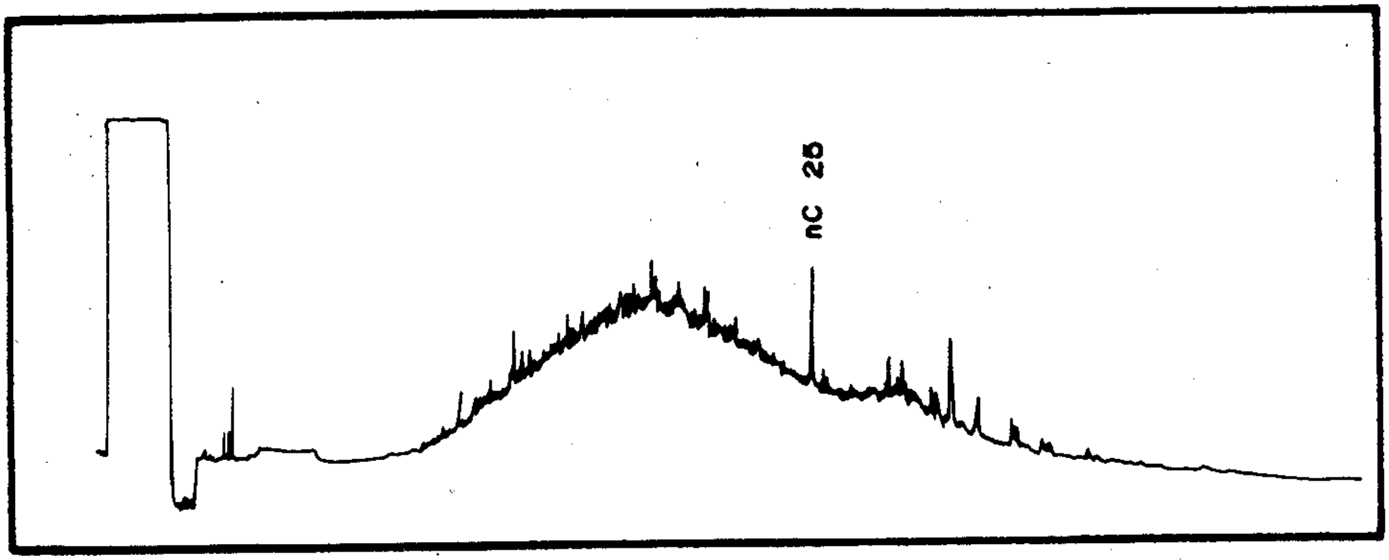
SKW102-19 3 KM S PUNTA BAYA HHWS



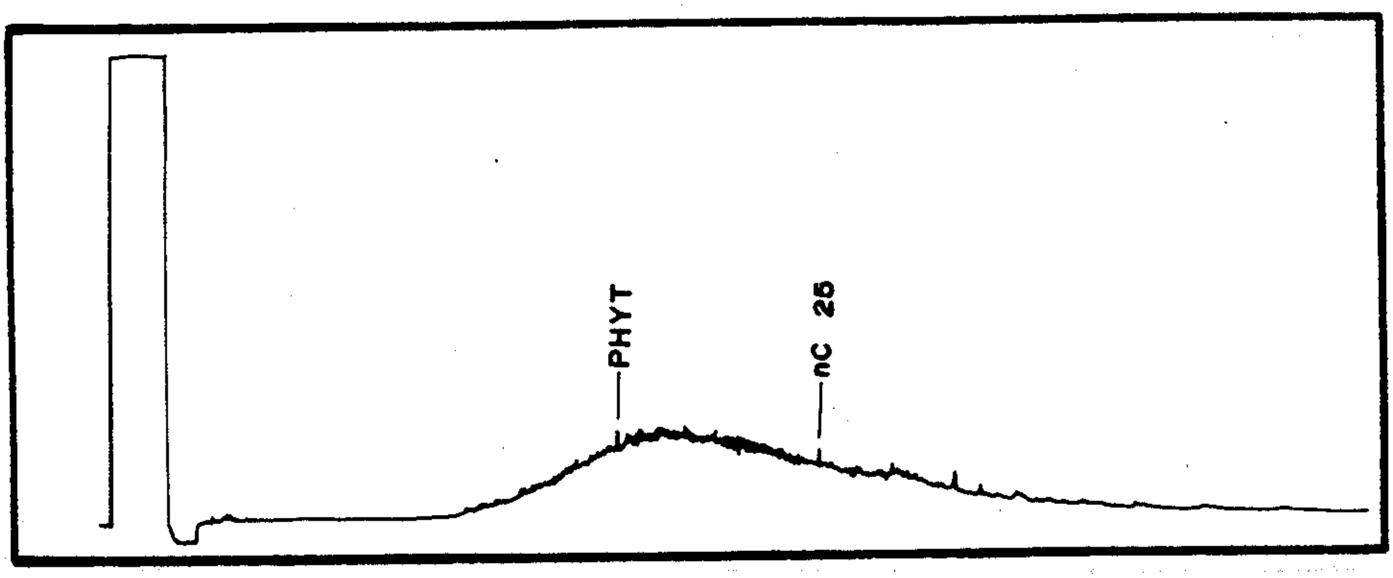
SKW102-20 PUNTA MALVINAS HHSW



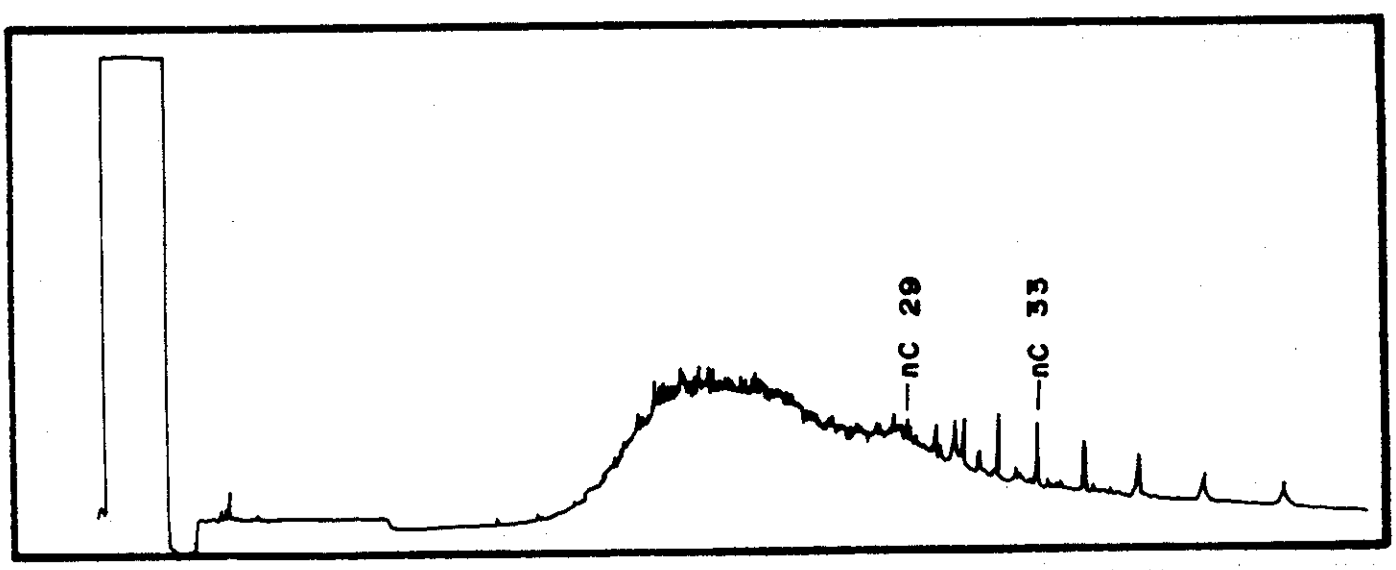
SKW102-21 PUNTA MALVINAS HHSW



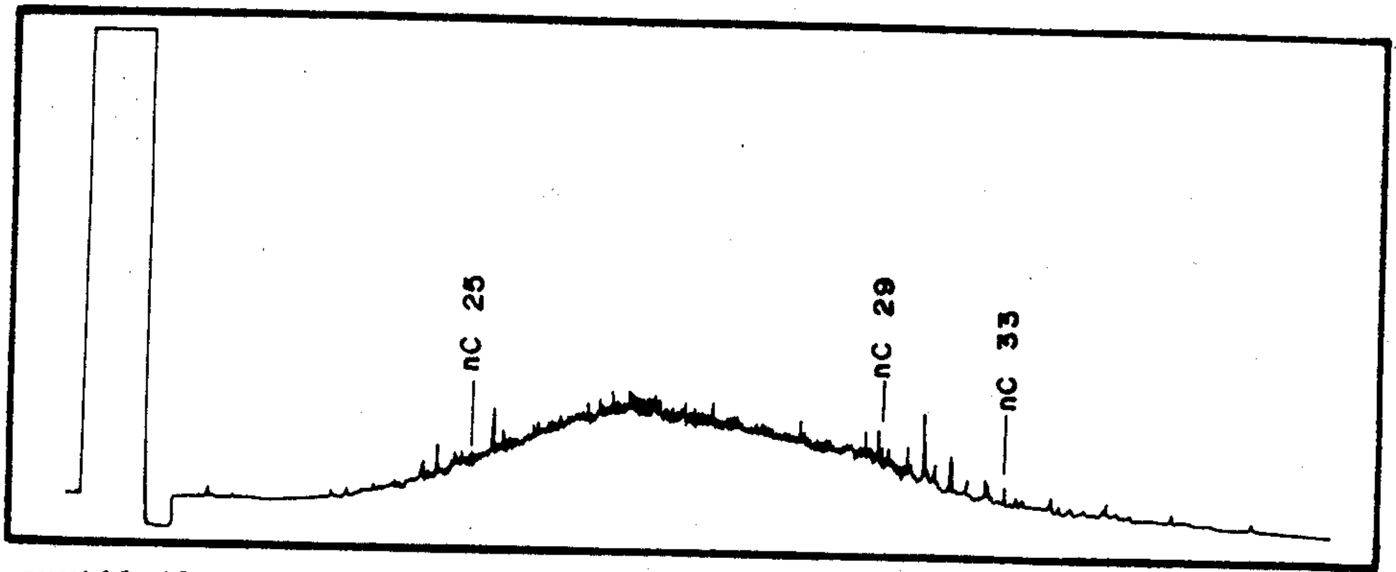
SKW102-22 PUNTA ESPORA LTT



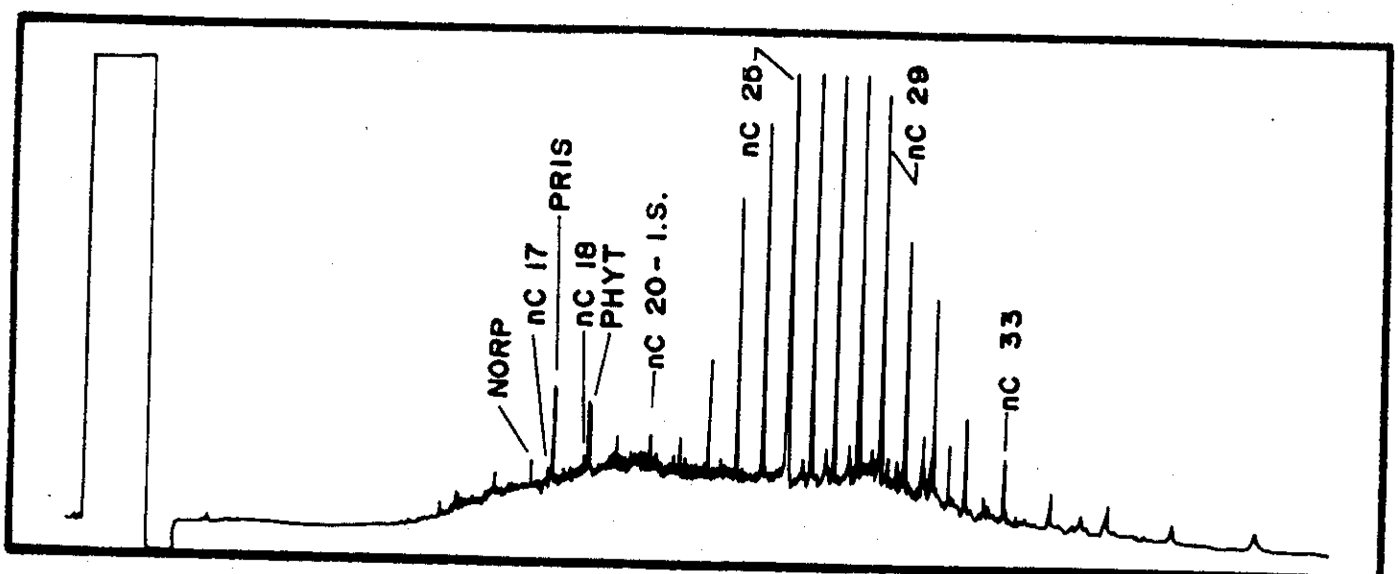
SKW102-23 PUNTA ESPORA LTT



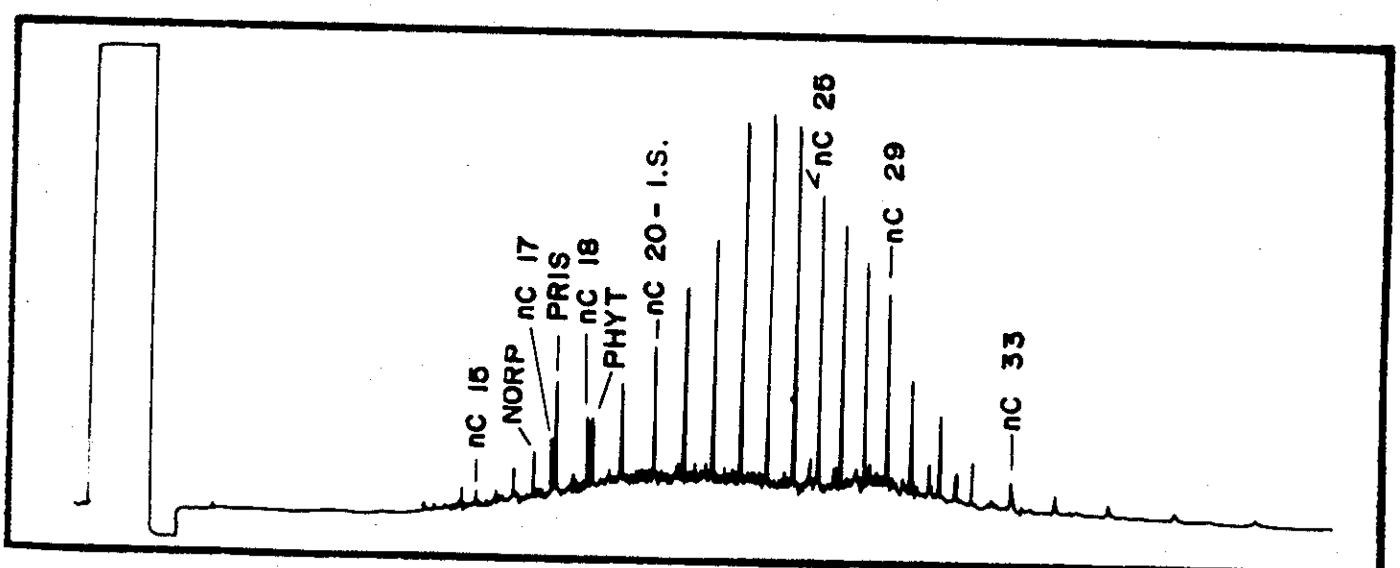
SKW102-24 PUNTA ESPORA BFSLOPE



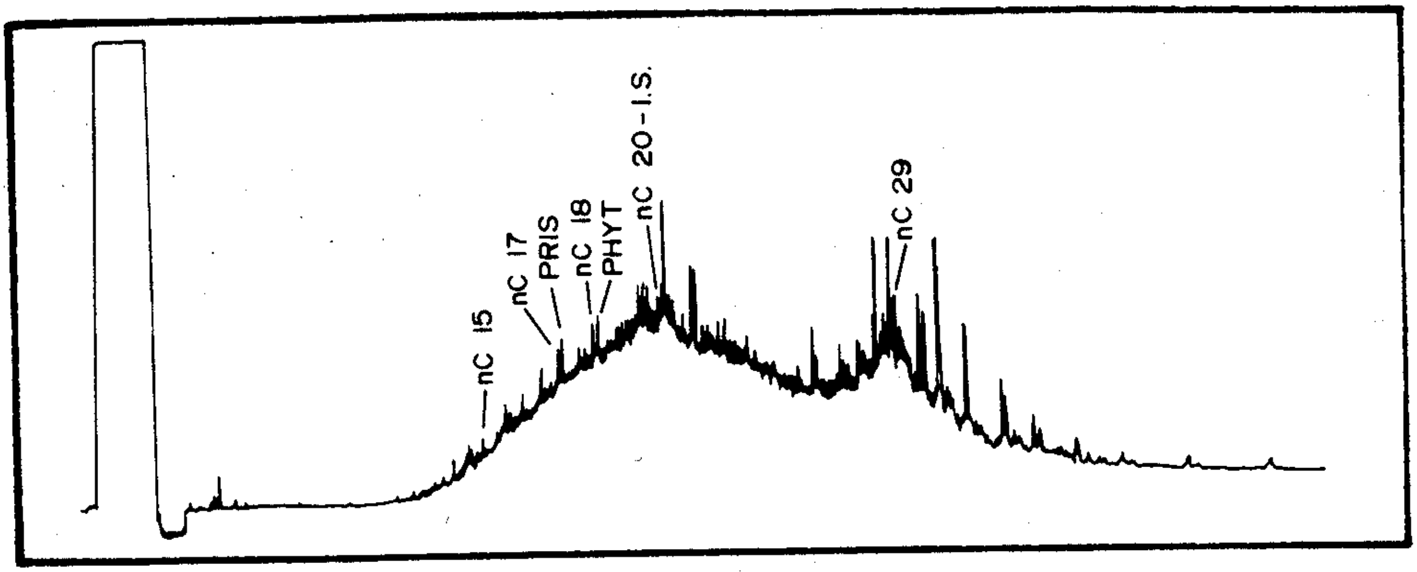
SKW102-48 PUNTA ESPORA LTT



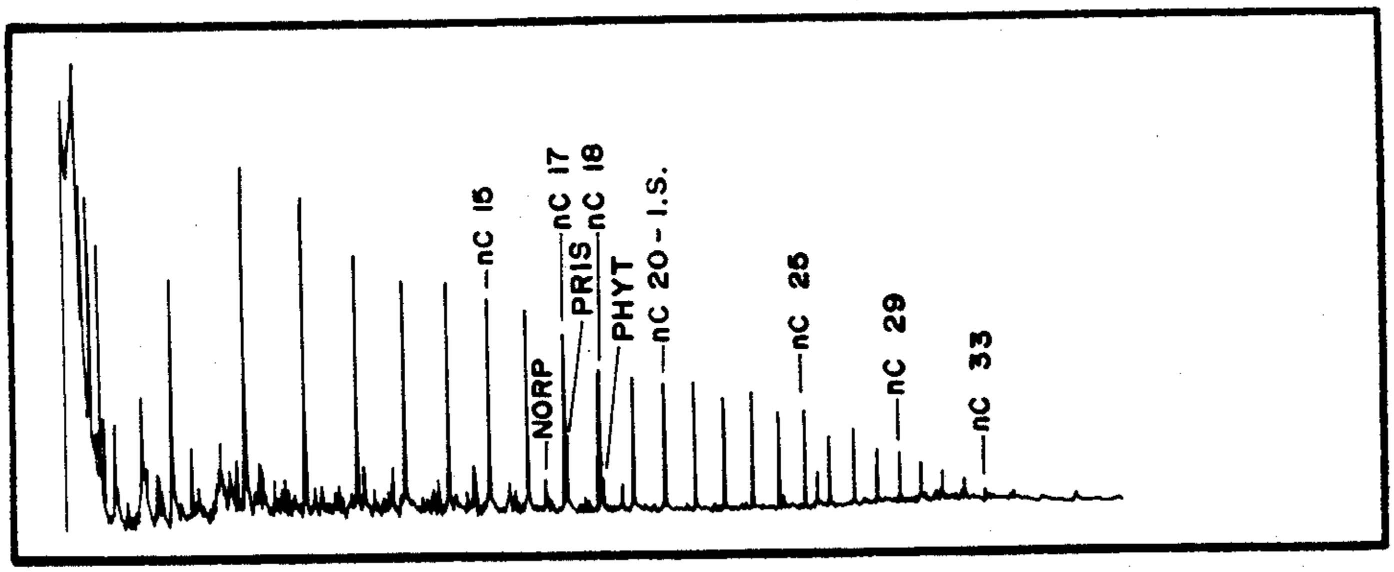
SKW102-52 ESPORA MARSH (CREEK) SUPRATIDAL



SKW102-53 ESPORA MARSH (CREEK) SUPRATIDAL



SKW102-54 ESPORA MARSH (CREEK) SUPRATIDAL



SKW102-55 ORIGINAL OIL