Bedford Institute of Oceanography
Dartmouth, Nova Scotia, Canada

SCIENTIFIC STUDIES DURING THE KURDISTAN TANKER INCIDENT: PROCEEDINGS OF A WORKSHOP

edited by J.H. Vandermeulen

October 1980 Report Series BI-R-80-3

Government of Canada
Gouvernement du Canada

The Bedford Institute of Oceanography is a Government of Canada research complex located on the shores of Bedford Basin in Dartmouth, Nova Scotia. The Institute conducts oceanographic studies and hydrographic surveys in a wide range of marine environments. Seven main groups affiliated with two departments are housed at BIO:

- the **Atlantic Oceanographic Laboratory, Marine Ecology Laboratory,** and **Institute Facilities** constitute Ocean Science and Surveys, Atlantic, of the Department of Fisheries and Oceans;
- the **Marine Fish Division** is part of the Resource Branch, Fisheries Management, Department of Fisheries and Oceans;
- the **Seabird Research Unit** is part of the Canadian Wildlife Service, Environmental Management Service, Department of the Environment;
- the **Atlantic Geoscience Centre** is part of the Geological Survey of Canada, Science and Technology, Department of Energy, Mines and Resources; and
- the **East Coast Office** of the **Resource Management Branch** is part of the Energy Policy Sector of the Department of Energy, Mines and Resources.

L'Institut océanographique de Bedford est un ensemble d'organismes de recherche du Gouvernement du Canada, situé sur le bassin de Bedford, à Dartmouth en Nouvelle-Ecosse. L'Institut poursuit des recherches océanographiques et effectue des levés hydrographiques dans des milieux marins très variés. Sept groupes principaux, relevant de deux ministères, sont domiciliés à l'L.O.B.:

- le **Laboratoire océanographique de l'Atlantique,** le **Laboratoire d'écologie marine** et les **Ressources de l'Institut** constituent les Sciences et levés océaniques, Atlantique, du Ministère des pêches et océans;
- la **Division des poissons d'eau de mer** fait partie de la Direction des ressources du Ministère des pêches et océans;
- l'**Unité des recherche sur les oiseaux de mer** fait partie du Service canadien de la faune du Service de gestion environnementale du Ministère de l'environnement;
- le **Centre géoscientifique de l'Atlantique** fait partie de la Commission géologique du Canada du Service des Sciences et de la technologie du Ministère de l'énergie, des mines et des ressources; et
- le **Bureau de la côte est** de la **Direction de la gestion des ressources** fait partie du Secteur Politique de L'énergie du Ministère de l'énergie, des mines et des ressources.

CA8100257

BEDFORD INSTITUTE OF OCEANOGRAPHY

Dartmouth, Nova Scotia
Canada

SCIENTIFIC STUDIES DURING THE "KURDISTAN" TANKER INCIDENT: PROCEEDINGS OF A WORKSHOP

June 26 and 27, 1979

Bedford Institute of Oceanography

Edited by

J.H. Vandermeulen

Marine Ecology Laboratory
Bedford Institute of Oceanography
Dartmouth, Nova Scotia
Canada B2Y 4A2

OCTOBER 1980 REPORT SERIES BI-R-80-3

ABSTRACT

On March 15, 1979, the tanker Kurdistan, carrying ca. 30,000 tons of Bunker C fuel oil, was en route from Cape Breton Island to Sept Iles, Quebec, when she encountered heavy pack ice. Sometime during March 15 the vessel developed two cracks in her hull, and during the night of March 15 she broke in two. As a result of the breakup, about 7,500 tons of Bunker C oil were spilled into the ice-infested waters of Cabot Strait.

The spill represents Canada's first major oil-in-ice spill, and a number of scientific studies were carried out, both at sea and on shorelines. This publication represents the proceedings of a workshop convened at the Bedford Institute of Oceanography on June 26 and 27, 1979, to discuss preliminary observations and conclusions obtained in these studies.

RESUME

Le pétrolier Kurdistan, avec environ 30,000 tonnes d'huile combustible Bunker-C à bord, était en route le 15 mars 1979 de l'Ile du Cap-Breton à Sept-Iles, Québec, quand il rencontra beaucoup de glace de banquise. Durant la journée du 15 mars deux fissures se sont développées dans sa coque et pendant la soirée le pétrolier s'est brisé en deux. Environ 7500 tonnes d'huile ont été déversées dans les eaux infestés de glace du Détroit de Cabot.

Cet incident représente le premier déversement majeur d'huile dans la glace au Canada. En consequence, plusieurs études scientifiques, conduites en mer et sur les côtes, ont été executées. Le 26 et 27 juin 1979, un atelier eu lieu à l'Institut océanographique de Bedford afin de discuter les résultats préliminaires de ces études. Ce rapport constitue le sommaire de ce rendez-vous.

TABLE OF CONTENTS

INTRODUCTION

On the night of March 15, 1979 the British tanker Kurdistan broke into two halves after she had encountered heavy pack-ice about 50 nautical miles north-east of Sydney, Cape Breton Island. As a result of the breakup circa 7,500 tons of her cargo, Bunker C fuel oil, was spilled into the Cabot Strait. The Canadian Coast Guard responded immediately, removing the crew from the stricken tanker halves under particularly dangerous conditions during gale storms. They also placed under tow the two halves of the tanker, and eventually hauled the stern section, still containing 16,000 tons of Bunker C, into Port Hawkesbury in nearby Chedabucto Bay, where the cargo was off-loaded. Ironically Chedabucto Bay was the scene of the February 1970 Arrow breakup and its spill of ca. 10,000 tons of Bunker C. The Kurdistan bow section with its 7,000 tons of oil was eventually towed to a disposal site on the Scotian Shelf Break, south of Sable Island, where it was sunk.

Except for an undertermined amount of oil that appeared in ice fields off south-east Cape Breton (estimated at 1000 to 2500 tons) most of the spilled 7,500 tons disappeared from view. However, in early April reports of oil sightings began to originate from farther out over the Scotian Shelf, over the Misaine and Banquereau Banks area. One week later, about April 9 and 10 and nearly a month after the breakup of the Kurdistan large amounts of oil began to come ashore on east coast Cape Breton. This continued with heavy oiling of the Sydney area on the north-east shore, until the entire north-east and east coast shorelines were oiled.

Since the breakup and spill occurred in the ice-covered waters of Cabot Strait, an opportunity was presented to the Canadian oceanographic community to examine the various aspects of oil/ice interaction under field conditions. Problems relating to oil spillage in ice-infested waters are only poorly understood, but they are likely to become real and complex when exploration, development and full exploitation of the submarine oil resources begins in the Canadian arctic. The papers in the following report represent the proceedings of a workshop convened at the Bedford Institute of Oceanography in June 1979 to bring together the various studies underway during the Kurdistan spill.

The papers are necessarily preliminary in nature since the workshop was held only three months after the Kurdistan broke up in Cabot Strait. Much of the data at the time of the workshop was still only in the first stages of analysis and indeed several of the participants had only just returned from the field. Nonetheless it was felt that the workshop would present a chance for the various investigators involved to have a first-hand look at what the others were doing, at all the investigations and studies underway.

Three aspects of the spill received special attention. One of these is the problem of slick movement. Three papers describe attempts at tracking the ephemeral oil slick with remote sensing methodology (Fingas *et al.*), and the testing of old and developing new trajectory models to incorporate the influence of varying Shelf currents and ice movement (Lawrence and Galbraith; Trites *et al.*). The second was the severe physical degradation of the spilled oil into smaller blobs, smears and particles (Vandermeulen *et al.*; Levy *et al.*; Fowler and Noll; Reinson *et al* This latter feature of oil-in-ice came unexpectedly for, although tar-ball and particle formation is a well-known adjunct of oil spills (for ex. *Arrow*), no one was quite prepared for the range of sizes of blobs and particles observed in the *Kurdistan* spill. Whether this breaking up of the oil into the smaller and smaller blobs and particles is a general feature of oil spills in ice is not now known. The third feature was the problem of identifying oil in association with ice, and how to distinguish it from other contaminants as soil or silt or from interfering physical features within the ice-field itself (Reimer).

Included also are some papers on biological aspects of the spill, although results are again preliminary or inconclusive. One reason for this is that the bulk of the spilled oil disappeared from view for about a month after the tanker breakup, and it became impossible to pinpoint the possible impact areas and to plan and carry out meaningful biological assessment. Fortunately, the Canadian fisheries management ichthyoplankton survey grid overlapped in part with the spill impact area and preliminary observations on plankton and chlorophyll for the effected area were fortuitously made available (O'Boyle). As in most spills observed to date, seabirds again suffered large mortalities, both observed and estimated (Brown and Johnson).

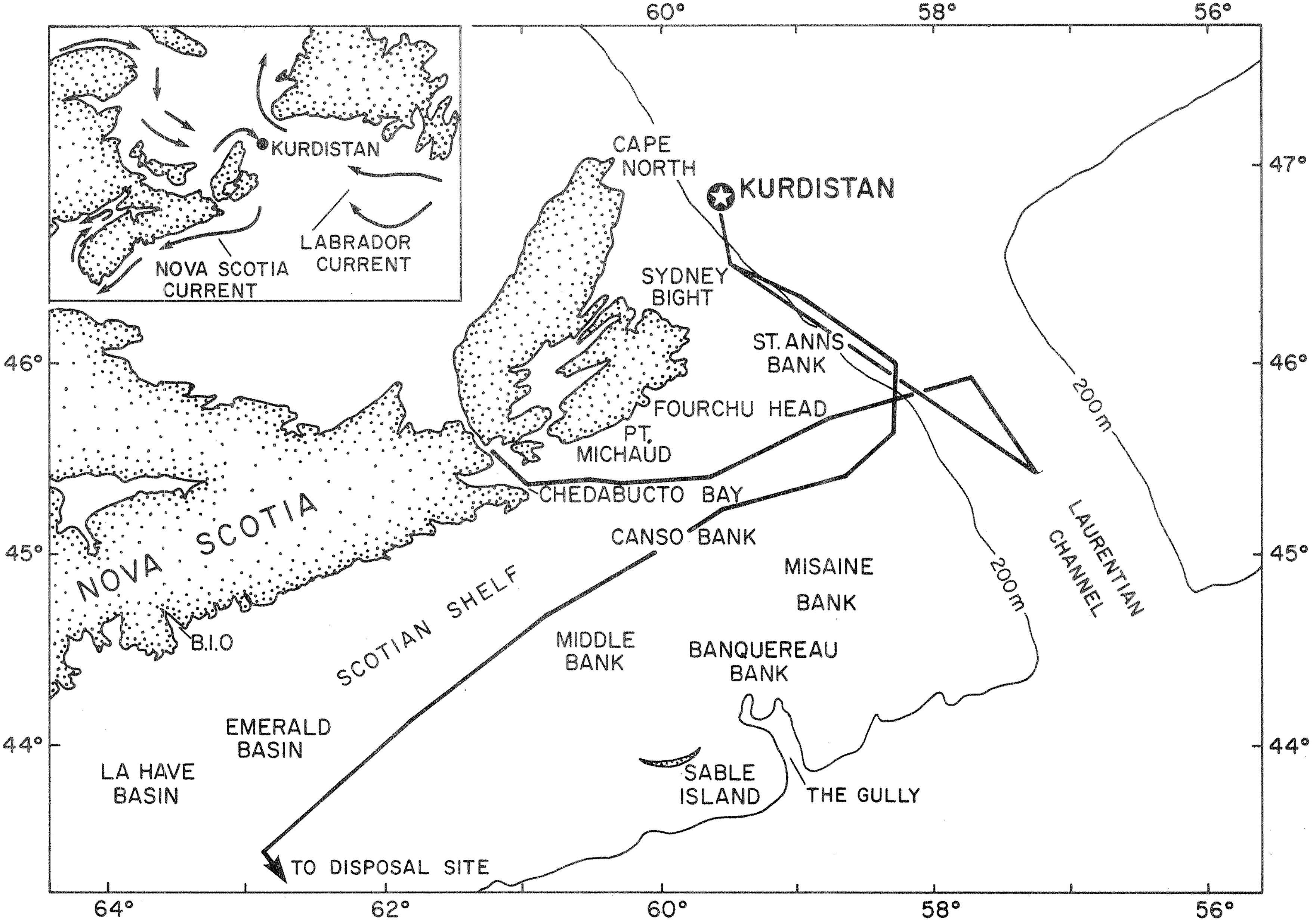
One paper dealing with the selection of disposal sites of oiled debris (Lin), deserves separate mention. How to get rid of thousands of tons of wet oily beach debris is an awesome problem common to all near-shore spills, but one that seldom receives attention at conferences. Indeed, one may well wonder if the disposal problem in the final analysis is not the single largest problem during a major onshore spill.

For the most part the papers in this workshop proceedings were printed as they were submitted, with only minor changes for the sake of standardization of format. Because these are workshop contributions the papers contain considerable detail and basic data (cruise reports, detailed oil sightings, flight track data, etc.). This sort of data, that normally does not form part of primary papers, was deliberately included (in Appendices) to make it available to other workers. Further detailed information on oilsightings and ice and weather information can be found in a preceding report (The Kurdistan Oil Spill, March 15/16, 1979 . Activities and observations of the Bedford Institute of Oceanography scientific response team. Vandermeulen, J.H. and D.E. Buckley, ed's. Bedford Institute of Oceanography Report Series, BI-R-80-2, 1980).

Various organizations participated in the field effort and in the workshop. Unfortunately the scientific field effort had to be created altogether too hastily, without adequate time to "think through" the questions to be studied, and without the assurance of the special funding necessary to organize and sustain an instant study program. Projects were organized on the spot, and scientific decisions had to be made instantly, often without sufficient data.

On the other hand a great deal of work was accomplished, some of it contained in these proceedings. In this respect I express my thanks to Mr. E.M. Reimer of C-CORE for co-organizing and co-chairing this first oil-in-ice workshop and to Dr. D. Thornton of the Canadian Environmental Protection Service for his assistance in bringing the workshop to completion.

J.H. Vandermeulen



Location map showing the site of the *Kurdistan* accident in relation to Cape Breton Island and the Scotian Shelf.

SESSION I. SLICK MOVEMENT AND OIL/ICE INTERACTION

Chairman

J.H. Vandermeulen
Bedford Institute of Oceanography

WAVE CLIMATE OVER THE CONTINENTAL SHELF AND ITS IMPACT ON THE OILSPILLS OF THE ARROW, ARGO MERCHANT and KURDISTAN

by
H.J.A. Neu
Atlantic Oceanographic Laboratory
Bedford Institute of Oceanography
Dartmouth, N.S.

In the open waters of the Continental Shelf of Atlantic Canada and New England States, waves are the most disturbing factor in tanker accidents and in the recovery of the oil which has been spilled. Wave heights vary with location and season, increasing from the New England coast to Newfoundland by about 1 to 2 m and being highest in the winter and about half of that during the summer. In this brief presentation, the impact of this seasonally varying seastate on the major tanker accidents, on salvage efforts and on recovery of the spilled oil is analyzed.

TANKER SPILLS

The tanker Arrow, which grounded during a storm on February 4, 1970, sank during the subsequent storm on February 12, 1970. At the approaches to Chedabucto Bay, the waves of both storms were in the order of 6 to 7 m, close to the monthly maximum value of the region. At the site, conditions were aggravated by refraction from shoals and ledges which focused wave energy from the SE toward Cerberus Rock on which the tanker was resting (Fig. 1).

In contrast, the Argo Merchant ran aground in calm weather on a sand bank near Nantucket Island on December 15, 1976, initially with minor damage and little oil spilled. Failure to salvage the vessel quickly and the continuous action of waves 1 to 2 m high weakened the vessel. Six days later a storm with 2 to 3 m waves broke the tanker and spilled the entire oil load into the ocean.

Completely different again is the experience of the Kurdistan on March 15, 1979, at the entrance to Cabot Strait. In heavy pack ice and with waves in the order of 6 to 7 m (Fig. 2), a crack developed in the hull and later the vessel broke into two parts, spilling more than 7,000 tons of

Bunker-C oil into the ice-infested waters of the Strait. The bow and stern sections remained intact and proved surprisingly seaworthy. Eventually, the stern section was brought into Port Hawkesbury, in the Strait of Canso and the bow section was sunk off the edge of the Continental Shelf.

From this brief account of the accidents, it is obvious that waves played an important role in the destruction of the tankers. All three mishaps occurred during the winter months when more than 250 North Atlantic weather disturbances propagate along the coast of North America and across the North Atlantic. These storms generate wave heights which vary with location. In Figure 3, the largest monthly significant wave heights of the North Atlantic, based on the 1970 to 1972 data, are given for the months December to March. It can be seen immediately that the waves which destroyed the tankers were, in the case of the Arrow and the Kurdistan, close to being the largest in the respective months.

SALVAGE EFFORTS

As soon as a tanker is in distress, salvaging the vessel and preventing oil from entering the sea is the priority task. In cases of groundings, these operations usually take weeks and require calm seas, a rare occurrence during the winter months.

Monthly height distributions are given in Figure 4, for the Scotian Shelf and for the 12 months of the year. Waves are large and frequent during the winter from November to March but grow appreciably smaller and less frequent until the summer months of June and July. Assuming 3 to 4 metre waves as the wave height limit for salvage operations on tankers in the open sea (wave heights given here are $H_{sig} = 4$ m and therefore include heights up to a maximum of 7.2 m), then it can be expected that during the summer months from May to August salvage operations can be performed during a large part of the time without undue interference from waves. However, during the winter, the critical wave height is exceeded about 25% of the time, equivalent to 7 days integrated time each month, or more realistically 12 to 14 storms of about half a day duration each month. Under these circumstances it would be extremely difficult to conduct successful salvage or repair operations on stricken oil tankers. But it should be noted that even 4 m waves can cause problems, as was demonstrated with the Kurdistan where towing just the bow section alone in a seastate with only 4 m waves was very difficult for the tugs available for the operation. This indicates the need for larger and more powerful sea-going tugs on the Atlantic Coast to meet such requirements.

OIL RECOVERY

For the recovery of oil from the surface of the ocean, oil booms and clean-up equipment have been developed; however, in none of the three accidents under discussion has oil been recovered from the surface of the ocean in any significant amount. The reason for this is that the most up-to-date equipment and recovery methods do not yet work in ocean conditions; even in the case of the *Argo Merchant* with its lower sea state no effort was made to apply them.

The question therefore arises whether oil recovery from the open ocean is at all feasible. In order to evaluate this, an upper wave height limit is again assumed at which oil booms, surface skimmers and other equipment are still useful. Disregarding specialized heavy duty equipment developed for specific applications on oil platforms in that North Sea, the critical height is about 1.5 to 2 m. Applying this wave height to the monthly wave height distributions in Figure 4, it is seen that only 25% of the waves in the summer months exceed this value. Provided that the equipment is sufficiently seaworthy to withstand higher waves during the waiting periods for calmer weather, oil can probably be recovered during the summer with a relatively high degree of success. During the winter, however, 80% of the waves exceed this critical value. Recovery of oil during this period then becomes very impractical.

OBSERVATIONS AND CONCLUSIONS

(1) The destruction of the tankers *Arrow*, *Argo Merchant* and the breaking of the *Kurdistan* into two parts took place during the winter, coinciding with high wave activity.

(2) During the destruction, waves were close to the maximum monthly level, except for the *Argo Merchant* where it was only half that value.

(3) The difficulties encountered in towing the bow section of the Kurdistan demonstrates the need for tugs on the Atlantic coast powerful enough to handle stricken tankers in heavy seas.

(4) With the exception of towing stricken tankers into protected areas or harbours, salvage operations in open sea during the winter are very impractical.

(5) With the present state of the art in the field of oil recovery and with equipment available today, oil can be recovered from the surface of the ocean only during the summer. During the winter months, efforts to do so will generally fail.

ACKNOWLEDGEMENT

The author acknowledges the assistance of R.E. Walker and F. Jordan in processing the data and preparing the paper.

BIBLIOGRAPHY

NEU, H.J.A. 1970. The hydrodynamics of Chedabucto Bay and its influence on the Arrow oil disaster. Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, Report 1970-76, Dartmouth, N.S.

NEU, H.J.A. 1976. Wave Climate of the North Atlantic - 1970. Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, Report/BI-R-76-10, Dartmouth, N.S.

WALKER, R.W. 1976. Wave statistics for the North Atlantic - 1970. Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, Data Series/BI-D-76, Dartmouth, N.S.

WALKER, R.E. 1977. Wave Statistics for the North Atlantic - 1971. Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, Data Series/BI-D-77, Dartmouth, N.S.

WALKER, R.E. 1978. Wave statistics for the North Atlantic - 1972. Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, Data Series/BI-D-78, Dartmouth, N.S.

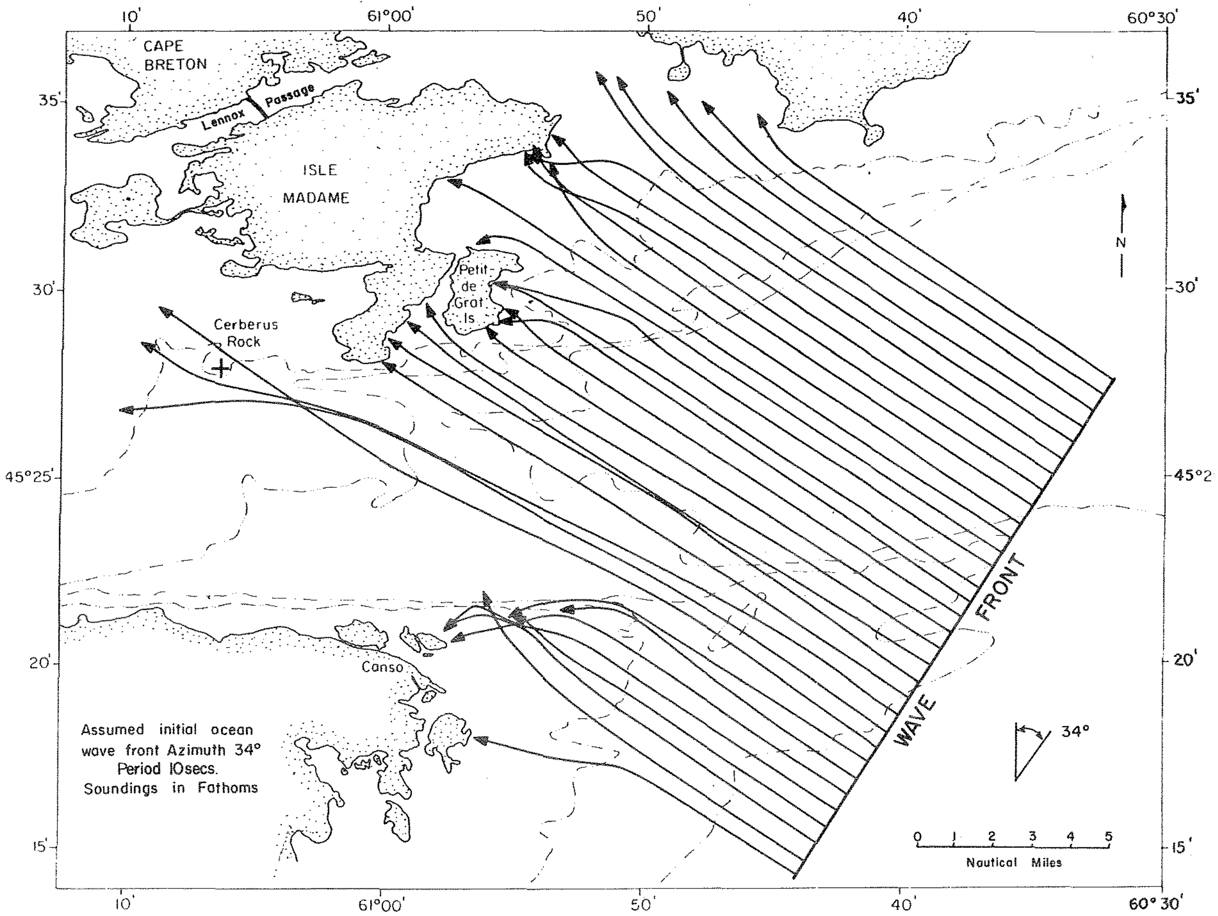


Figure 1. Wave refraction diagram of a 10-second wave train in Chedabucto Bay - 34° wave front.

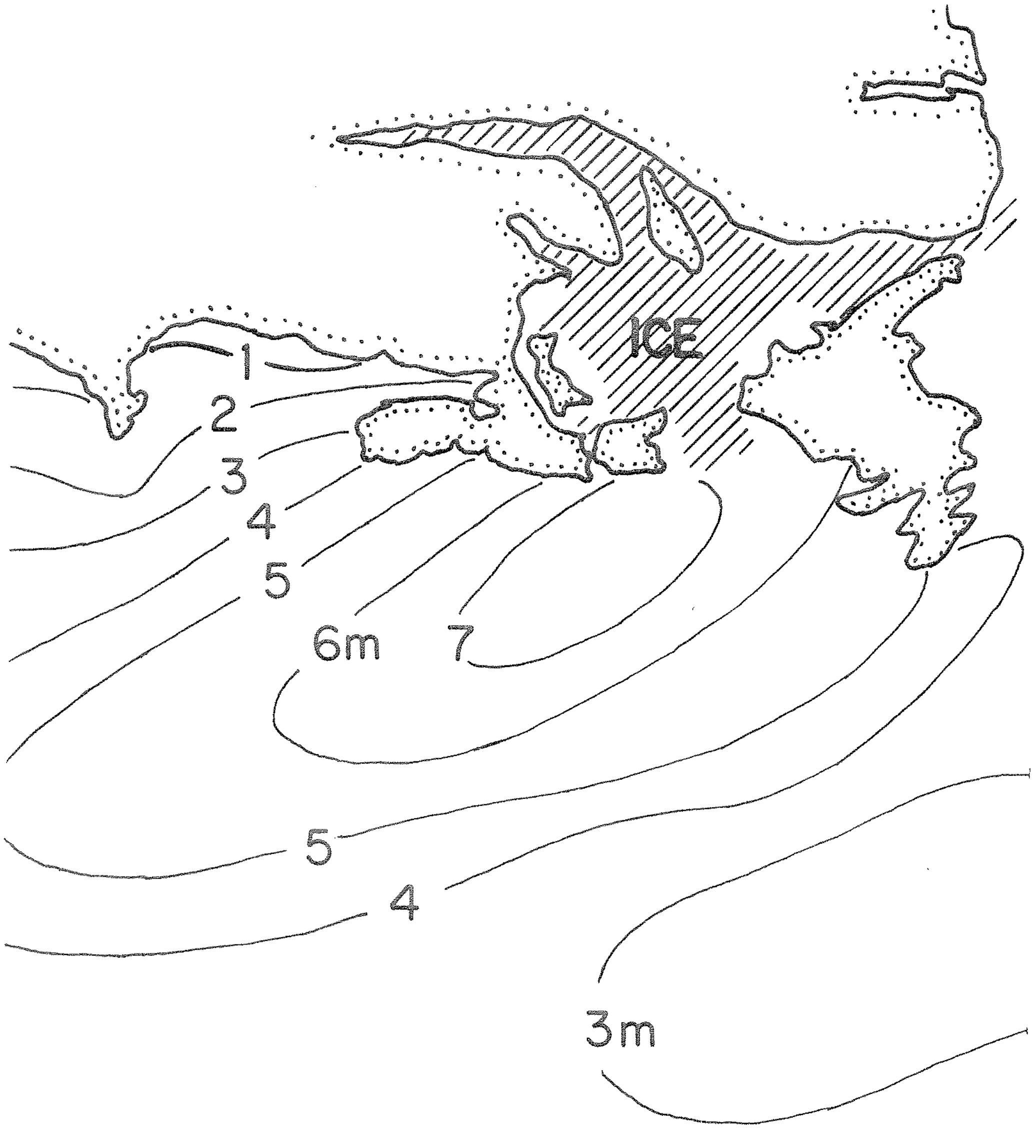


Figure 2. Wave data chart, 15 March 1979, 1200Z (from C.F. METOC Centre).

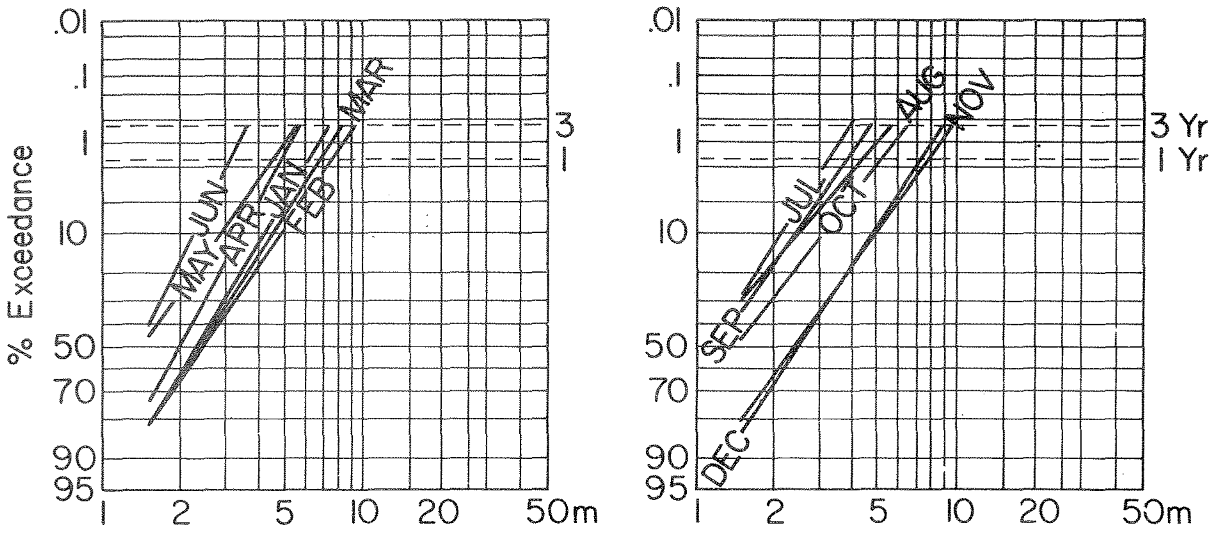


Figure 3. Largest monthly wave height (H_{sig} in m) of the North Atlantic from December to March.

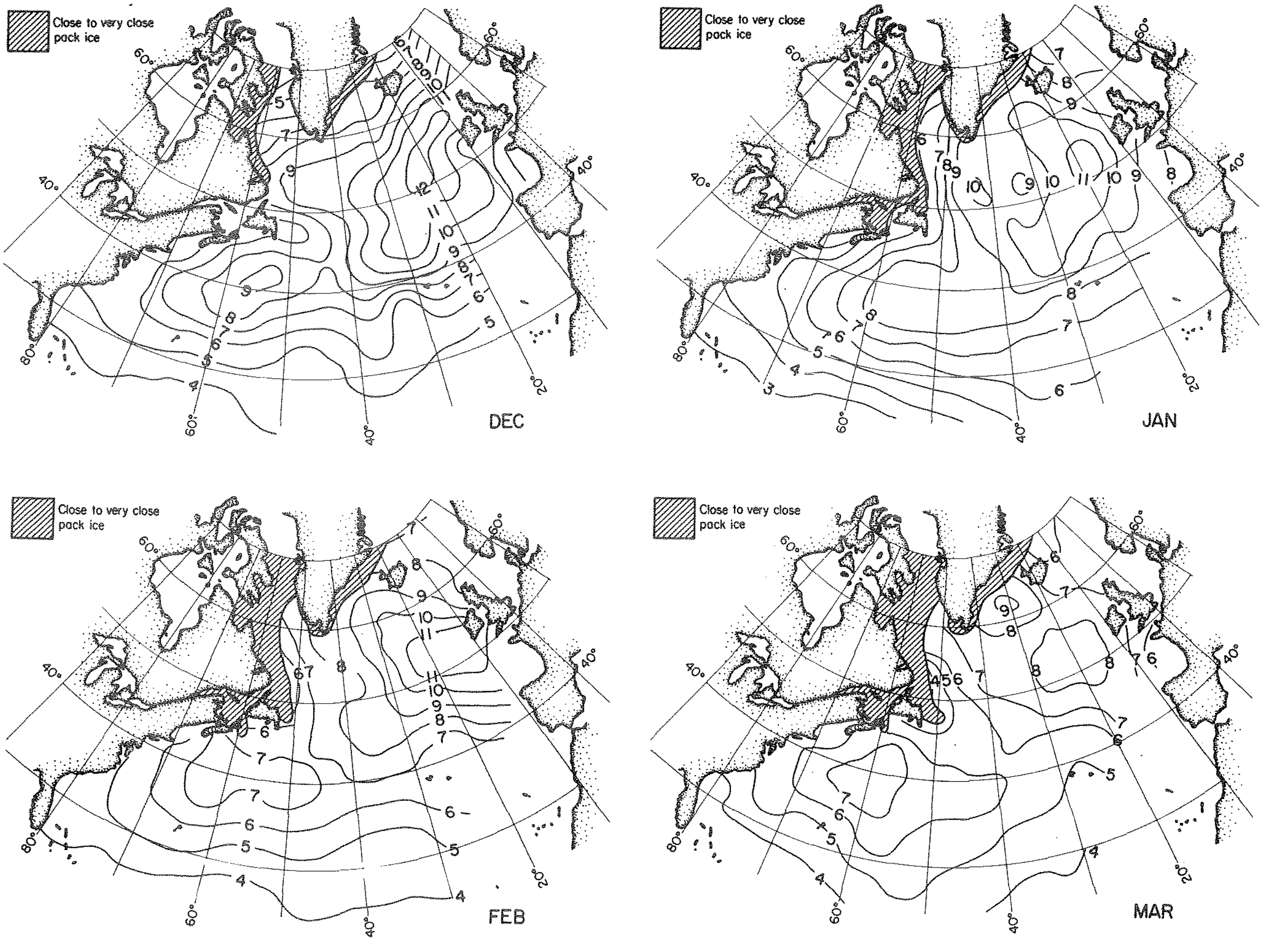


Figure 4. Monthly wave height distribution (H_{sig}) of the Scotian Shelf.

A SIMPLE OILSPILL TRAJECTORY MODEL FOR THE SCOTIAN SHELF, USING SINGLE AND MULTI-POINT WIND FIELDS

D. Lawrence[1] and P. Galbraith[2]

[1]Atlantic Oceanographic Laboratory
Bedford Institute of Oceanography
Dartmouth, N.S. Canada B2Y 4A2

[2]Atmospheric Environment Services (AES)
Bedford, N.S. Canada

INTRODUCTION

In projecting trajectories for oil slick movement at sea a number of factors come into play, including residual surface current, Coriolis force, tidal currents and winds. The last of these, surface winds, presents a particular problem in that winds for a large area are not constant in either direction or speed, but vary, sometimes greatly, from point to point. We have examined this problem with respect to spill movement during the Kurdistan accident, and have looked at several sources of wind data and contrasted their performance. We have also explored the importance of the surface residual currents in constructing a wind-current derived model.

MODELS AND DISCUSSION

'Six-point' wind vectors as derived from surface pressure maps (Appendix I) are shown in Figure 1. In general the large scale features for each of the six sites are similar, although there are differences in detail between the various sites. These differences are mainly minor differences in wind directions and speeds. The locations of the sites chosen for the analysis are shown in Figure 2, together with their circles of influence (radius R=500 km). These circles denote the limit of influence of each site in the R2D2 spatial interpolation scheme (Appendix I). Wind vectors for any point on the Scotian Shelf then can be calculated using the known wind vectors for each of the sites impinging on that point, with most points of the Shelf being influenced by two or more sites.

The relevance of these pressure-map derived winds to real observed winds is demonstrated in Figure 3, which shows 'six-point' winds for site 3, southwest of Sable Island, compared with the observed winds for Sable

Island. Sable Island is considered the best site for direct wind observations over the Scotian Shelf area (Petrie and Smith, 1977). Large scale features are similar, but differences in amplitude and in direction do exist. For example, the Sable Island extremes tend to be of lower amplitude, probably because of the 6-hour smoothing applied before plotting.

To predict trajectories, we used a very simple model: vector-addition of a residual current to 3% of the wind vector at each time-step. We ignored Coriolis deflection, dispersion, and any oil weathering processes (including movement of submerged oil, viz. Fingas et al., this volume).The 6-point wind vector was obtained by using the spatial interpolation scheme. A direct comparison of trajectories based on the two wind sources, 6-point and real observed, is made in Figure 4. The trajectories were started at site 3. They were stretched out for better display by the use of a modest, but realistic residual current (10 cm s^{-1}) parallel to the Scotian Shelf break direction (245°T). After 30 days, the end points are remarkably close although the paths do diverge as they proceed farther from the Sable Island observation site.

We examine this spatial variability more systematically in Figure 5. Using only the 6-point winds, we start trajectories simultaneously at three positions along the line connecting sites 2 and 3. These points were chosen so that a gradient of wind-regimes would be experienced in the calculations. Again the residual current is used to stretch out the trajectories. Small scale features (e.g., at days 96, 106 and 116) can be recognized on all trajectories. The end positions differ considerably. The large scale movement between days 96 and 106 differs considerably at location C, perhaps due to Gulf Stream forcing.

Finally we examine the influence of residual current on the trajectories. In Figure 6, residual currents of 10 cm s^{-1} both parallel to and normal to the Scotian Shelf break are contrasted with the zero current case. The displacements produced by even such relatively low currents are several times greater than those due to the wind alone, and dramatize the plight of the modeller in these regions where residual current data is often lacking, or is inappropriate due to the presence of strong low frequency motions.

A second demonstration of the important role of current (Fig. 7) uses trajectories started farther north, close inshore. This shows that a current parallel to the shelf, but in the opposite direction to that previously used, can take a trajectory close to the Newfoundland coastline.

CONCLUSION

In this preliminary study, we have discussed our method of extraction of surface winds at six specific sites from pressure maps, and the spatial interpolation scheme to adapt the data for trajectory modelling on the Scotian Shelf, based on an integrated influence of winds from multiple sites. We have depicted the magnitude of the differences between trajectories based on this scheme and those based on the directly observed winds at a single site. There is little difference directly near Sable Island in the two trajectory schemes. However, the six-point wind scheme probably is the better of the two when one gets further out over the ocean, as over the Gulf Stream, where there are no reliable observed winds. This probably applies for nearshore situations as well, including Cabot Strait, where shorebased stations are sheltered and observed winds are not representative of winds over the Shelf.

The importance of residual currents in trajectory modelling has also been shown.

ACKNOWLEDGEMENTS

We appreciate the assistance of colleagues in Atmospheric Environment Services in wind-data analysis, and with special thanks to J.H. Vandermeulen and R. Trites, Marine Ecology Laboratory for participation in manuscript critique and preparation.

BIBLIOGRAPHY

PETRIE, B. and P.C. SMITH. 1977. Low-frequency motions on the Scotian Shelf and Slope. Atmosphere-Ocean <u>15</u> (3), 117-140.

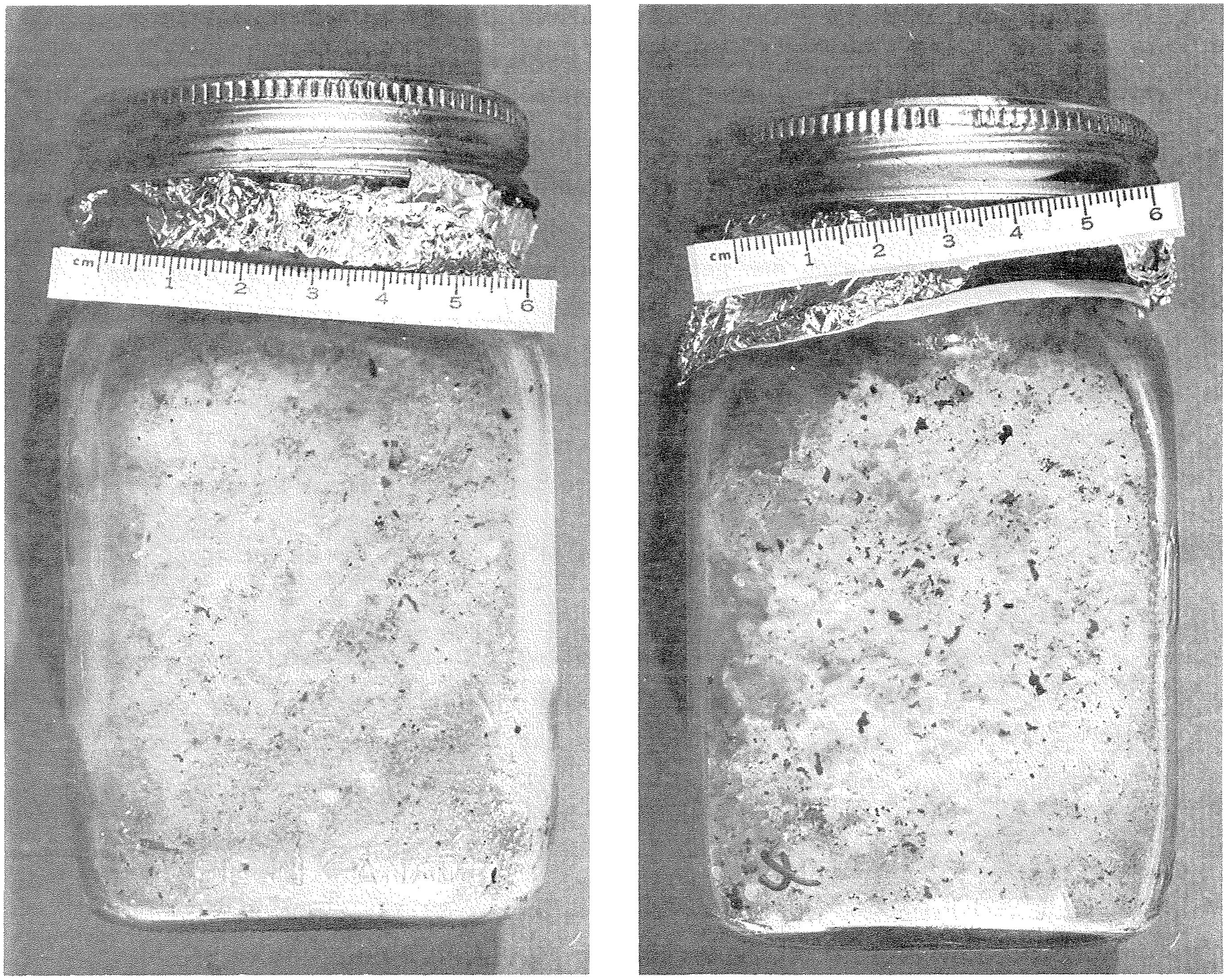


Figure 1. Wind-vectors for the period beginning March 15, 1979 for six sites on the Scotian Shelf. The winds were abstracted from surface pressure maps every 6 hours. For location of sites viz. Figure 2.

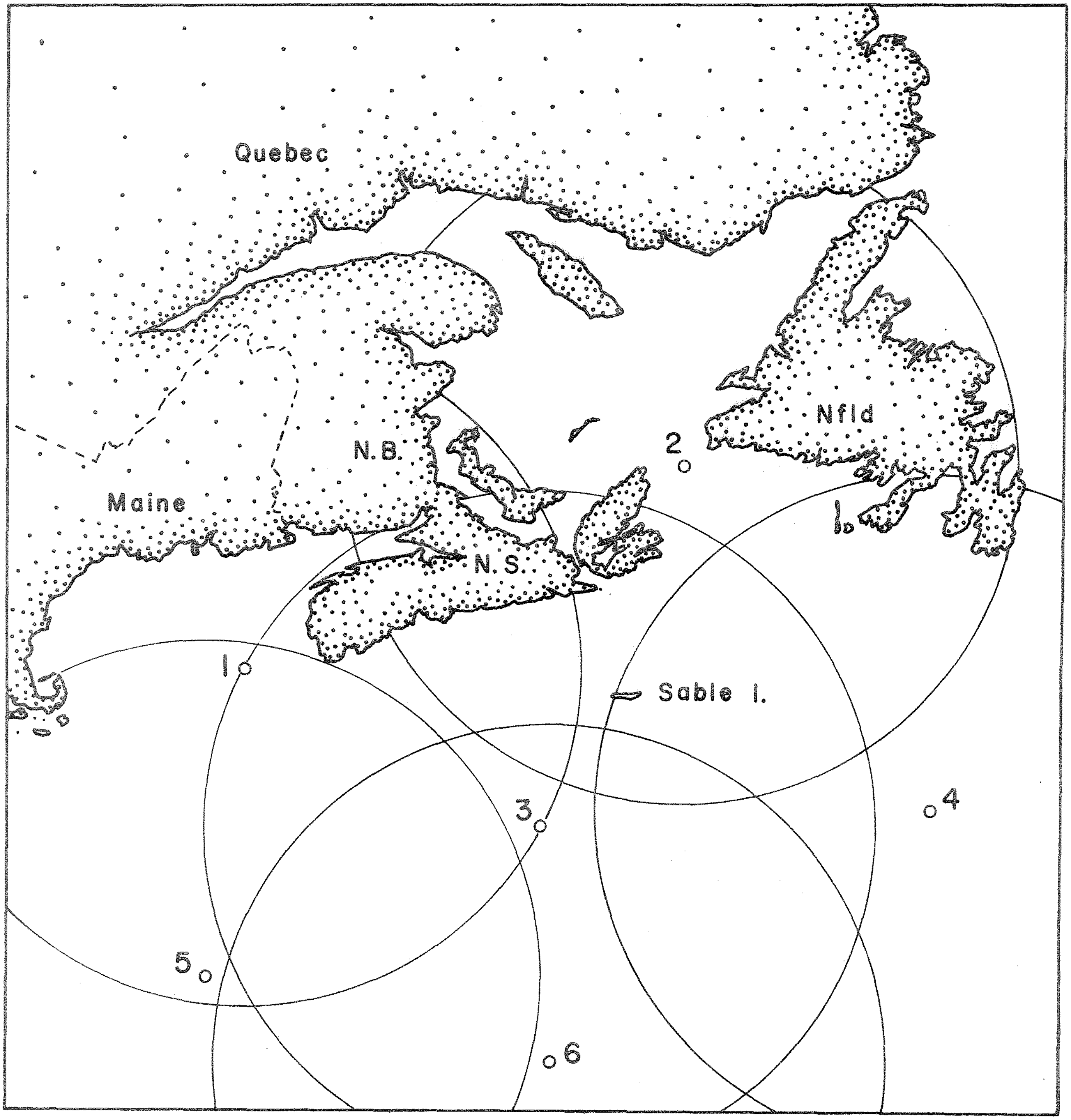


Figure 2. Location of 'six-point' wind sites on the Scotian Shelf. Circles indicate circles of influence (radius R=500 km) for each of the sites.

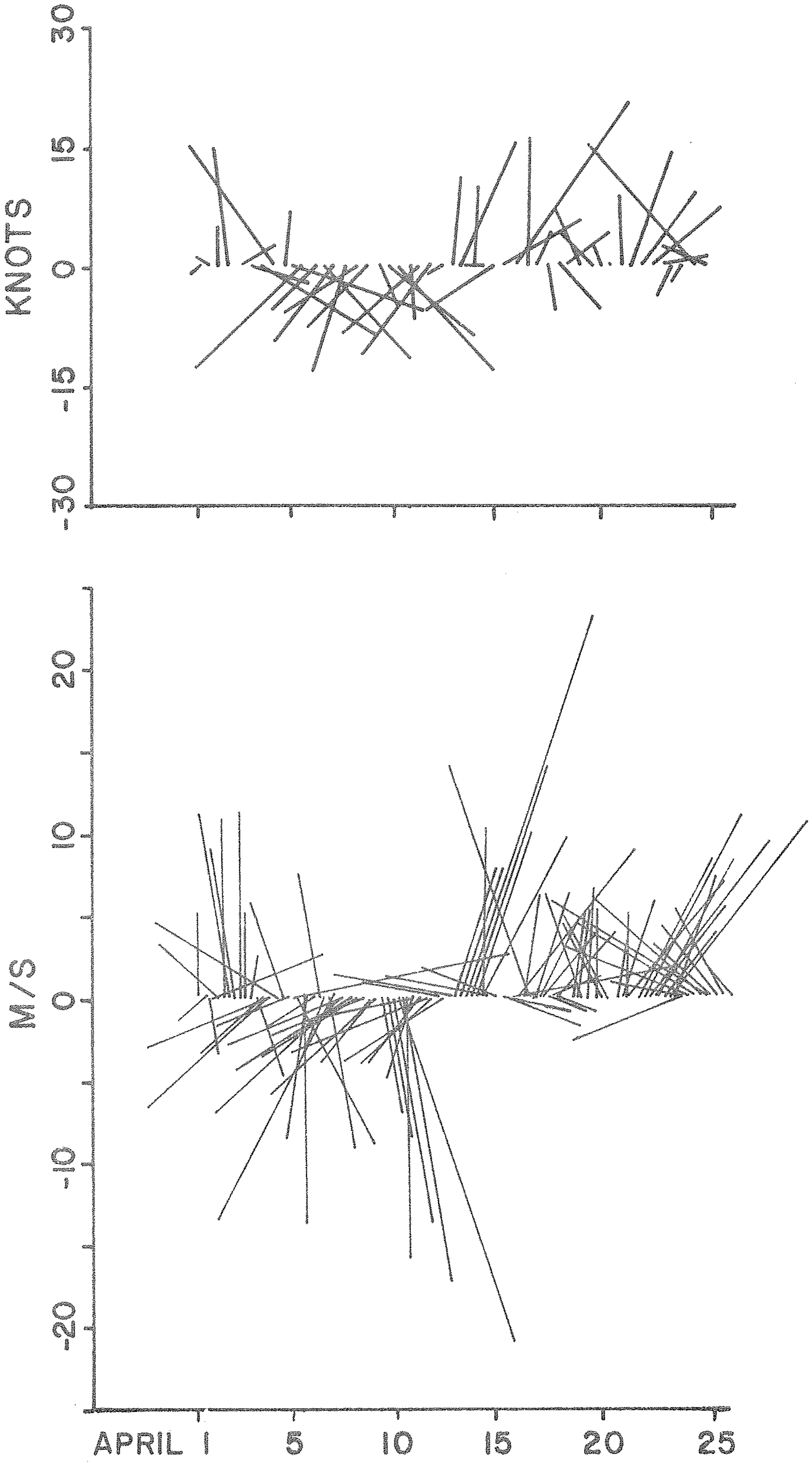


Figure 3. Wind vectors for the period April 1 through 25, 1979 for Sable Island (upper figure, real observed winds) and for site 3 ('six-point' winds). (15 knots = 5.7 m s^{-1}).

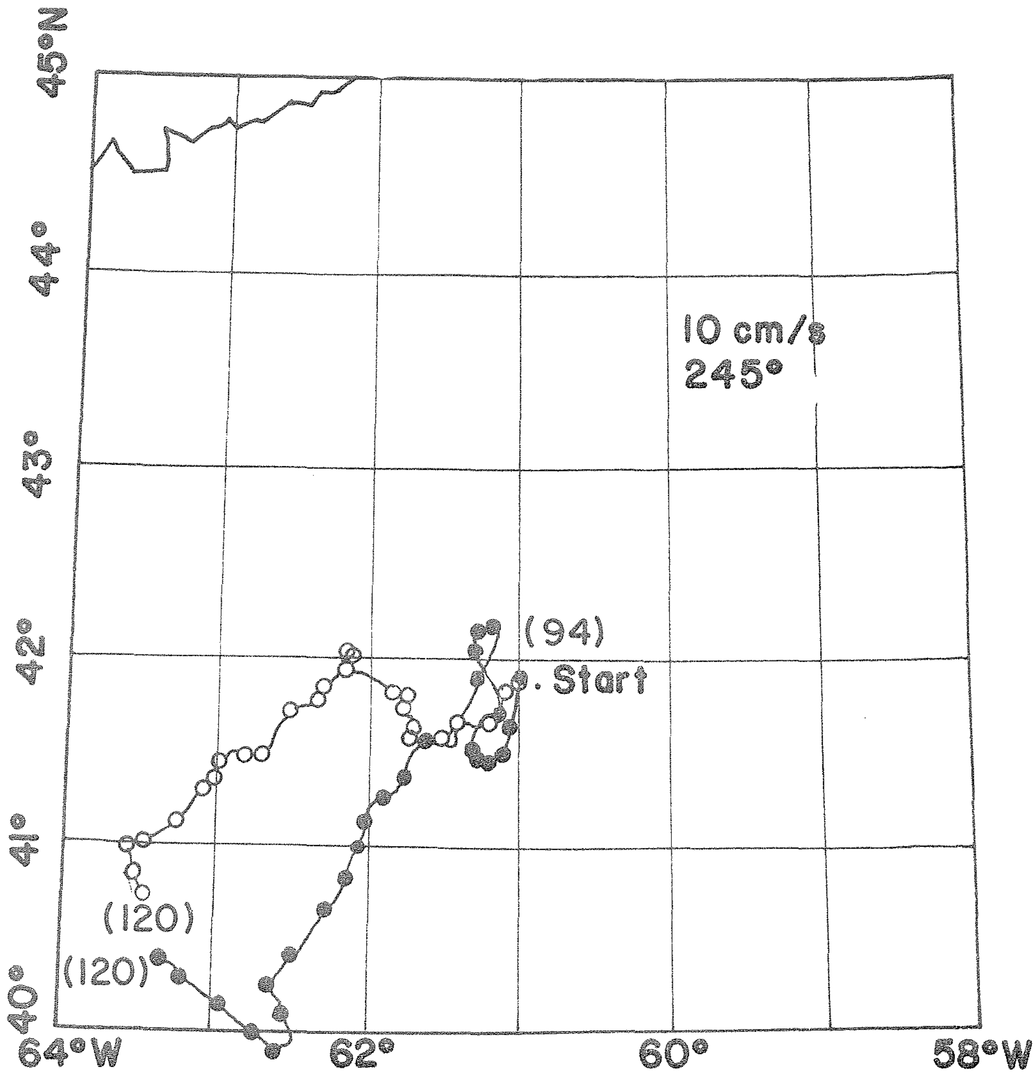


Figure 4. Comparison of trajectories based on real observed Sable Island winds (open circles) and on 'six-point' winds (closed circles), starting at site 3 on day 91 (April 1, 1979), using 3% of the wind and including a residual current.

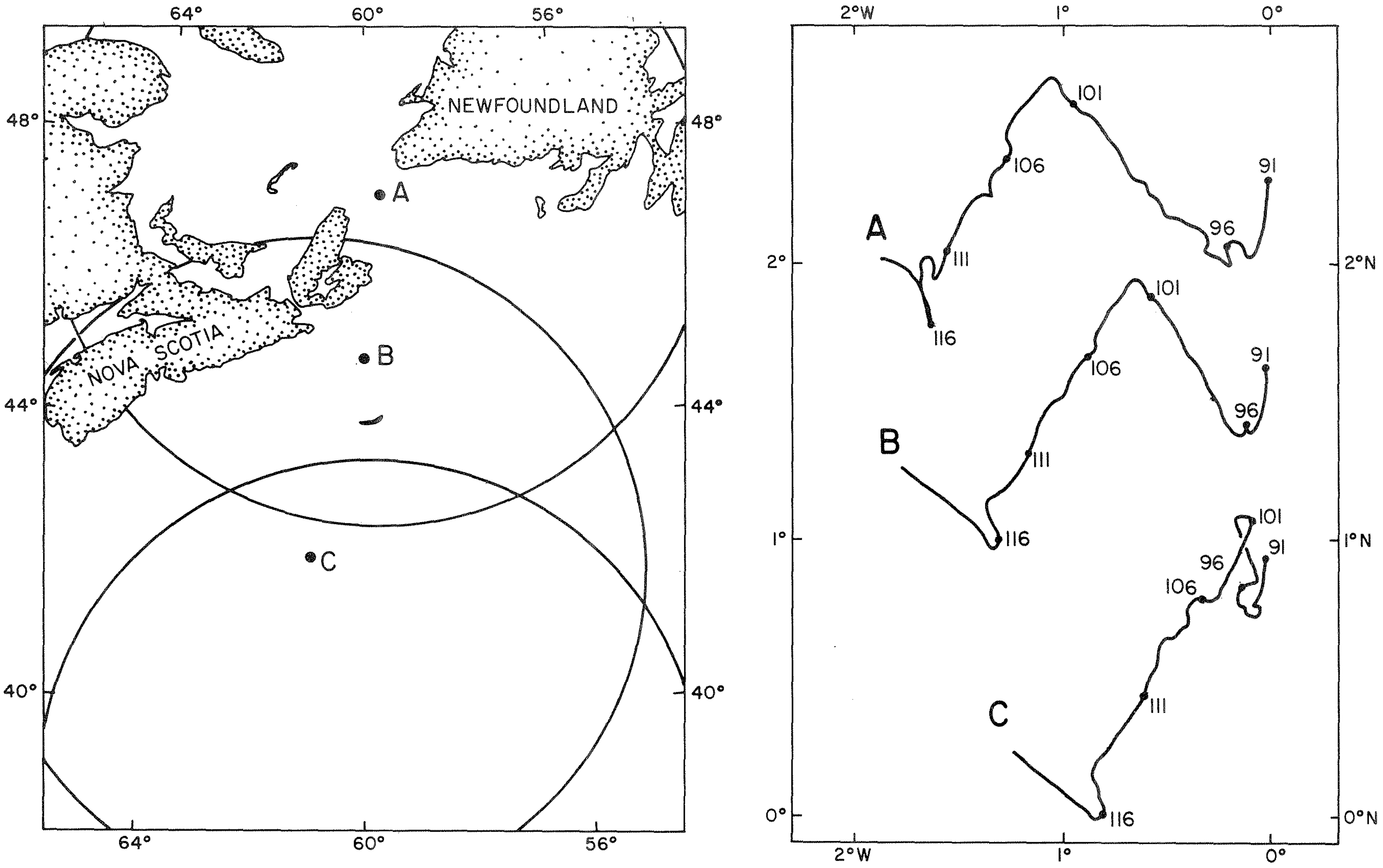


Figure 5. Comparison of influence of 'six-point' winds on trajectories released at three points (A,B,C) on the Scotian Shelf. The release points were chosen so as to include a gradient of circles of wind influences. Three percent reduction and residual current (10 cm s^{-1}, 245°T) were used.

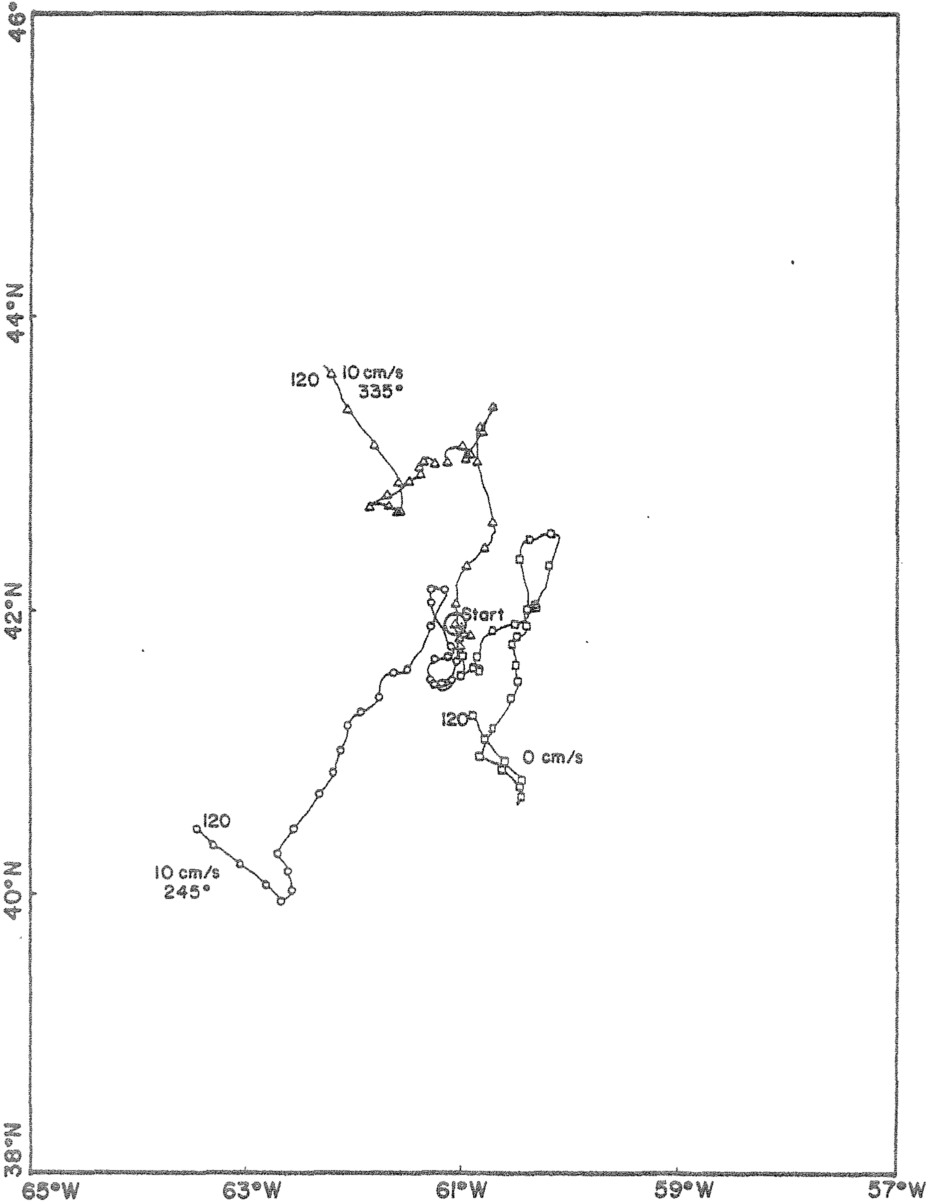


Figure 6. Influence of residual current on trajectories from a single release point (Site 3), south of Sable Island. Winds are six-point winds, 3% reduction.

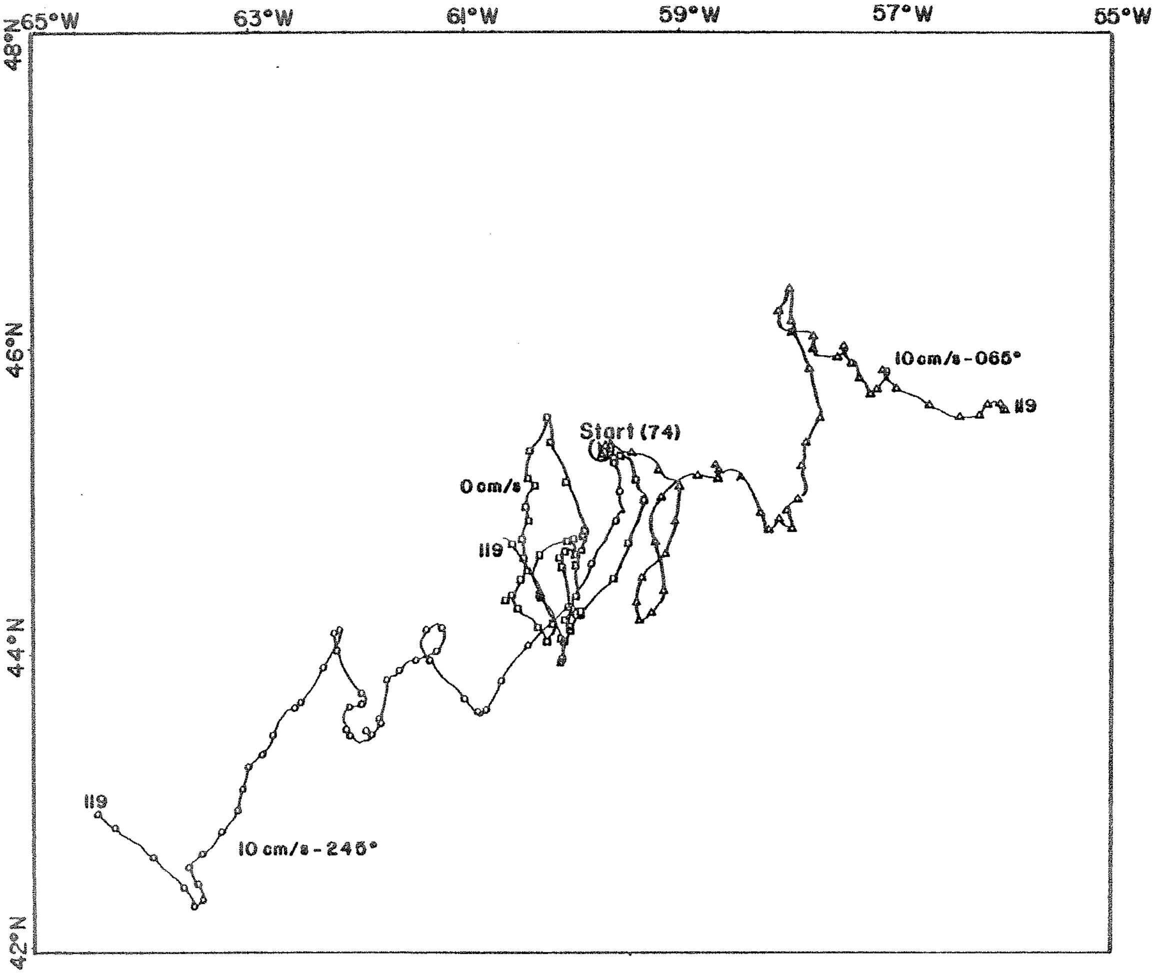


Figure 7. Influence of residual current on trajectories from a common release point, north of Sable Island. Winds are six-point winds, 3% reduction.

BIBLIOGRAPHY

CRESSMAN, G.P. 1959. An operational objective analysis scheme. Mon. Wea. Rev. 87 (10), 367-374.

HAASE and WAGNER. 1971. On the relationship between geostrophic and surface wind at sea. Mon. Wea. Rev. 99 (4).

MOOERS, C.N.K., J. FERNANDEZ-PORTAGAS and J.F. PRICE. 1976. Meteorological forcing fields of the New York Bight. (1st year's progress report). Tech. Rept. Nov. 30, 1976. Univ. Miami, Rosenstiel School of Mar. and Atmos. Science.

APPENDIX I

PROCEDURE FOR ABSTRACTION OF WIND RELATED TO OIL SPILL TRAJECTORY ANALYSES

The wind at each point was determined by the following procedure:

(a) The geostrophic wind was scaled from Maritimes Weather Office surface pressure analyses from 0000 GMT, 0600 GMT, 1200 GMT and 1800 GMT. Direction was recorded to the nearest 10° and speed to the nearest knot.

(b) An estimation of the temperature difference (°C) between the air and the sea surface was taken as an indicator of low level stability ($T_a - T_s$).

The radius of curvature of the flow at the point, whether cyclonic or anticyclonic, was estimated in degrees.

(c) The graphical relationships in Figures A1a to A1c were used to obtain an expected speed based on the geostrophic wind speed taking into account the estimated stability (Haase and Wagner, 1971).

(d) This speed estimate was corrected for curvature effect using Figure A2 and the estimated radius of curvature.

(e) The geostrophic direction was corrected to expected direction by backing the wind 20°.

(f) The speed and direction estimates so derived were checked against any reports from nearby land stations and for ships. Adjustments to the estimates were made where necessary.

Wind Interpolation

The spatial interpolation scheme is done by the Cressman synoptic method (Cressman, 1959), where the unnormalized weights W_j for the vector average are given by:

$$W = \frac{R^2 - D_j^2}{R^2 + D_j^2}$$

where R = radius of influence, D_j = distance from the interpolated site to the grid point j, and $W_j = 0$ for $D_j > R$. This scheme has been found to work well in the New York Bight (Mooers *et al.*, 1976).

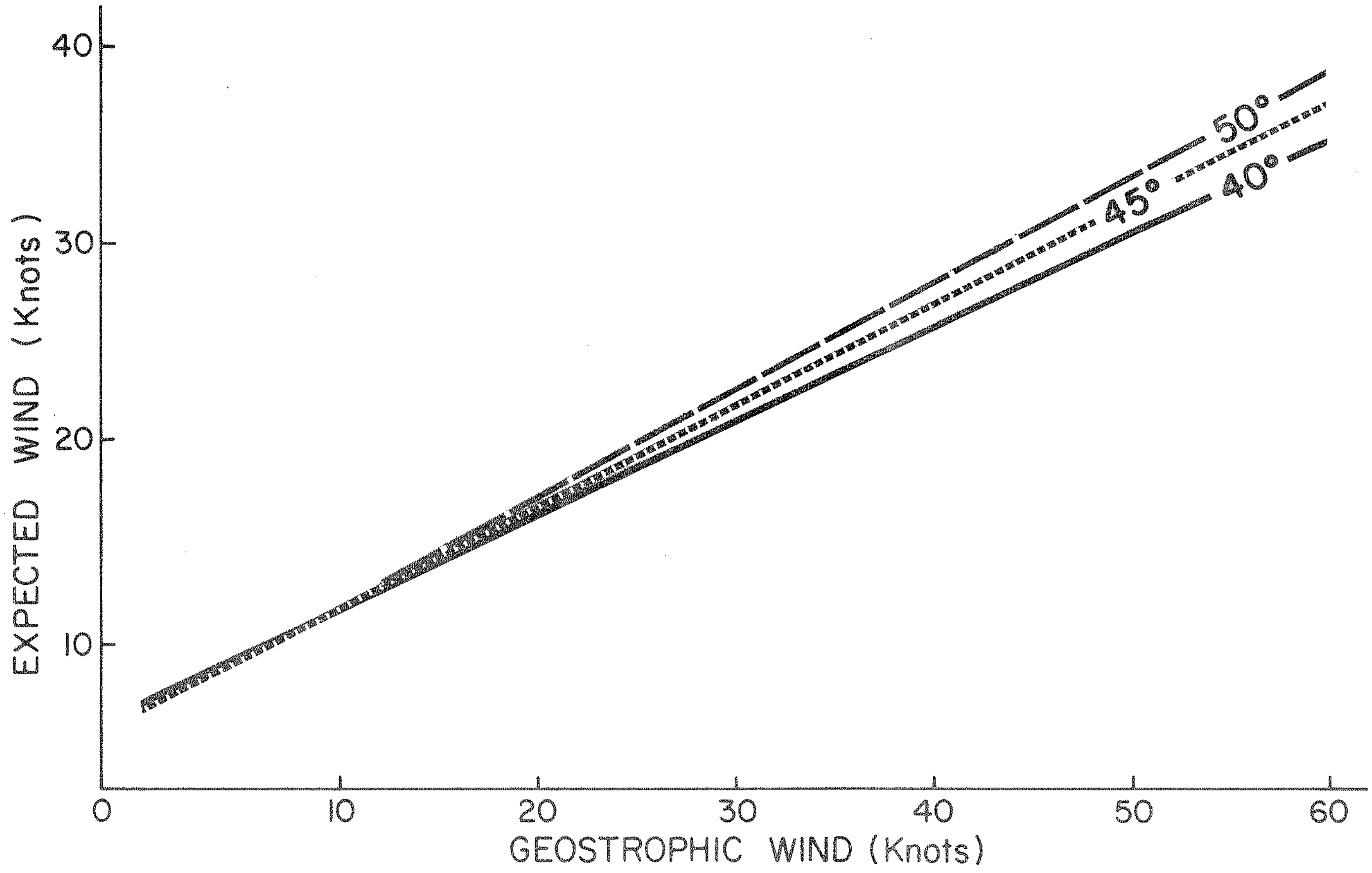


Figure A1. Expected winds at sea (straight isobars). (From Haase and Wagner, 1971).

Figure A1 (a) - unstable $T_A - T_S \leq -1.3^oC$.

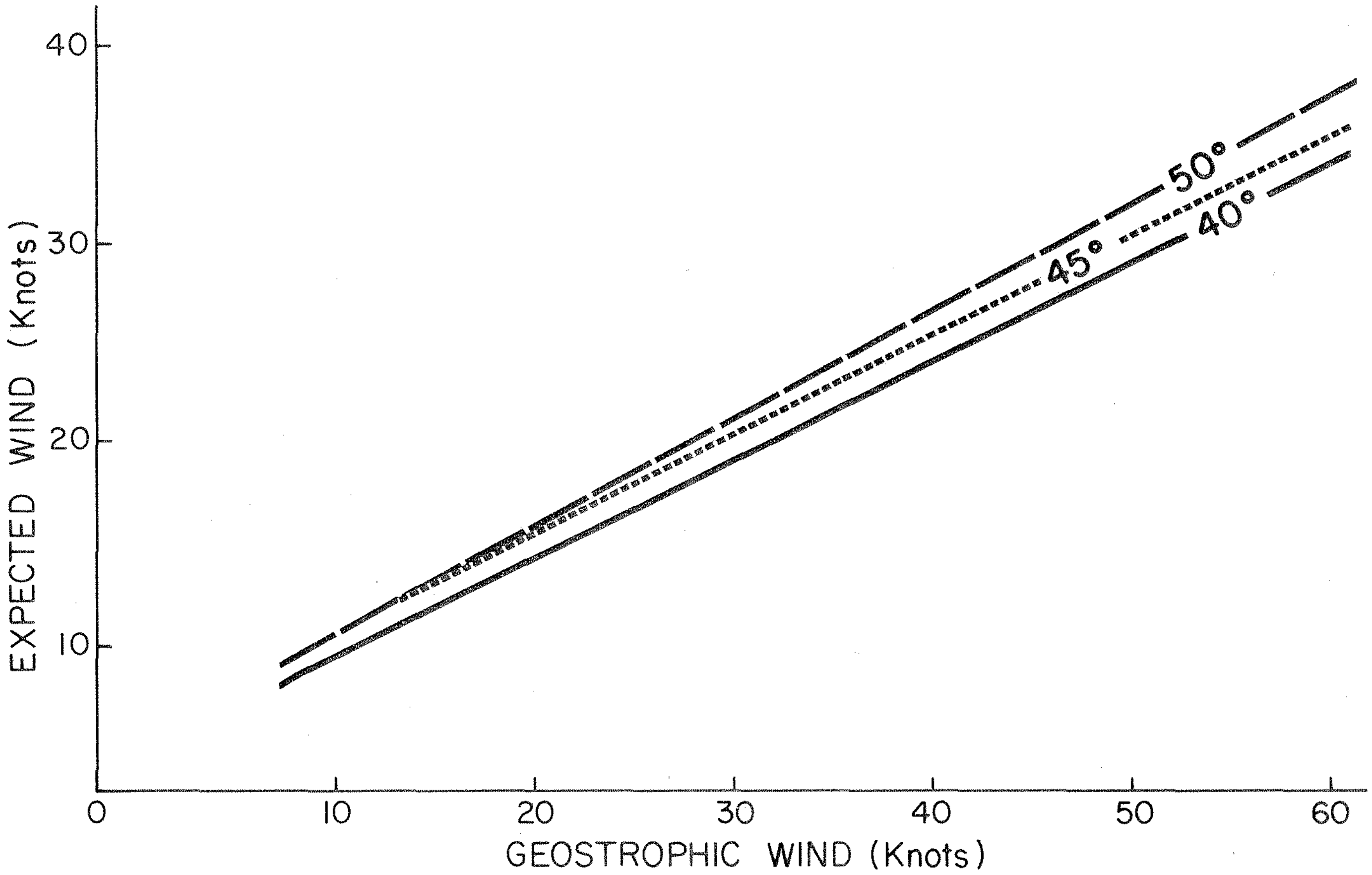


Figure A1(b). Neutral $-1.3^\circ C < T_A - T_S \leq 0.8^\circ C$.

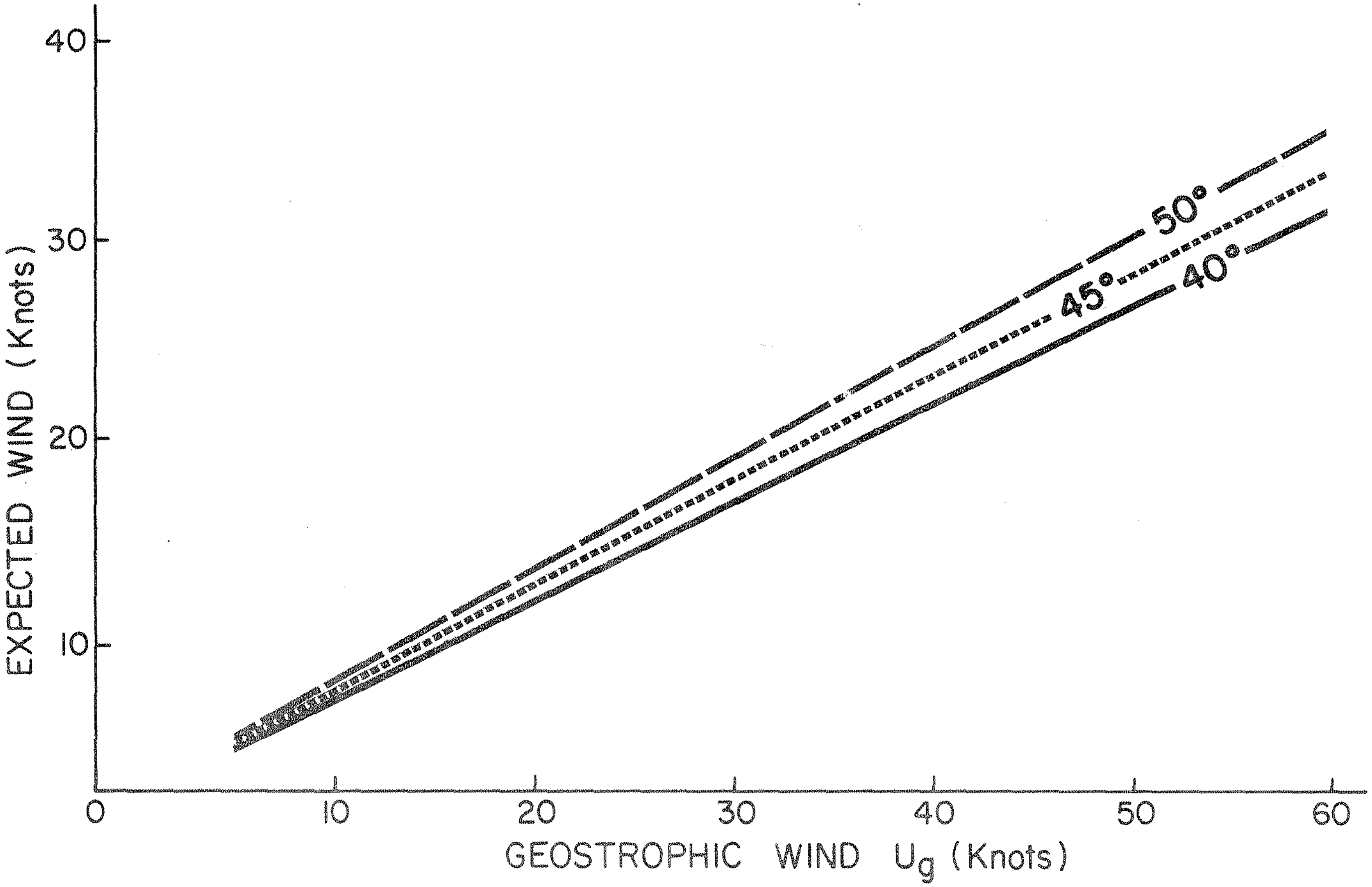


Figure A1(c). Stable $T_A - T_S \geq 0.8°C$.

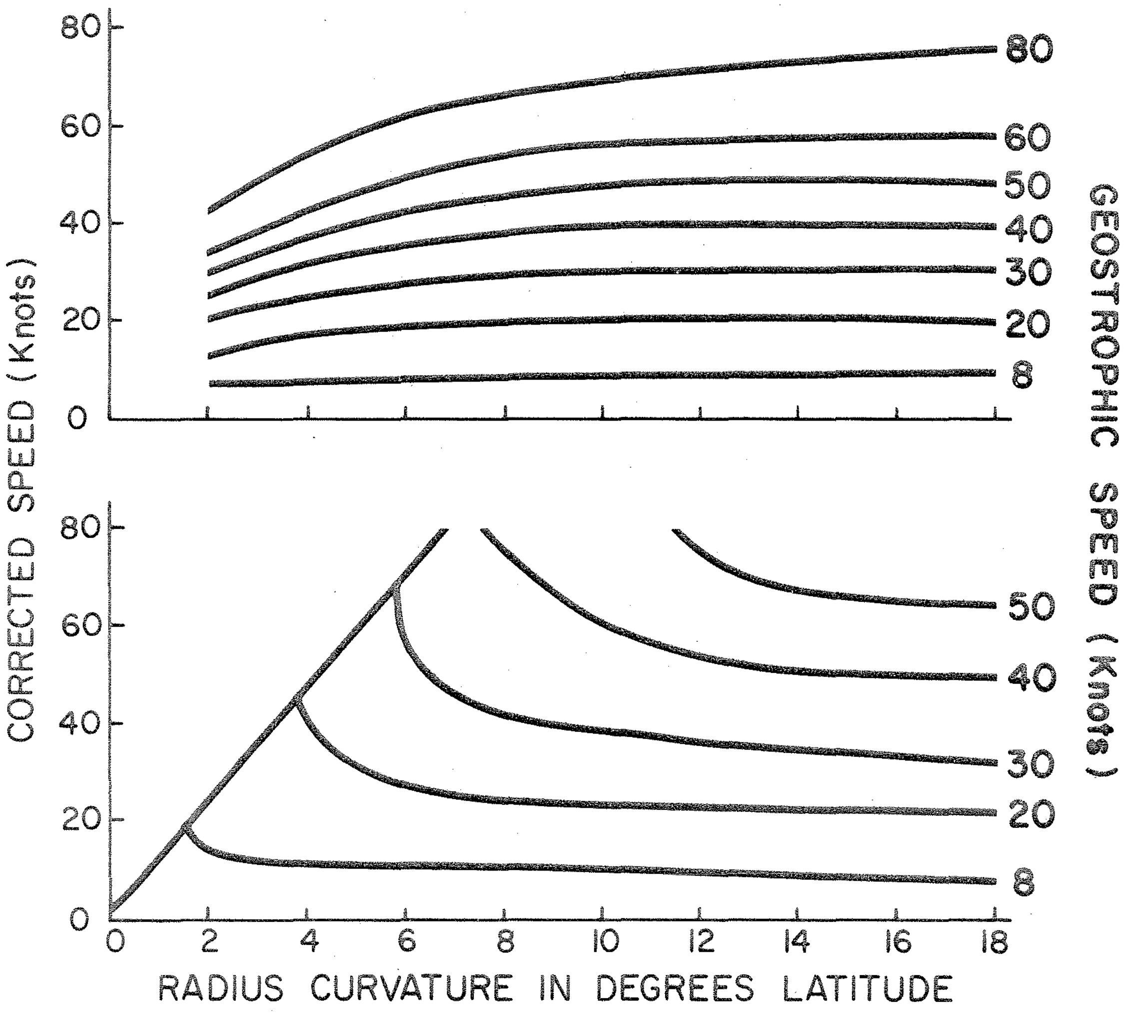


Figure A2. Conversion figures for correction for curvature used in the wind abstractions. Upper figure for cyclonic curvature, lower figure anticyclonic curvature. Curved lines are geostrophic speeds (scale at right). Horizontal straight lines are corresponding corrected winds (scale at left). Graphs are for 47.5°N, or with in approximately 5° latitude.

KURDISTAN SPILL MOVEMENT

R.W. Trites, J.H. Vandermeulen and D. Lawrence

Oceans and Aquatic Sciences
Bedford Institute of Oceanography
Dartmouth, N.S. Canada B2Y 4A2

INTRODUCTION

When the tanker Kurdistan broke into two on March 15, 1979 in the Cabot Strait about 7,000 tons of Bunker C fuel oil were spilled into the ice-infested waters. However, except for periodic sightings of small oil slicks at sea, mostly over the Misaine Bank and Banquereau Bank, and for oil trapped in ice off the south-east coast of Cape Breton Island, no major oil slick was seen. Essentially the spilled oil was lost for nearly a month following the spill, until April 13 when large amounts of it began to come ashore on Cape Breton Island.

We became interested in the possible role played by the ice in these waters in the movement and dispersal of the spilled Kurdistan oil, and in the driving forces moving surface slicks. In the course of our study we have also 'back-tracked' the oil from its stranding on Cape Breton's New Waterford-Sydney area March 13 and 14.

Specifically we have examined two possible oil movement scenarios, one in which the Kurdistan oil was entrapped by the ice and movement was ice-dominated, the other in which most if not all of the oil escaped entrapment and moved unhindered by ice over the Scotian Shelf (Fig. 1A + B). Based on an analysis of ice-movement, current information, wind data and oil sightings we favor the second of these possibilities - that a considerable part of the Kurdistan oil moved freely of the ice. Consequently the bulk of the oil remained offshore from Nova Scotia for approximately four weeks before coming ashore onto Cape Breton Island under the influence of strong southeasterly winds followed by northeasterly winds.

OVERVIEW, OIL AND ICE MOVEMENT, MARCH 15 TO APRIL 23

Figure 2 summarizes the location of oil sightings as they were obtained from Canadian Coast Guard SITREPS (oil sighting reports; courtesy K.C. Curren), federal fisheries Scotia Shelf ichthyoplankton cruises (courtesy Mr. O'Boyle, this volume), and from individual sightings on Bedford Institute cruises (Vandermeulen and Buckley, 1980).

Ice data for this period were obtained from the Atmospheric Environment Services (AES), Ice Information Bureau, Ottawa.

March 8 to 15

Ice cover during this period varied considerably. It was at its maximum extent on March 8, a week before the tanker break-up, with a large ice-field comprised of about 1/10 first-year ice lying offshore from Cape Breton's east coast reaching down to and past the entrance to Chedabucto Bay. A large open water area separated this icefield from the mainland of Cape Breton, with the entire Sydney Bight area north-east of Sydney free of ice.

In the days following March 8 the ice edge receded markedly, towards the Cabot Strait. Eventually much of the area between Cape Breton and Newfoundland was free of ice, except for an ice-field in the middle of Cabot Strait. The tanker Kurdistan began its passage to Quebec during this open-water period. She encountered ice north-northeast of Sydney, where the ice edge had receded to its minimum position.

March 16 to 22

Sometime during the days March 15 or 16 the ice-field once again began its southeasterly movement, flowing through the Cabot Strait and down the Laurentian Channel. The tanker broke up during the night of March 15 in or near the newly advancing ice-edge. By March 20 the entire Sydney Bight area was ice-fast, with only some open water offshore from Cape Breton's east coast. A broad ice-tongue extended past Scatarie Island and past the entrance to Chedabucto Bay.

During this period there were several scattered sightings of oil, all but one from just southward of the southward advancing ice-edge. The exception was a lenghty streak of oil in the narrow ice-field off Point Michaud, estimated at circa 2500 tons (Trites, 1980).

March 23 to April 5

This two-week period was marked primarily by a regression of the ice-edge, and by continuing scattered reports of minor oil quantities offshore from Cape Breton over the northern part of the Scotian Shelf.

All of the Sydney Bight area from Scatarie Island to Cape North at the northern-most tip of Cape Breton Island remained ice-bound. There were no oil sightings from this area during this period.

April 6 to 8

Open water first appeared in the Sydney Bight area during these dates. At the same time there were an increasing number of oil reports, both offshore from the Scotian Shelf area (Middle Bank to Banquereau Bank) and onshore from the Chedabucto Bay area. There were no reports of oil from the open water in the Sydney Bight, nor from the ice-fields in the rest of the Cabot Strait.

April 9 to 12

This period was marked by continuous regression of the ice-cover, with open water now extending throughout the Sydney Bight area from Scatarie Island to Cape North. Except for a narrow tongue of ice, comprised largely of strip and patches of first-year ice, the main body of ice had retreated through the Cabot Strait into the Gulf of St. Lawrence.

There were few oil sightings for this period from the northeastern part of the Scotian Shelf. There were a number of sightings of oil slicks and patches from the southern half, offshore from Nova Scotia's south shore.

April 13 to 14

Except for some remnants of rotting ice in the middle of Cabot Strait, most of the waters offshore from Cape Breton Island were ice-free by these dates.

Simultaneously with this opening up of the Cape Breton waters heavy oiling was reported from Cape Breton's east cost, followed a day later by heavy and continuous oiling of the Sydney Bight area.

April 15 to 23

Oiling of the Sydney area of Cape Breton continued for several days, while the oiling of the east coast decreased in severity. There were continued reports of offshore oil sightings originating from further south, between Nova Scotia mainland and Sable Island.

ICE BUDGET: CABOT STRAIT

A simplified ice budget for the area seaward of a line joining Cape North and Port aux Basques, Newfoundland, was developed from the periodic ice reports for this area (viz. Appendix A), and is summarized in Figure 3. The ice-field in the Strait area is very dynamic, both with respect to movement through the Strait and with respect to its composition. During the period March 15 to April 15 the ice-cover underwent large-scale changes with major regressions and advances of the ice-edge extending well over one hundred nautical miles. In the course of these movements large areas of water opened up and closed, both along the Newfoundland side of the Cabot Strait and in the Sydney Bight area.

Besides these large changes in transport of ice through the strait there were rapid changes in its composition, with ice-fields forming and reforming continuously. In this respect the ice-field typing or coding (new ice, grey ice, etc.) used by the Canadian AES serves only as a general aid in identification of ice conditions, since it is nearly impossible to continuously follow any one ice area or ice-field with certainty as it moves through the Strait area. This is largely because the ice concentrations and composition changes daily, and is highly susceptible to wind changes (personal communication, Ice Forecasting Central, AES).

WIND DATA

Some of the available wind data (wind speed and direction, six-hourly) are shown in Figure 4. Since the relevant oil-spill area lies nearly intermediate between the Cabot Strait and Sable Island the wind data for both these points are shown for comparison. Generally speaking there is good agreement between the directions of the two sets of wind vectors, with only minor variations overlying the basic correspondence. The wind speeds for the Cabot Strait area are, however, appreciably higher than for

Sable Island.

The period of March 15 to 23, the week immediately following the Kurdistan breakup, was marked by strong north-westerlies swinging steadily to north-easterlies. This was followed by a period of southerlies from March 24 through March 30. Following a shift to northerlies during April 1 to 4, the period April 5 through 12 was marked by continuous south-easterlies, increasing in strength to gale force during April 11 and 12. From April 13 on, the period of heavy oiling of Cape Breton, winds were generally from the north or northeast through to the 25th of April.

SPILL TRAJECTORIES (FIGURES 5 AND 6)

Spill trajectories for two periods of the Kurdistan incident are shown in Figures 5 and 6. These are the period immediately following the tanker break-up (March 15 through 20) and the period immediately prior to and including the week of heavy oiling of Cape Breton a month later (April 4 to 13). The trajectories are based on wind vectors calculated for Cabot Strait from a six-point wind analysis (viz. Lawrence and Galbraith, this volume), using the 3% figure for oil slick movement due to wind alone.

For surface current velocity we used 13 cm s^{-1} (1/4 knot) moving in the direction 160°T, this being considered representative for this area and season.

March 15 to 20

Assuming free movement of the oil, unhindered by ice, the general direction of drift of an oil slick originating at the site of the Kurdistan breakup was southeasterly for the first three days after the accident. Beginning approximately mid-day March 18 the trajectory projects a swing to the southwest. Net distance travelled during this five-day period would have been approximately 60 nautical miles (Fig. 5). If superimposed on the chart of the area this trajectory places the oil slick on March 20 in the vicinity of Scatarie Island, offshore from the eastern most point of Cape Breton.

Simultaneous displacement of an ice-mass for this same period was also modelled, based on computed ice-drift figures (for methods viz.

Neralla et al., 1978) supplied by Ice Information Branch, AES. The computed daily drift, using Sydney anemometer records and an assumed residual current of 13 cm s^{-1} (1/4 knot) flowing towards 160°, is shown in Figure 5. The results indicate that the ice movement, although generally similar to that of the oil, was somewhat slower. Whether indeed Kurdistan oil responded to the wind in a way typical of surface oil slicks is not known. However, it does appear from our projections that if oil were spilled near the edge of an ice field, with the wind directed towards open water, that some separation of oil and ice would occur and that the oil would tend to drift free of the ice.

April 4 to 14

A trajectory for slicks arriving at Sydney on the morning of April 13 is shown in Figure 5. Working backwards from time of stranding, 0800 hours on April 13, slicks would have arrived offshore from Sydney on April 12, having drifted towards the northwest from a position south of Scatarie Island. Variable winds between April 4 and 9 would have resulted in a more or less stationary position for an oil-mass offshore from Louisbourg, east coast of Cape Breton. Following a major wind change on April 10 the general drift would have been northwest, passing Flint Island late April 10.

DISCUSSION

Any attempt at reconstructing the trajectory or movement of the Kurdistan oil following the tanker breakup involves some fairly large assumptions and a considerable number of unknowns. In its simplest form trajectory modelling is merely vectorial summation of current and a windspeed factor, as for example in a non-tidal river system. In the present case, that of oil in ice-covered waters, there are the further problems of ice-movement, varying winds-speeds, differences in windspeed for different source points, coriolis force, varying residual current directions and velocity, among others. As well there is the question of the behavior of the oil volume itself relative to the water column, that is, whether it floats on the surface of the water column or is submerged. Several reports of oil sightings, for example, indicated movement of submerged oil in the

Banquereau Bank area. Unfortunately virtually nothing is known of this phenomenon, or of the movement of such submerged oil, or how much of the Kurdistan oil did in fact float submerged.

For the purpose of this first approximation of oil trajectory for the Kurdistan, then, we are considering only surface oil driven by surface winds and currents, and have concentrated primarily on putting together the available data on ice movement, wind speeds and current data (and have ignored coriolis force, etc). In fact, the information on ice movement is at best sketchy, since the ice charts are really only best available approximations of the day-to-day ice conditions, being an assembly of over-flight reports, satellite information, and computerized smoothing plus ice-breaker and vessel reports, not all of these continuous. The problem in using the ice-data is further compounded by the very dynamic character of the ice-cover of this area, since it forms and reforms with daily and hourly wind-changes.

With regard to the wind data, those for Cabot Strait are computed from the atmospheric pressure maps, which we judged to be more realistic than anemometer records from shore-based stations at Sydney and Port Aux Basques. We made the assumption that these pressure-derived winds were good enough for our first-approximation calculations for what happens, not only in the Cabot Strait area but seaward of this as well. A more accurate result would presumably be achieved by spatially adjusting the wind speed and direction values as the computed path moved into the Misaine Bank area. This has been examined in part in a parallel study (Lawrence and Galbraith, this volume), but for our purposes we felt that the wind patterns from the Cabot Strait site and from Sable Island were sufficiently similar generally that we could apply the Cabot Strait information throughout without introducing too great an error in this first trial (Fig. 4).

Having made these various assumptions and with the various oil, wind and ice data available to us, we have the two alternative spill scenarios - on the one hand the ice-dominated spill model and on the other hand an ice-free spill model - plus of course some combination of these two schemes.

The initial overview of oil sightings and ice-cover movements (viz. Fig. 2) would support the ice-dominated scenario. The supporting data points are as follows: One - the coincidence of the Kurdistan breakup with the maximum regression of the ice-edge and the subsequent reported encircling advance of the ice-edge during the 48 hrs immediately after the accident. Two - oil sightings in open water during the subsequent four-week period were generally scattered, and the amount of oil reported was small and inconsistent with the presence of a large undetected 7,000 ton or larger oilslick. Three - the close agreement in time between the regression and disappearance of the Cabot Strait ice-field in early April and the appearance of large volumes of oil on Cape Breton shorelines. A fourth argument for the ice-dominated spill scenario is the highly weathered state of the oil, i.e., particulate, that came ashore in April, this weathering being taken as evidence of the eroding action of ice floes on an entrapped oil mass.

Initially, when we considered all these bits of information, we were generally in agreement with the ice-dominated scenario. However, when we reviewed each of the four arguments again, and re-examined the chronology of the oil sighting reports together with the available wind data for the time period we recognized some weaknesses in the ice-dominated scenario. For example, while it is tempting to take the ice-charts as hard evidence for an encircling ice-field movement of March 15 through 17 (Fig. 2) it must be remembered that these data derived from ice-charts are only approximate as discussed above. There was a considerable open-water area at the time of the accident, and it is possible that a large wind-driven oil slick (there were very strong northwesterly winds on March 16) easily outdistanced an ice-edge moving in the same general direction. As well, much of the ice-field lying in the area northeast of Scatarie consisted primarily of strips of 2-tenths first-year ice, essentially a highly porous ice-field.

Similarly it can be argued that while no large oilslick was reported between the tanker sinking and the April oiling of Cape Breton, in fact much of the oilslick or slicks may have been drifting submerged, and out of view of the casual observer. Certainly there is great difficulty in observing spills or slicks from the air (Neu, 1980; also Canadian Coast Guard, personal communication). As well, there was not a concentrated gridded search for the northern part of the Scotia shelf, and most of the oil sightings were obtained on a random chance basis from the various vessels passing through the area. That is to say, while the lack of oil sightings may be taken as evidence for the absence of a large slick, on the other hand it is not evidence that a slick did not exist. In fact, if we replot the oil sightings chronologically (Fig. 7), a general pattern of movement emerges. Beginning April 10 the oil reports focus on the inshore area of southeast Cape Breton, with numerous reports of oiling of shorelines for the Ardoise-Gabarus Bay portion. This was followed by sightings of oil offshore from Sydney, and on Flint Island on April 11 and 12. On April 13 the Sydney region was heavily oiled. When viewed in this way the pattern of oil sightings suggests some sort of offshore holding of a large oil volume somewhere over the northern part of the Scotian Shelf for the period March 18 to roughly April 8 or 9.

Finally, while the close agreement in timing between the breakup and disappearance of the Cabot Strait ice and the heavy oiling of the Sydney area suggests some relationship between these two events, a closer examination of the chronology and possible drift distances seems to rule this out. The break-up of the ice-field and the Sydney oiling occurred too far apart in time. As well the winds for the period immediately prior to the Sydney oiling simply do not support the notion of a large oil volume maintained in ice offshore from Sydney Bight for the period March 18 to April 8 or 9.

While we ourselves at first favored an ice-dominated scenario, we have been continuously led to the conclusion that most of the Kurdistan oil probably escaped entrapment in the ice-field, and that it lay offshore from northern Nova Scotia somewhere in the Misaine Bank to Banquereau Bank area. The reports of heavy oiling over the Misaine Bank area from the Fisheries Ichthyoplankton cruise (O'Boyle, this volume) add support to this interpretation. With the change in wind direction the slick was then driven firstly onto the southeast shores of Cape Breton Island. It was subsequently driven northward past Scatarie Island and Flint Island into the Sydney Bight area. Our calculated back-track (Fig. 6) for that model would put the oil on Flint Island on the night of April 10. In fact the following day, April 11, the Flint Island light-house keeper reported oiling there.

The wind-change of April 13 to the northwest then put the slicks ashore in the Sydney-New Waterford area.

Whether in fact the oil that came ashore on Cape Breton represented the bulk of the Kurdistan spilled cargo is unknown. However, we feel that we can at least account for the trajectory of that which came ashore.

ACKNOWLEDGEMENTS

We acknowledge the considerable assistance from A. Beaton and J. Folkingham, Ice Forecasting Central, Atmospheric Environment Services, Ottawa, and that from the staff of the Canadian Coast Guard, Dartmouth, Nova Scotia.

BIBILIOGRAPHY

NERALLA, V.R., W.S. LIU, S. VENKATESH and M. BANARD. In Press. Techniques for predicting sea-ice. In Proceedings of Symposium on Sea Ice Processes and Models. September 1977. ICSI/AIDJEX Symposium on Sea Ice Proceses and Models. September 1977. University of Washington, Seattle.

TRITES, R.W. 1980. Preliminary observations from CSS Hudson. In: The Kurdistan Oil Spill, March 15/16, 1979. Activities and observations of the Bedford Institute of Oceanography scientific response team. (Vandermeulen, J.H. and D.E. Buckley, eds.). Bedford Institute of Oceanography Report Series, BI-R-80-2.

VANDERMEULEN, J.H. and D.E. BUCKLEY, editors. 1980. The Kurdistan Oil Spill, March 15/16, 1979. Activities and observations of the Bedford Institute of Oceanography scientific response team. Bedford Institute of Oceanography Report Series, BI-R-80-2.

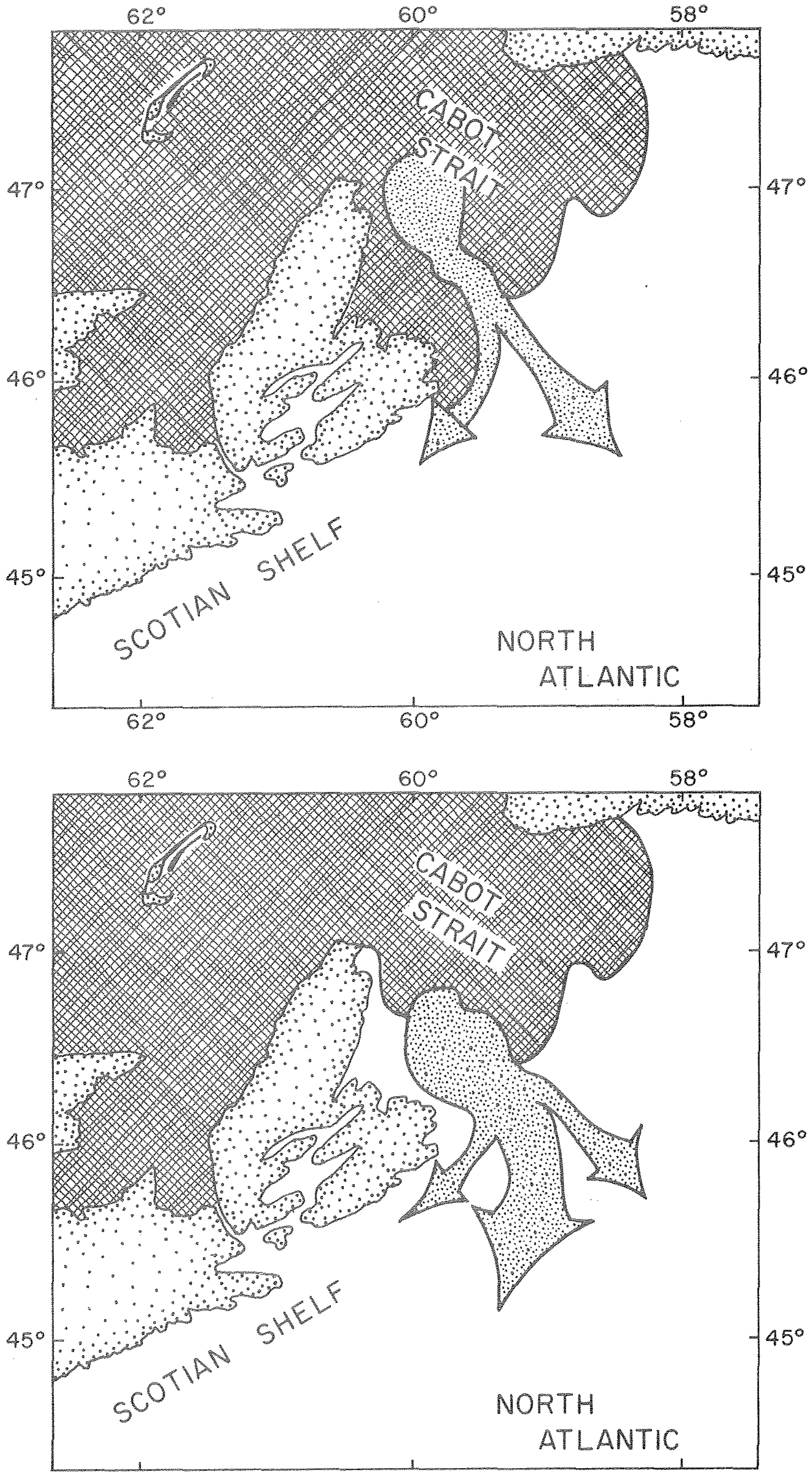
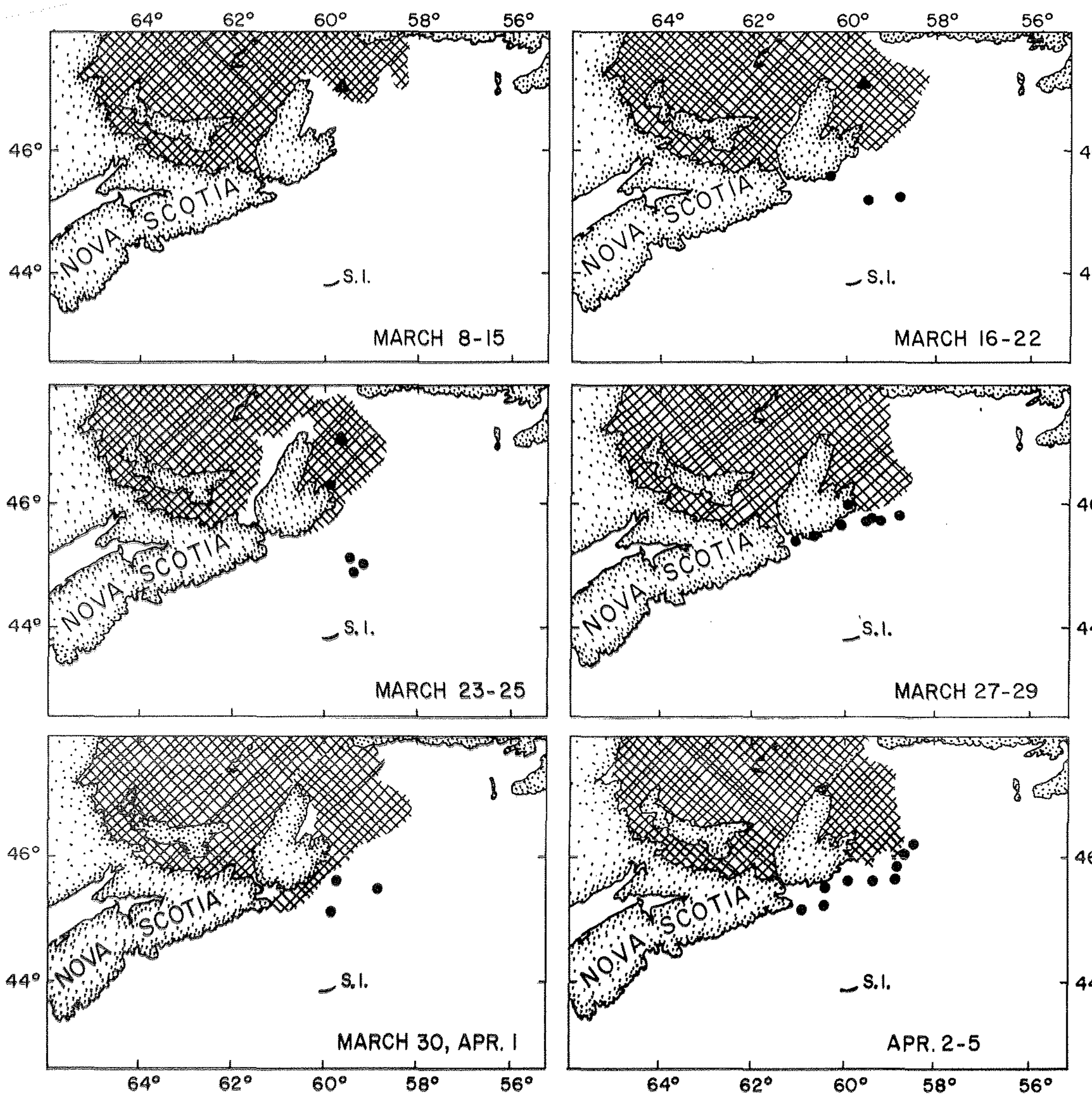


Figure 1. Oil spill scenarios considered for the <u>Kurdistan</u> tanker breakup, March 15, 1980. Hatched area indicates ice-covered waters. Arrows indicate possible oil-spill movement in ice-dominated scenario (upper fig.) and in ice-free scenario (lower fig.).



MARCH 8-15

MARCH 16-22

MARCH 23-25

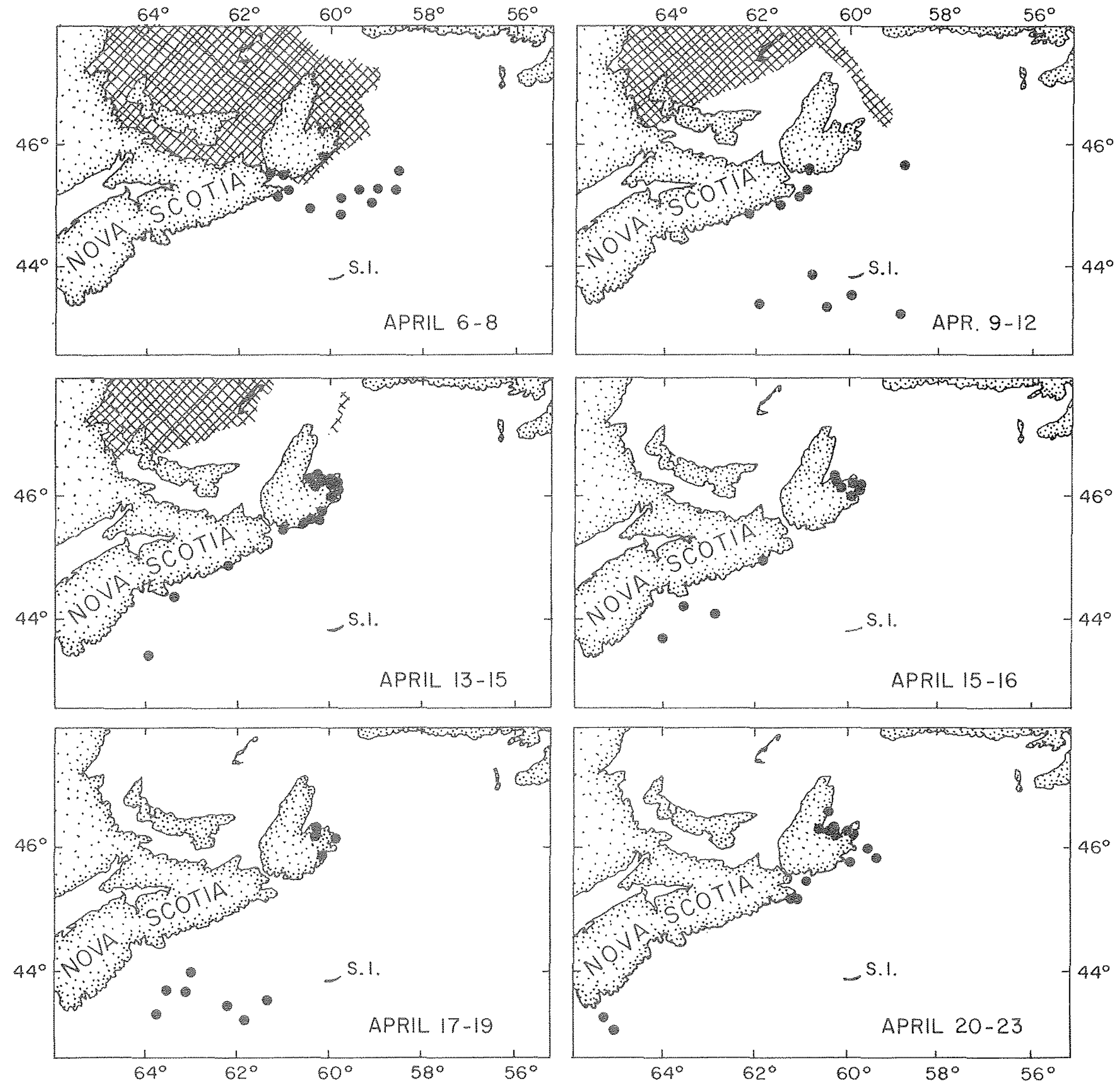
MARCH 27-29

MARCH 30, APR. 1

APR. 2-5

Figure 2. Ice movement and reported oil sightings during the Kurdistan incident and subsequent period. Ice data obtained from Atmospheric Environment Services ice-charts. Oil sightings (0) taken from Department of Transport pollution reports and from Scotia Shelf ichthyoplankton survey cruises (Vandermeulen and Buckley, 1980).

Symbols: P.E.I. - Prince Edward Island; C.B. - Cape Breton Island; N.S. - Nova Scotia mainland; S.I. - Sable Island; 0 - oil sighting.



Symbols: P.E.I. - Prince Edward Island; C.B. - Cape Breton Island; N.S. - Nova Scotia mainland; S.I. - Sable Island; ● - oil sighting.

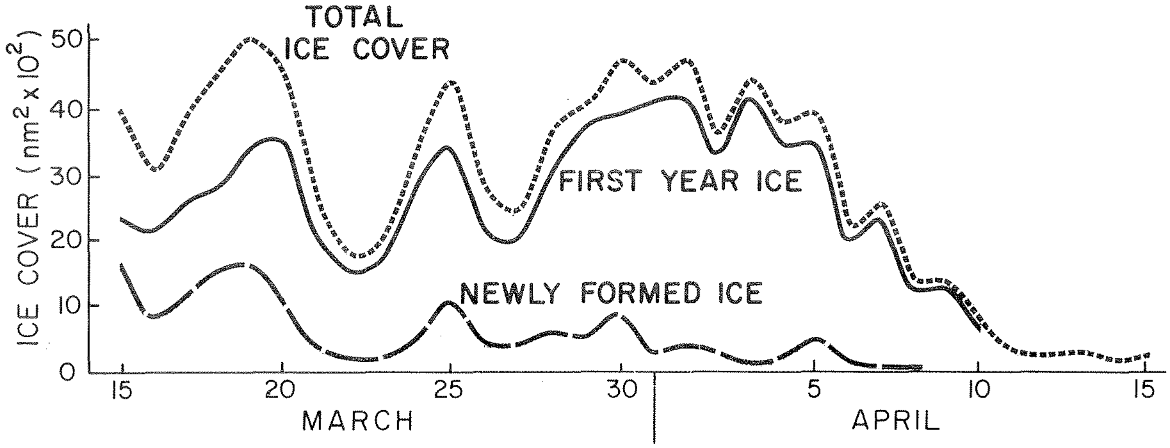


Figure 3. Ice-budget seaward of Cabot Strait at its narrowest point (Cape North to Port Aux Basques, Nfld) for the period March 15 to April 15, 1979.

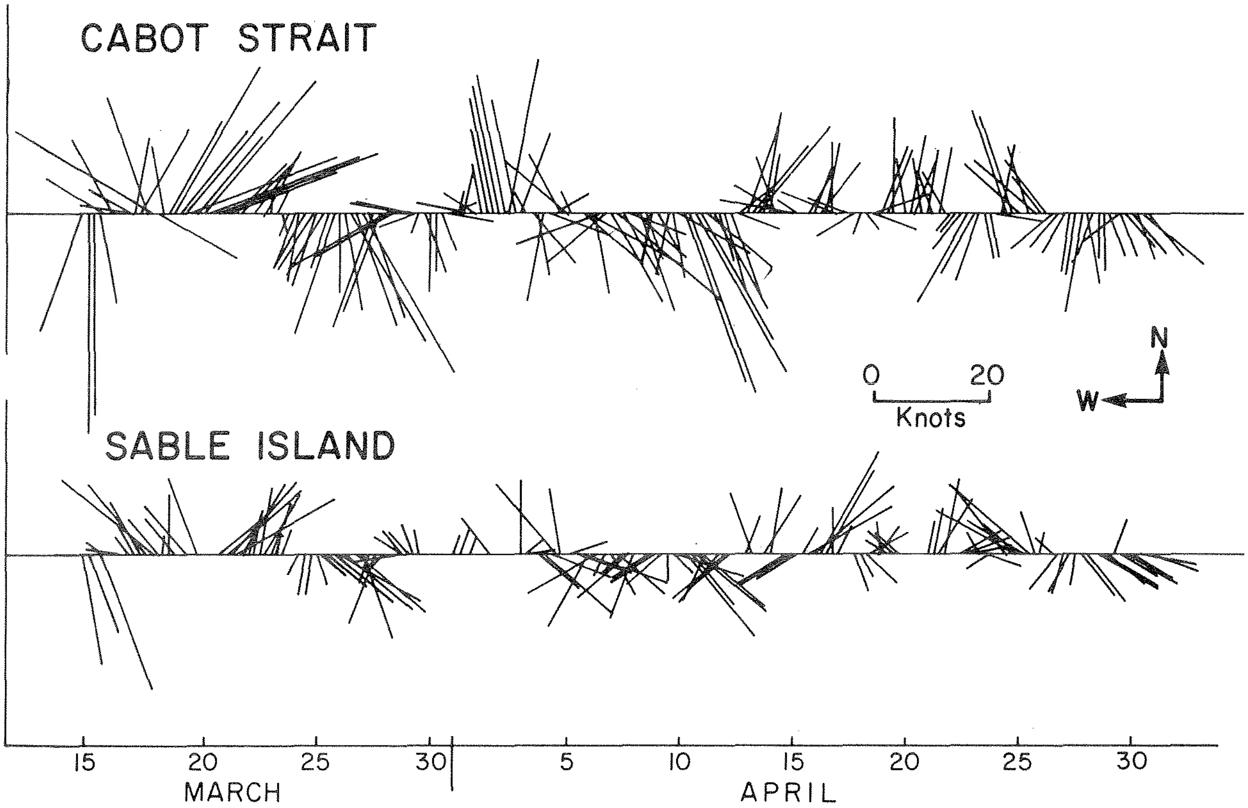


Figure 4. Comparative winds for Cabot Strait and Sable Island for the period March 15 to April 30, 1979. Winds for the Cabot Strait were derived from six-hourly atmospheric pressure maps (6-point wind analysis, Lawrence & Galbraith, this volume). Sable Island winds were observed hourly and smoothed over six hours.

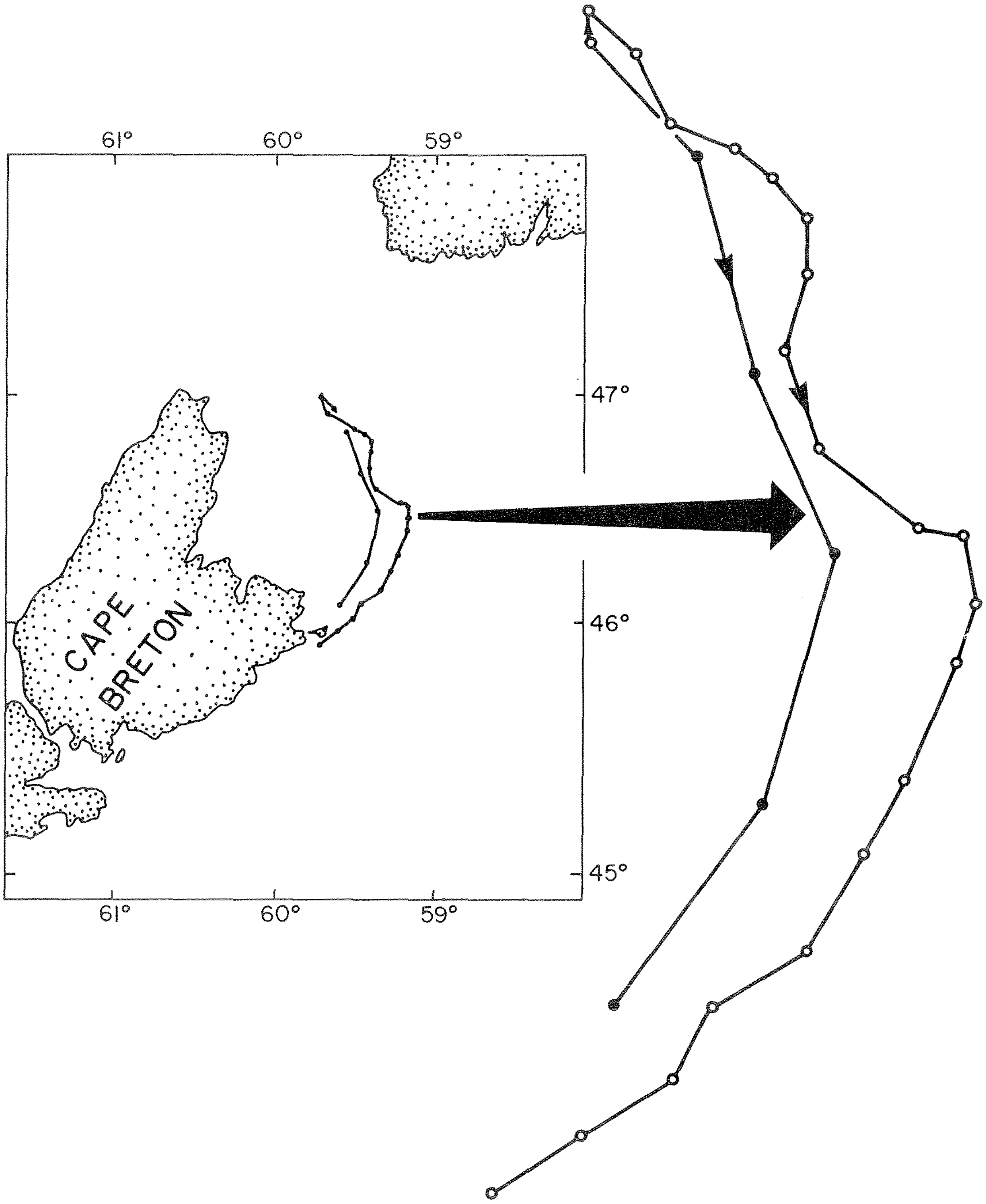


Figure 5. Kurdistan slick trajectory model for the period March 15 1800Z (15/18) through March 20 1800Z (20/18), 1979. Model calculated using simple vectorial addition of wind and residual current (13 cm s^{-1}, 1600). O - spill trajectory; ● - ice movement. Inset shows trajectory of oil and ice in relation to Cape Breton coastline and Scotian Shelf.

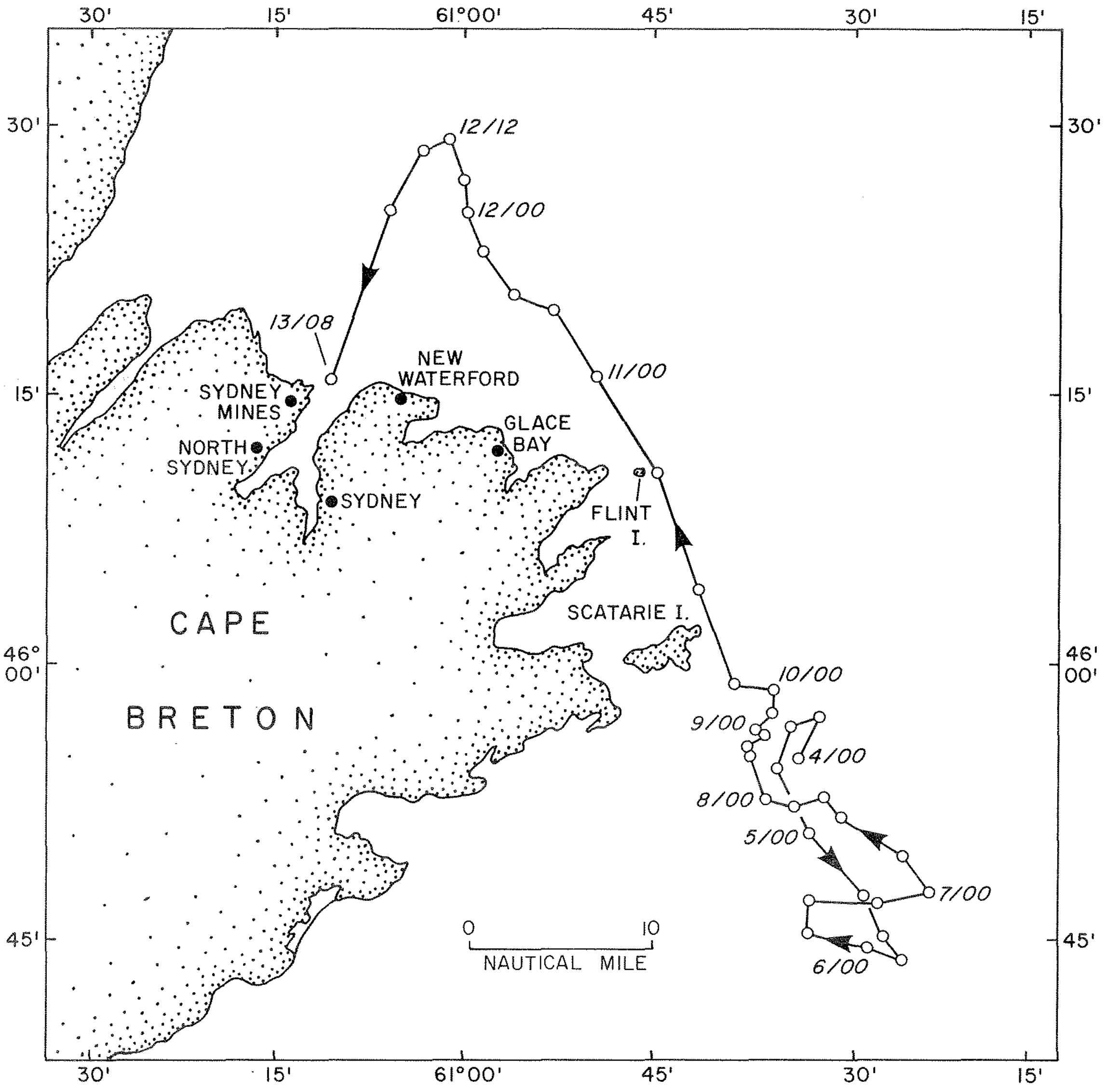


Figure 6. 'Backtrack' spill trajectory model for the period prior to the oiling of the northeast coast of Cape Breton Island, April 4, 0000Z (4/00) to April 13, 0800Z (13/08) 1979. [Cabot Strait six-point winds plus 13 cm s^{-1} current (160°T)].

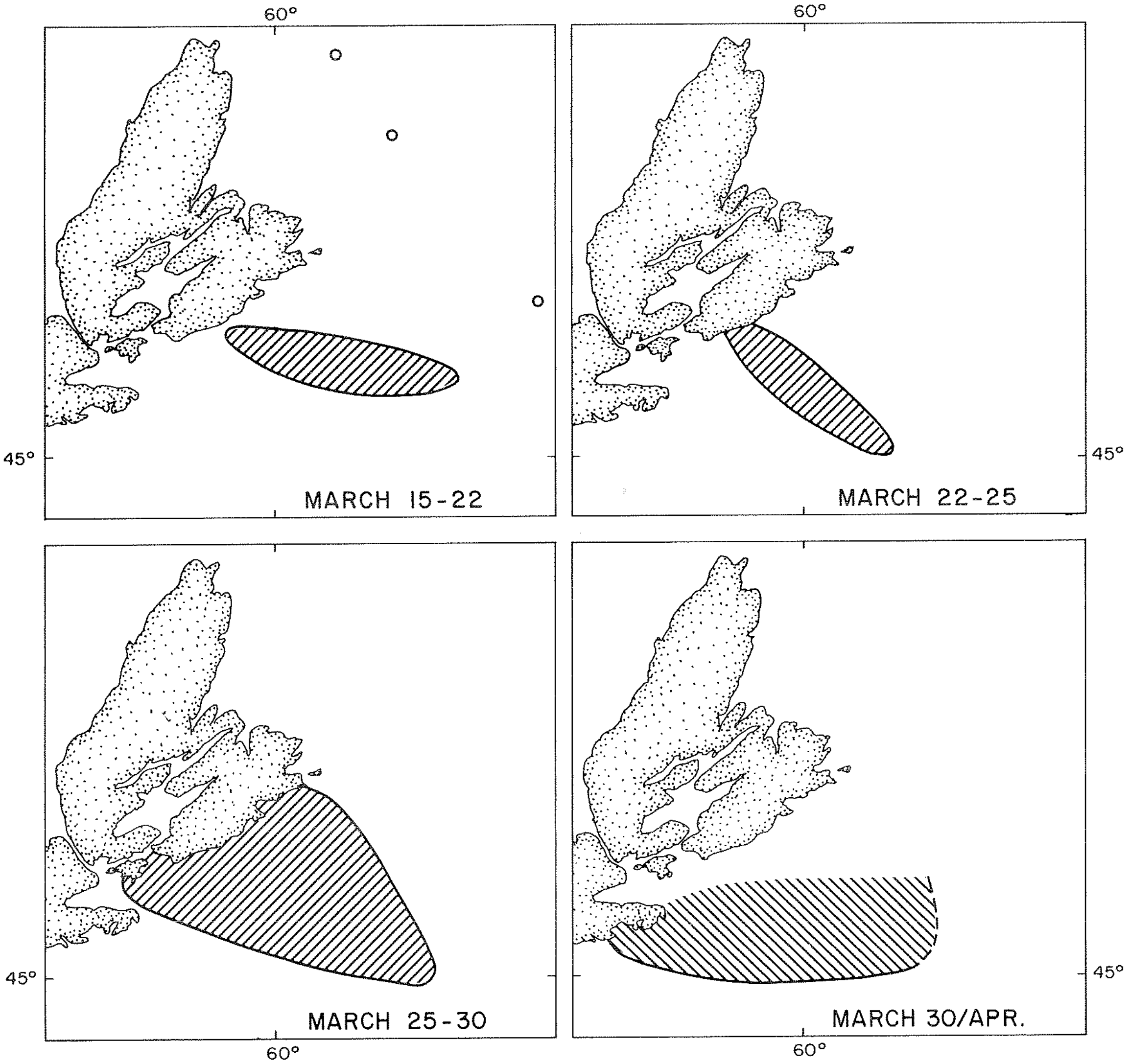


Figure 7. Chronological plot of oil pollution reports for the northern half of the Scotian Shelf March 15 through April 13, 1979. Hatched envelopes indicate areas from which new oil pollution reports originated.

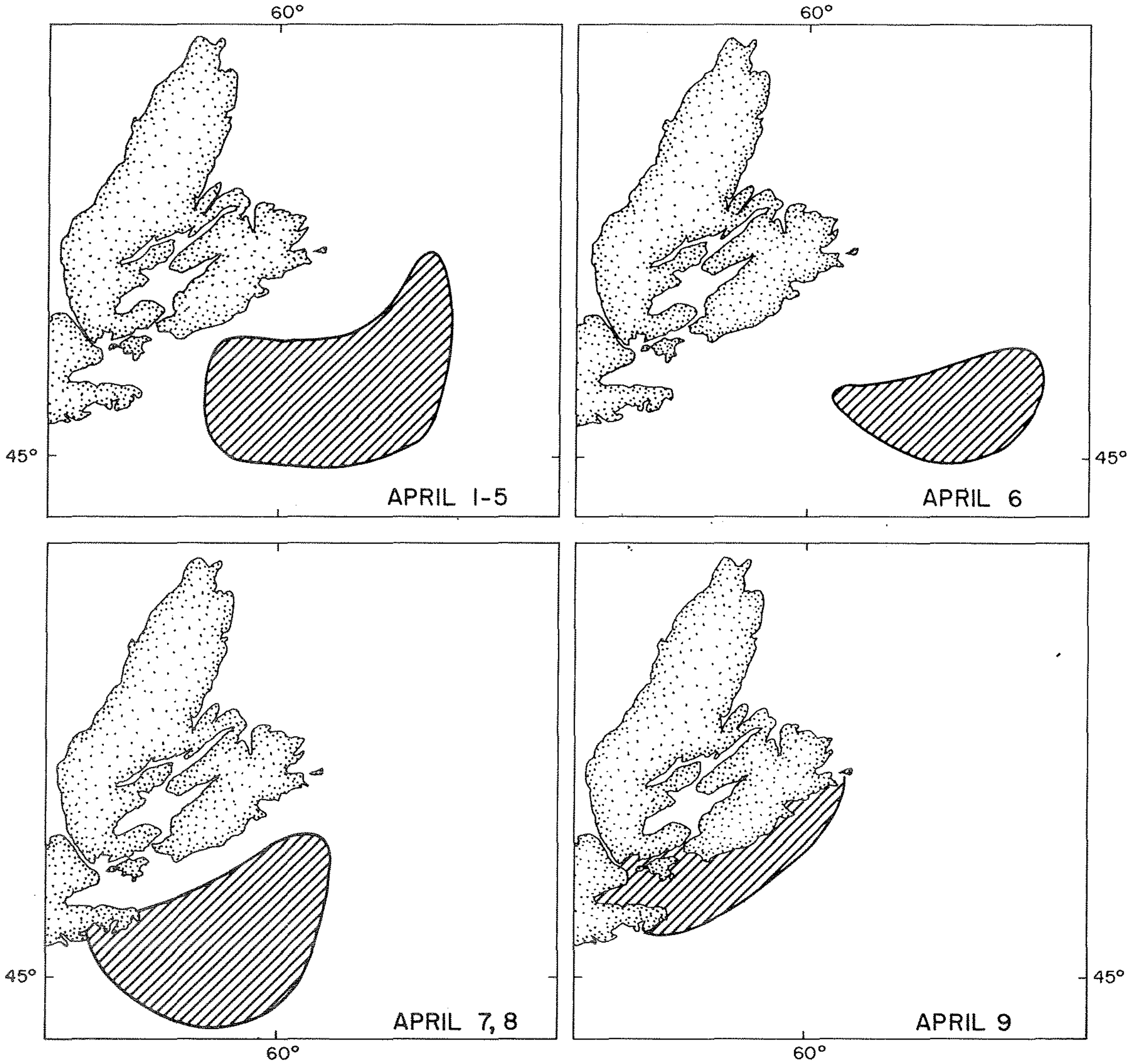


Figure 7. Continued.

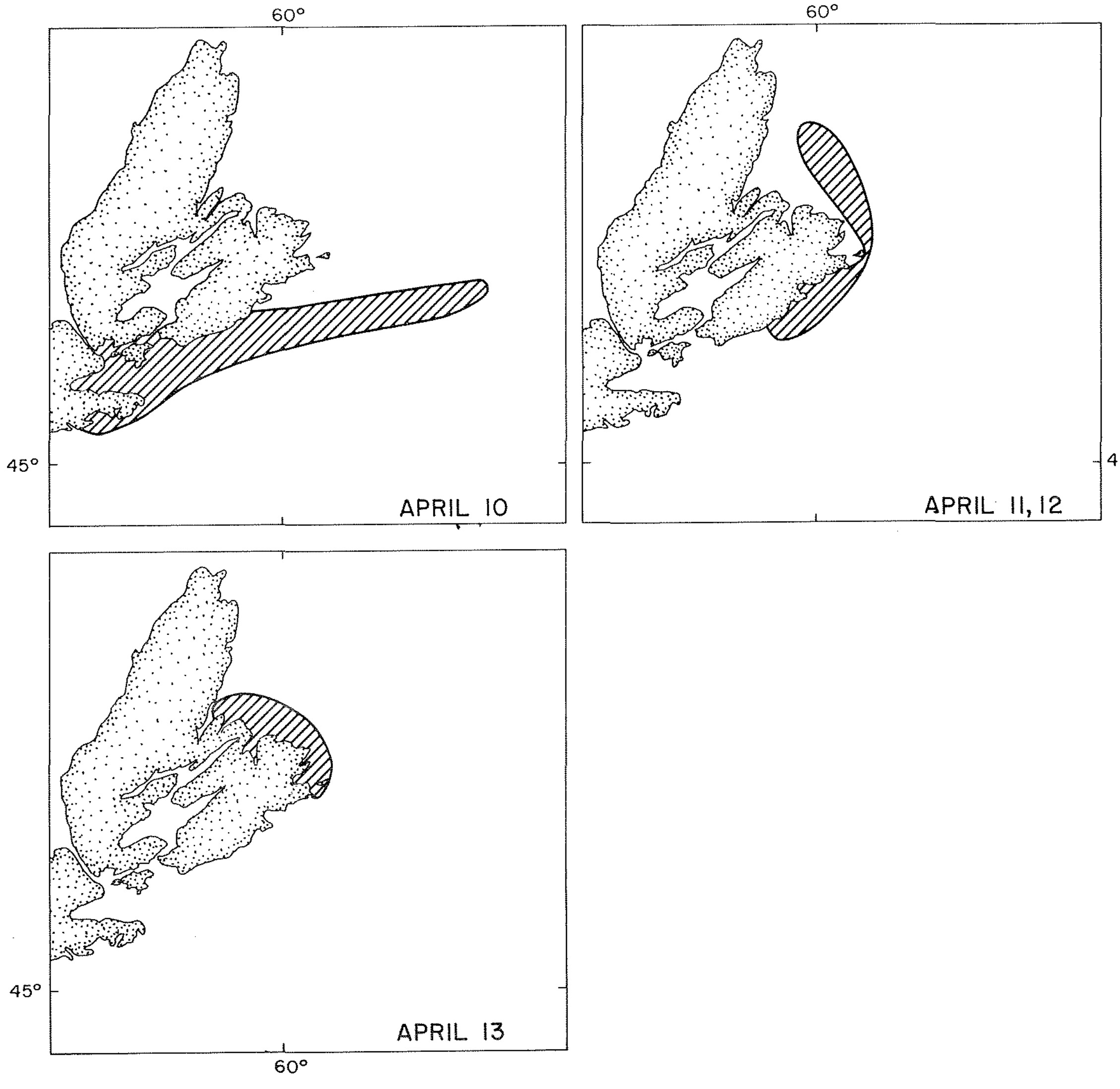
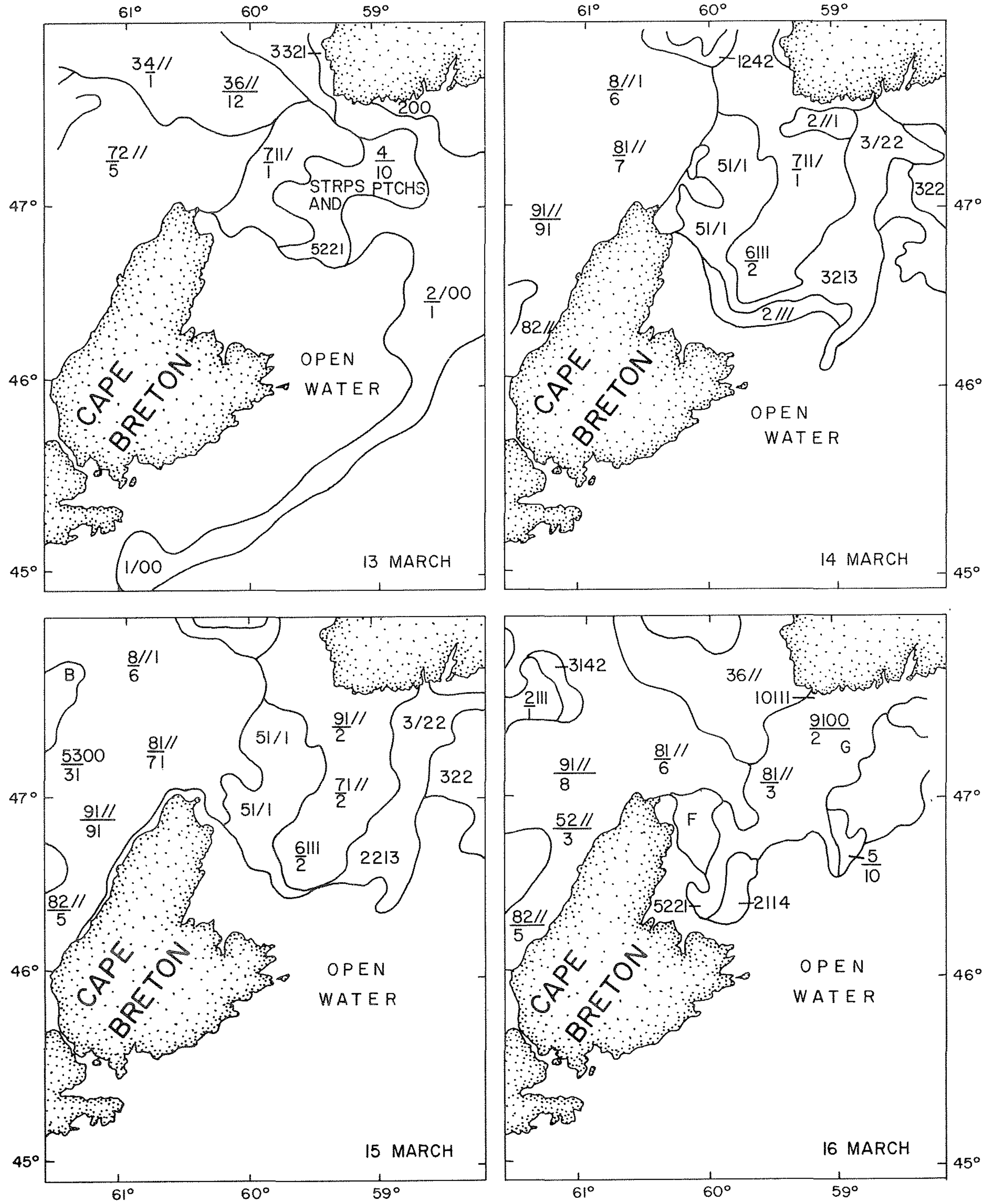


Figure 7. Continued

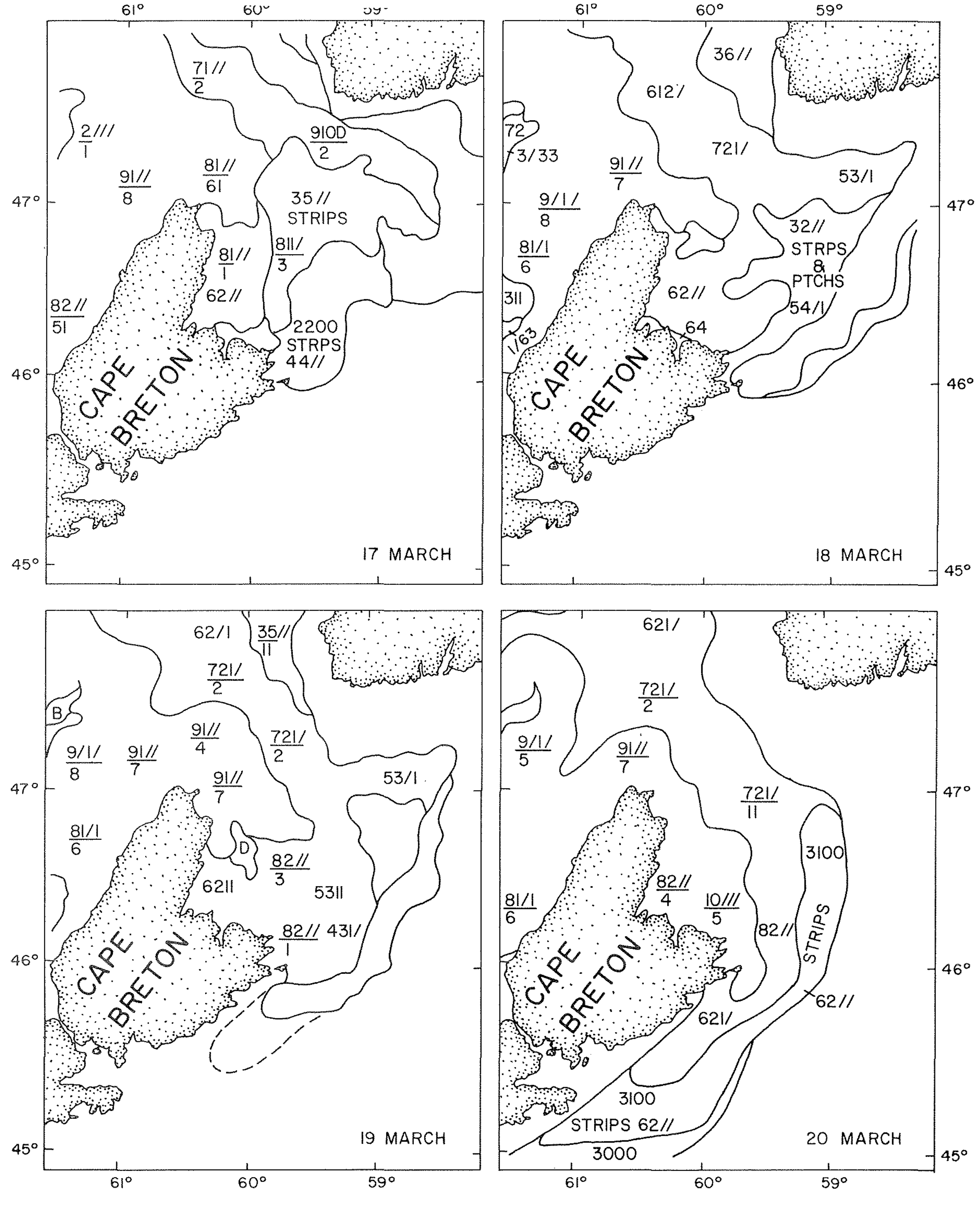
APPENDIX A

Ice reports for Cabot Strait, March 13 to March 20 and April 5 through 14, 1979. Figures reproduced from charts supplied by Ice Forecasting Central, Atmospheric Environment Services, Ottawa. Code numbers indicate total ice concentration, stage of development, and floe size.

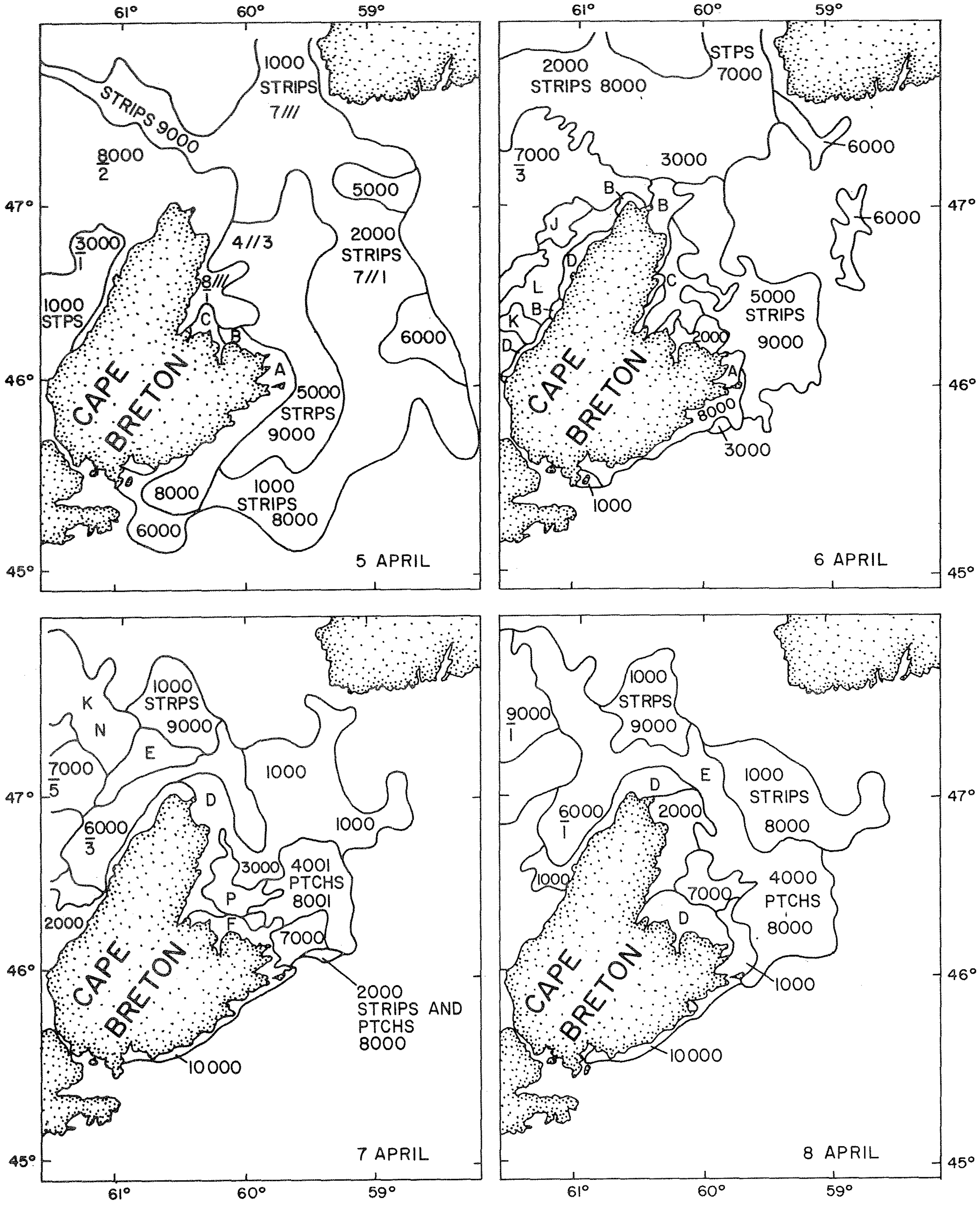
APPENDIX A


61°
60°
59°
47°
46°
45°
3321
34//
1
36//
12
200
72//
5
711/
1
4
10
STRPS AND PTCHS
5221
2/00
1
OPEN WATER
CAPE BRETON
1/00
13 MARCH
1242
8//1
6
2//1
81//
7
51/1
711/
1
3/22
322
91//
91
51/1
6111
2
3213
2///
82//
14 MARCH
B
8//1
6
5300
31
81//
71
91//
91
82//
5
51/1
91//
2
3/22
322
71//
2
6111
2
2213
15 MARCH
3142
2111
1
36//
10111
9100
2
G
91//
8
81//
6
81//
3
52//
3
F
5
10
5221
2114
16 MARCH

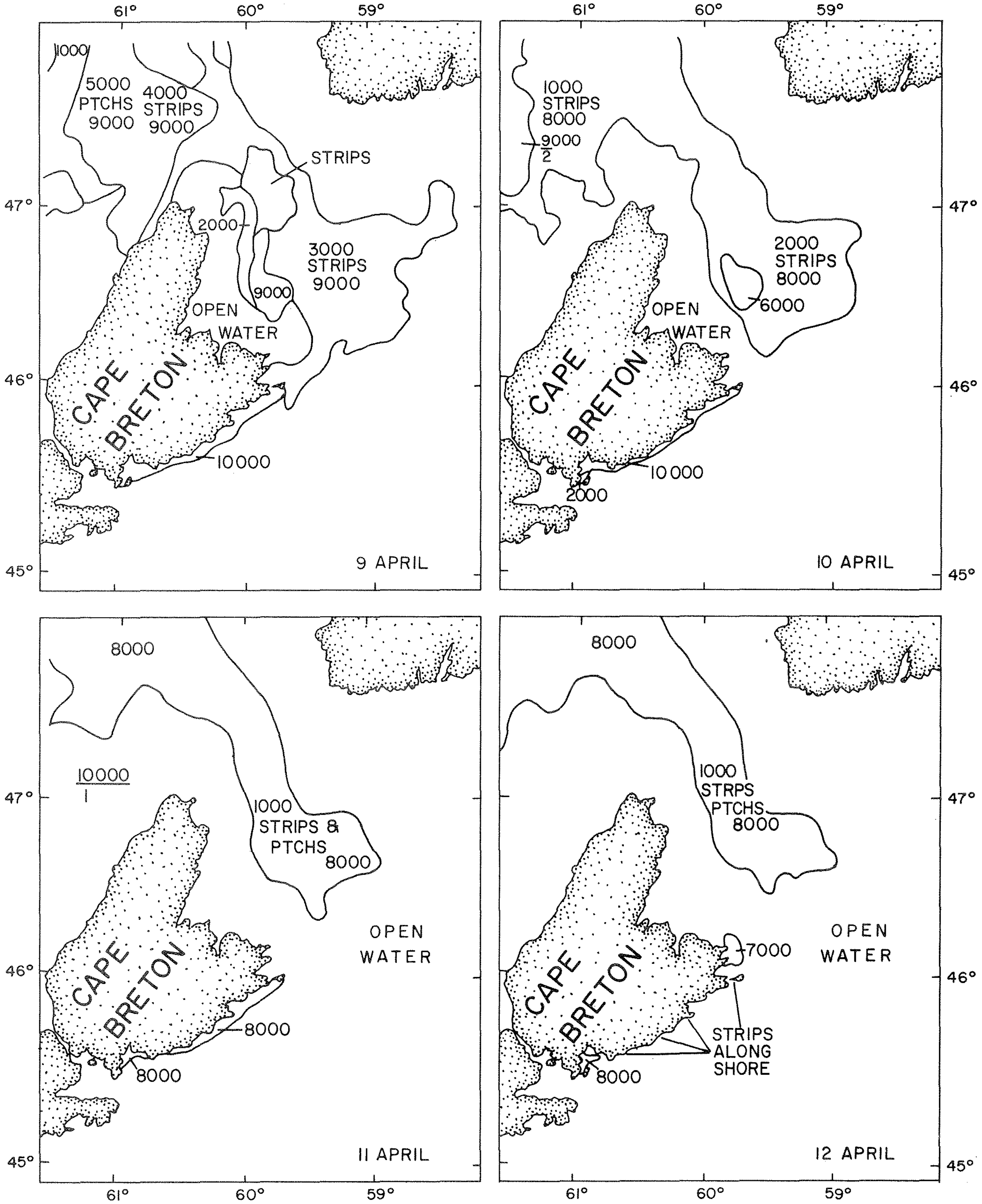
APPENDIX A


61°
60°
59°
47°
46°
45°
71//
2
2///
1
9100
2
91//
8
81//
61
35//
STRIPS
81//
1
811/
3
82//
51
62//
2200
STRPS
44//
CAPE
BRETON
17 MARCH
36//
612/
72
3/33
721/
91//
7
53/1
9/1/
8
32//
STRPS
&
PTCHS
81/1
6
311
62//
54/1
1/63
64
18 MARCH
62/1
35//
11
721/
2
B
91//
4
9/1/
8
91//
7
721/
2
53/1
91//
7
81/1
6
D
82//
3
6211
5311
82//
1
431/
19 MARCH
621/
721/
2
9/1/
5
91//
7
721/
11
3100
82//
4
10///
5
82//
STRIPS
81/1
6
62//
621/
3100
STRIPS 62//
3000
20 MARCH

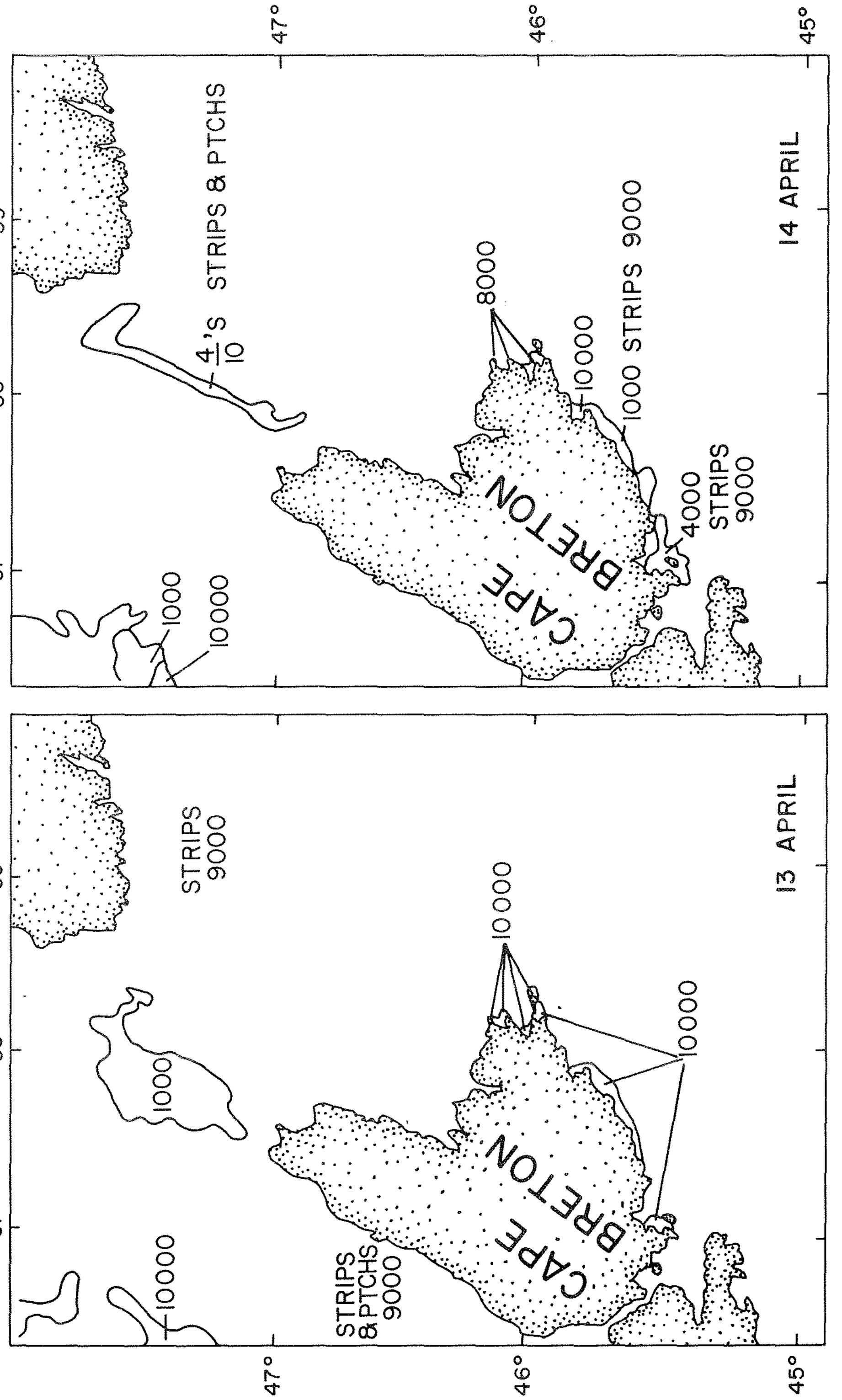
APPENDIX A


61°
60°
59°
47°
46°
45°
1000 STRIPS 7///
STRIPS 9000
8000 / 2
5000
2000 STRIPS 7//1
3000 / 1
4//3
8/// / 1
1000 STPS
C
B
A
6000
5000 STRPS 9000
CAPE BRETON
8000
1000 STRIPS 8000
6000
5 APRIL
2000 STRIPS 8000
STPS 7000
7000 / 3
3000
6000
6000
B
B
J
D
L
B
K
D
C
5000 STRIPS 9000
2000
A
8000
3000
1000
6 APRIL
1000 STRPS 9000
K
N
E
7000 / 5
1000
D
1000
6000 / 3
3000
4001 PTCHS 8001
P
F
7000
2000
2000 STRIPS AND PTCHS 8000
10000
7 APRIL
9000 / 1
1000 STRPS 9000
D
E
1000 STRIPS 8000
6000 / 1
2000
1000
7000
4000 PTCHS 8000
D
1000
10000
8 APRIL

APPENDIX A


61°
60°
59°
47°
46°
45°
1000
5000
PTCHS
9000
4000
STRIPS
9000
STRIPS
2000
3000
STRIPS
9000
9000
OPEN
WATER
CAPE
BRETON
10000
9 APRIL
1000
STRIPS
8000
9000
2
2000
STRIPS
8000
6000
OPEN
WATER
CAPE
BRETON
10 000
2000
10 APRIL
8000
10000
1
1000
STRIPS &
PTCHS
8000
OPEN
WATER
CAPE
BRETON
8000
8000
11 APRIL
8000
1000
STRPS
PTCHS
8000
7000
OPEN
WATER
CAPE
BRETON
STRIPS
ALONG
SHORE
8000
12 APRIL

APPENDIX A



47°
46°
45°
59°
60°
61°
14 APRIL
STRIPS & PTCHS
4/10 'S
8000
10000
1000 STRIPS 9000
4000
STRIPS 9000
CAPE BRETON
1000
10000
13 APRIL
STRIPS 9000
1000
10000
10000
10000
STRIPS & PTCHS 9000
10000

PRELIMINARY RESULTS OF REMOTE SENSING OVERFLIGHTS DURING THE KURDISTAN OPERATION

M.F. Fingas[1], R.A. O'Neil[2], V. Thomson[3] and R.A. Neville[3]

[1]Environmental Emergency Branch
Environmental Protection Service (EPS)
Hull, Quebec

[2]Canada Centre for Remote Sensing (CCRS)
Department of Energy Mines and Resources
Ottawa, Ontario

[3]Intera Environmental Consultants
Ottawa, Ontario

INTRODUCTON

On the fifteenth of March, the captain of the tanker Kurdistan reported that it had suffered structural damage in the approaches to Cabot Strait. By the night of the same day, with a Canadian Coast Guard ship nearby, she broke into two. The Coast Guard ship reported seeing oil in the vicinity, and after discussing the matter with the ship's crew determined that at least 3 thousand tonnes of oil had been lost. Subsequent calculations put the loss of oil at 7 to 9 thousand tonnes.

The remote sensing missions were initially activated to locate and map the oil spill, of which at the time little was known both as to its extent and its location. In addition, the spill afforded a unique opportunity to test the Arctic Marine Oilspill Program (AMOP) sensor package on a heavy oil spill in ice-infested waters under real field conditions. In the later phases of the study, another objective of the program was to provide imagery to those groups studying the behavior of oil in ice.

CCRS personnel were able to assemble the instruments, mount these on the aircraft (DC-3, Falcon Jet), and fly to Halifax, Nova Scotia, on the night of the 16th and the morning of the 17th of March.

REMOTE SENSING INSTRUMENTATION AND OVERFLIGHTS

The sensor packages that were used on the *Kurdistan* mission included:

(a) Sensors mounted on the DC-3 (C-GRSB)

(i) Multi-Spectral Scanner
The visible and infra-red channels were used to produce final imagery. The instrument employed actually produced 10 channels of imagery.

(ii) Low-Light Level Television

(iii) Two 70 mm Cameras
One was mounted forward and used UV-sensitive film, the other was mounted to view the nadir (look directly downward) and was loaded with color film.

(iv) MEIS
The MEIS is an experimental sensor employing an electronically scanned diode array. The sensor detects radiation in the 300 to 395 mm and 705 to 750 mm ranges on two channels, one polarized horizontally, the other vertically.

(b) Sensors mounted on the Falcon Jet (C-GRSD)

(i) DCLS (Dual Channel Line Scanner)
This line scanner selected imagery in the IR and UV regions.

(ii) RC-10 Camera
This camera was mounted to view the nadir. It was packed with color film on three sorties, and on a fourth sortie (IR) with false color film.

The prime oil sensor, the laser fluorosensor, was out for repairs and was not employed in these missions.

A detailed summary of the CCRS sorties conducted during the Kurdistan spill appears in Appendix 1. In total 15,774 km were flown by the two aircraft employed, of which 5,360 km were in the target area. A total of 1,676 sensor kilometers were accumulated between the two aircraft. Of this distance 292 km were immediately over oil or over oil-contaminated areas. This massive program has, needless to say, resulted in a considerable accumulation of data. Thus, it will not be possible in this paper even to summarize all the flights, locations or results of the program. Instead a complete set of data will be compiled by C-CORE into a final report on the behaviour of the oil from the Kurdistan spill. As well a complete data set is available at EPS, Halifax.

The major problems encountered in the overflight program were the vast search area and weather conditions. The DC-3 has a 'safe' range of approximately 500 miles over water and to cover an area in detail a track spacing of one or two miles is required, depending on the altitude. For this reason only small areas can be covered in one single day. It was because of this that the Falcon Jet (although it has weight limitations) was used in the later stages of the remote sensing exercise. The other problem, that of poor weather, was encountered especially during the first few days of the spill. Indeed on several days it was not possible to fly at all. On other days the cloud ceiling restricted overflights to lower altitudes - thus again lowering the areal coverage.

IMAGERY AND RESULTS

A summary of the locations of major oil sightings and of oil-contaminated shoreline and ice are given in Table 1. Particular details of segments of flight lines are illustrated in Figures 1 through 6.

Oil on Ice - Aerial View

Oil on the ice surface appeared to be black, grayish or brownish and appeared in large swirls or streaks. The fluid motion of the ice surface underneath was clearly visible. Much of the oil, especially during the early stages of the spill, was of a pale coloring, mainly because it

TABLE 1

Summary of Events and Oil Observations Kurdistan Spill

Date	Basic Events	Visual Sightings of oil	CCRS Remote Sensing Observations
March 15	Kurdistan reports it was holed by ice at approx. 14:00 AST at 46°55.8'N 59°39.7'W		
March 15	At 22:19 AST Kurdistan broke in two, oil loss estimated by EPS to be 9,904 tonnes (66,026 barrels, 2,310,933 gallons).	Coast Guard reported seeing oil in area of breakup	
March 18			"possible" oil streak located at 46°26.6N 58°58.2'W
March 20	Disposal site chosen for bow and decision made to tow stern section to port		
March 21			"Mousse" found between bow and stern
March 22		CCG helicopter reports large oil-stained ice area between Point Fourchu and Point Michaud (45°43'N, 60.1°W to 45°35'N, 60.41°W)	
March 23	Stern section is towed into Port Hawkesbury	Stained ice section confirmed by several several parties. "Dart Europe" reports oil in same area as CCRS	Large area (approx. 130 x 45 km) of slick found directly east of Port Hawkesbury plus stained ice
March 24		Tracker aircraft reports 10 or more patches of oil (about 1 mile radius each) 45°05'N 59°23'W	

TABLE 1 continued

Date	Basic Events	Visual Sightings of oil	CCRS Remote Sensing Observations
March 27		Oil comes ashore at several points on Cape Breton Coast	
March 29			Contaminated ice and shoreline mapped.
April 1	Bow section is sunk at approx. noon AST at 41°55.2'N 60°58'W		
April 2			Contaminated ice and shoreline mapped, south portions of several bays are contaminated.

was mixed with slush ice or with snow. As melting proceeded the color of the oil became correspondingly darker.

Oil on Water - Aerial View

Oil on the water appeared in several different forms. Chocolate mousse was seen in several locations, and on several days (Fig. 1). It was a bright chocolate brown in appearance. Mousse was distributed as small circular pans (i.e. a few meters in diameter), and was generally scattered fairly widely over the ocean surface, with concentrations of mousse pans never exceeding fifty or more in any one area.

Thin sheens of oil were also observed on several occasions. A particularly large area covered by sheen oil was observed on the 23rd of March overflight over the northern part of the Scotian Shelf (Fig. 2). The thin sheen layer was broken only occasionally by wind or waves. In the western portion of this contaminated area the slicks were not continuous, and total coverage there was estimated to be only ca. 20% of the sea surface.

Coincident with sheen oil slicks were what appeared to be submerged pans of oil floating just below the sea surface. The coloring of these pans was black, and thus may have consisted largely of unemulsified oil. No search was made for such submerged oil in other areas not covered by sheen oil slicks. Nor was ground-truthing of this submerged oil carried out. It should be noted that during the course of this spill there was much speculation that the oil was submerging and resurfacing. In fact there was only one documented report where the CCGS *Daring* steamed through such submerged oil, bringing it to the surface in the vortex of the ship's screws.

SENSOR EVALUATION

The output of the sensors from the missions over the *Kurdistan* spill in areas of open water did not yield any new information not already available (*viz.* Neville *et al.*, 1979). Of greater interest was the detection of oil on or with ice. It is felt that the most useful of the sensors employed for this purpose were the IR and UV line scanners. On the UV scanner the oil on the ice appeared grey to black (depending on density of oil on the ice) whereas the ice appeared featureless and white. This indicates that oil has a much higher UV absorbance than ice and can easily be distinguished. In the case of oil on the sea surface the color of the oil was usually grey compared to the 'black' water, allowing one to distinguish between these as well. The UV technique then, depending on the differential UV absorbance of oil relative to either ice or seawater, appeared to be useful in the detection of oil.

With respect to IR as a sensing technique, oil on ice absorbs much more solar radiation than the ice around it and has a high IR emmissivity. Thus the oil on ice appears as white on a black background with IR scanner imagery. Our conclusion is that a combination or comparison of IR and UV imagery should prove very useful in future exercises to distinguish between oil and other possible contaminants. Certainly in the future the IR and UV instrumentation will be employed for more routine mapping of the distribution of the oil.

The use of IR and UV has, however, some limitations. In the case of oil-in-ice little research has been done on the responses and properties of oil and of interfering materials. For example, it is known that soils will behave similar to oil, i.e., with high absorbance in UV and high IR emmissivity, and thus could be mistaken for oil. In addition the physical distribution of soil in the ice-fields appears to be similar to that of oil. As much of the ice in the Cape Breton vicinity contained large amounts of soil (viz. Vandermeulen and Buckley, 1980; Reimer, this volume) this caused problems in the use of UV and IR. In the case of the Kurdistan spill we managed to overcome this problem by ground truthing, establishing oil and densities of oil in particular areas, and our maps do reflect fairly accurately the distribution of the oil in the top layer of the ice.

Unfortunately the laser fluorosensor was not available for these missions to assess its response to the oil on the ice, since it is anticipated that laser fluorimetry will be used as the primary 'yes - no' device to determine the presence of oil. Hopefully future tests will show that the fluorosensor can take the place of the presently much needed ground truthing.

SUMMARY

A large amount of valuable data has been collected. It will be possible to map, to a certain extent, the distribution and movement of oil on ice from the *Kurdistan* spill. This should prove to be invaluable as far as examining the fate and behaviour of the oil in this environment. The data on the distribution of oil on the water should be valuable in assessing the overall oil budget of the *Kurdistan* spill as well as in modelling the movement of oil along the coast.

The remote sensing study was also useful in determining the requirements and problems of sensing oil on ice. Further analysis of the mission is planned and results of this will be incorporated into a report being prepared by CCRS for AMOP to recommend on a sensor system for use in ice-infested waters. As noted before, a data set has also been provided to C-CORE for analysis and incorporation into a major report on the behavior of oil in the *Kurdistan* spill.

BIBLIOGRAPHY

NEVILLE, R.A., V. THOMSON, R.A. O'NEIL, L. BUJA-BIJUNAS, L. GREAY, B. HAWKINS and K. DAGG. 1979. Remote sensing of oil spills. Spill Technol. Newsletter *4* (2), 111-146.

VANDERMEULEN, J.H. and D.E. BUCKLEY, editors. 1980. The *Kurdistan* Oil Spill, March 15/16, 1979. Activities and observations of the Bedford Institute of Oceanography scientific response team. Bedford Institute of Oceanography Report Series, BI-R-80-2.

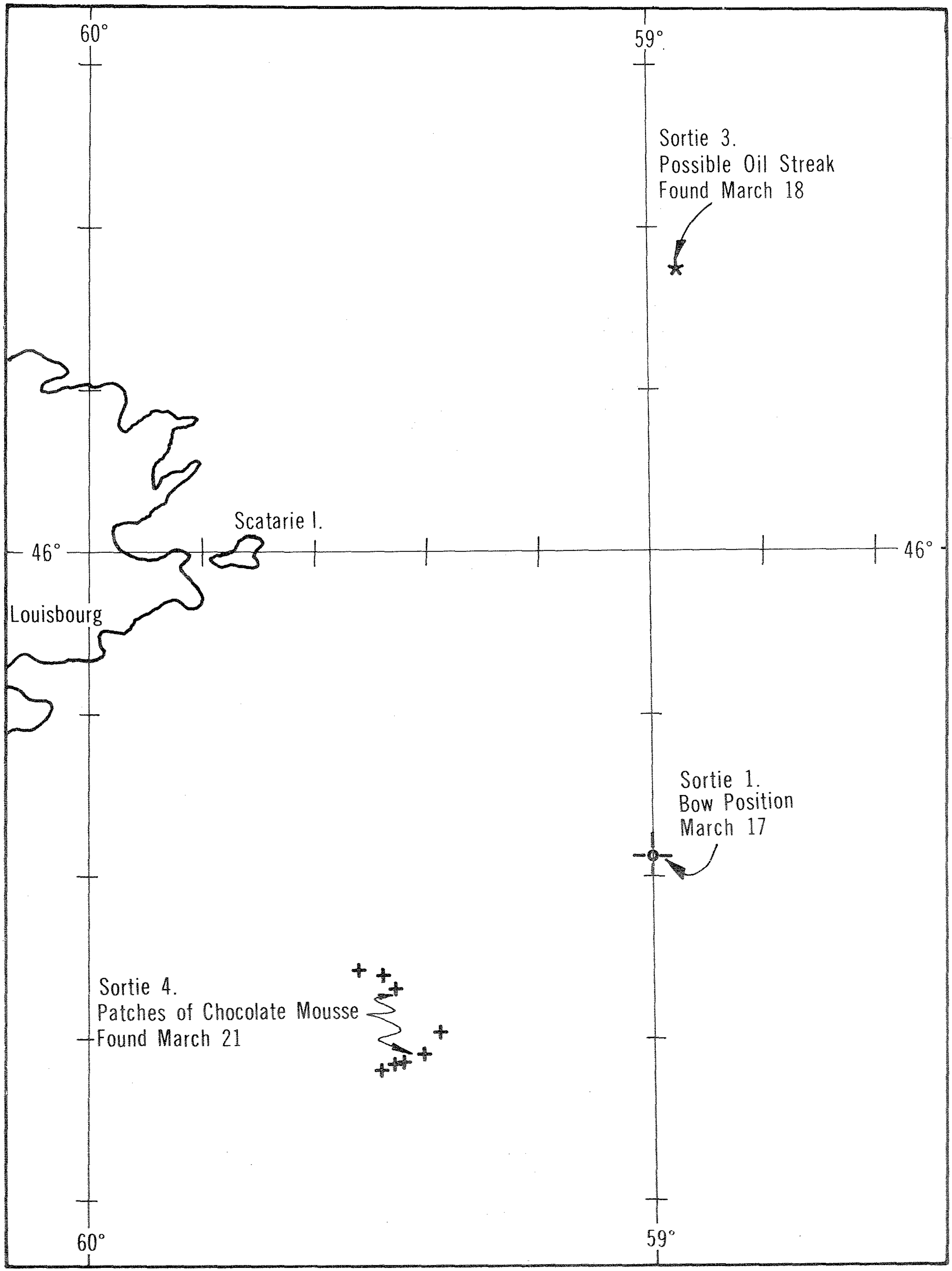


Figure 1. Oil Detection by Remote Sensing Mission Sorties 1-4, 17-21 March 1979.

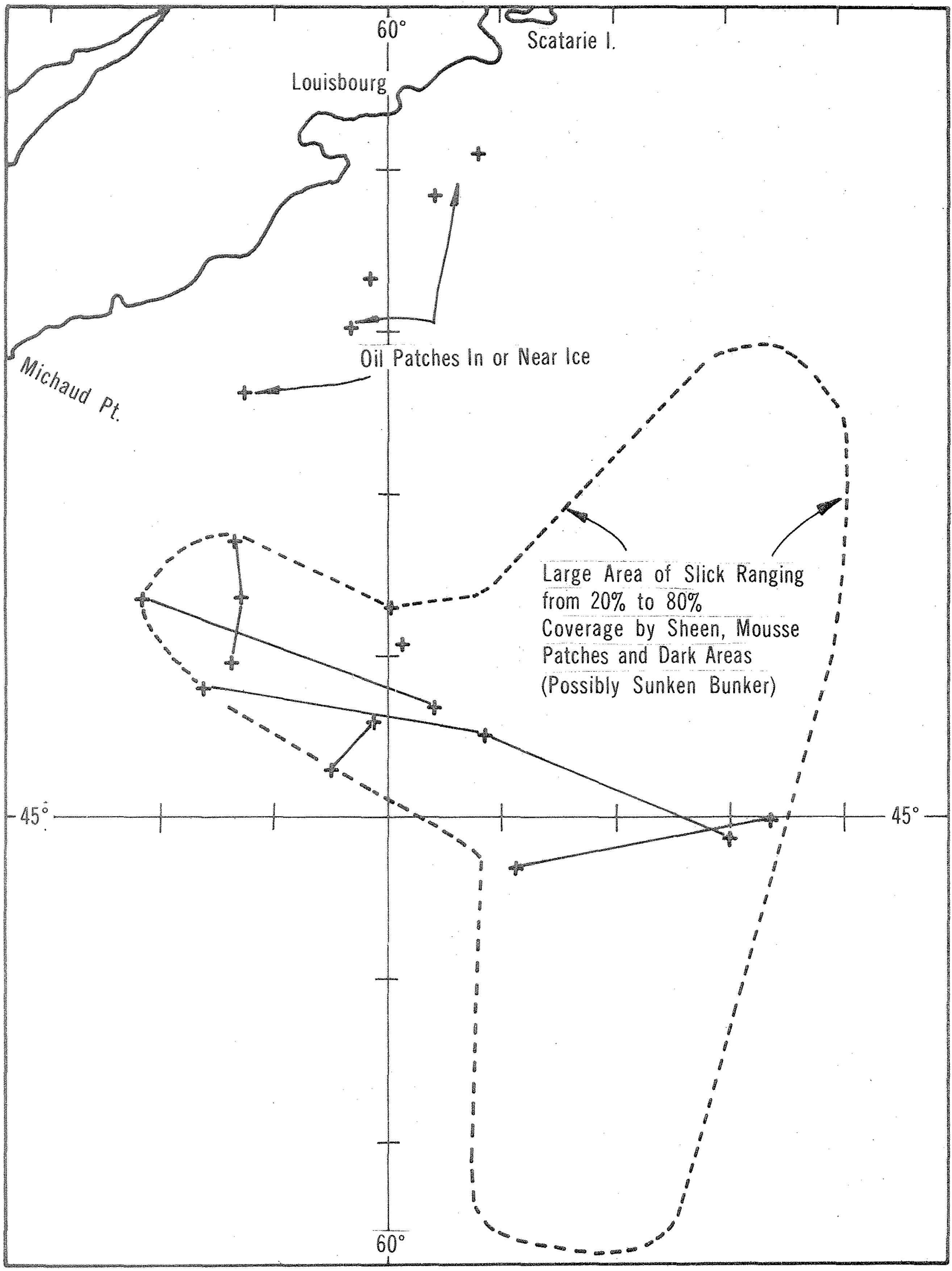


Figure 2. Oil Detected by Remote Sensing Mission Sortie 5, 23 March 1979.

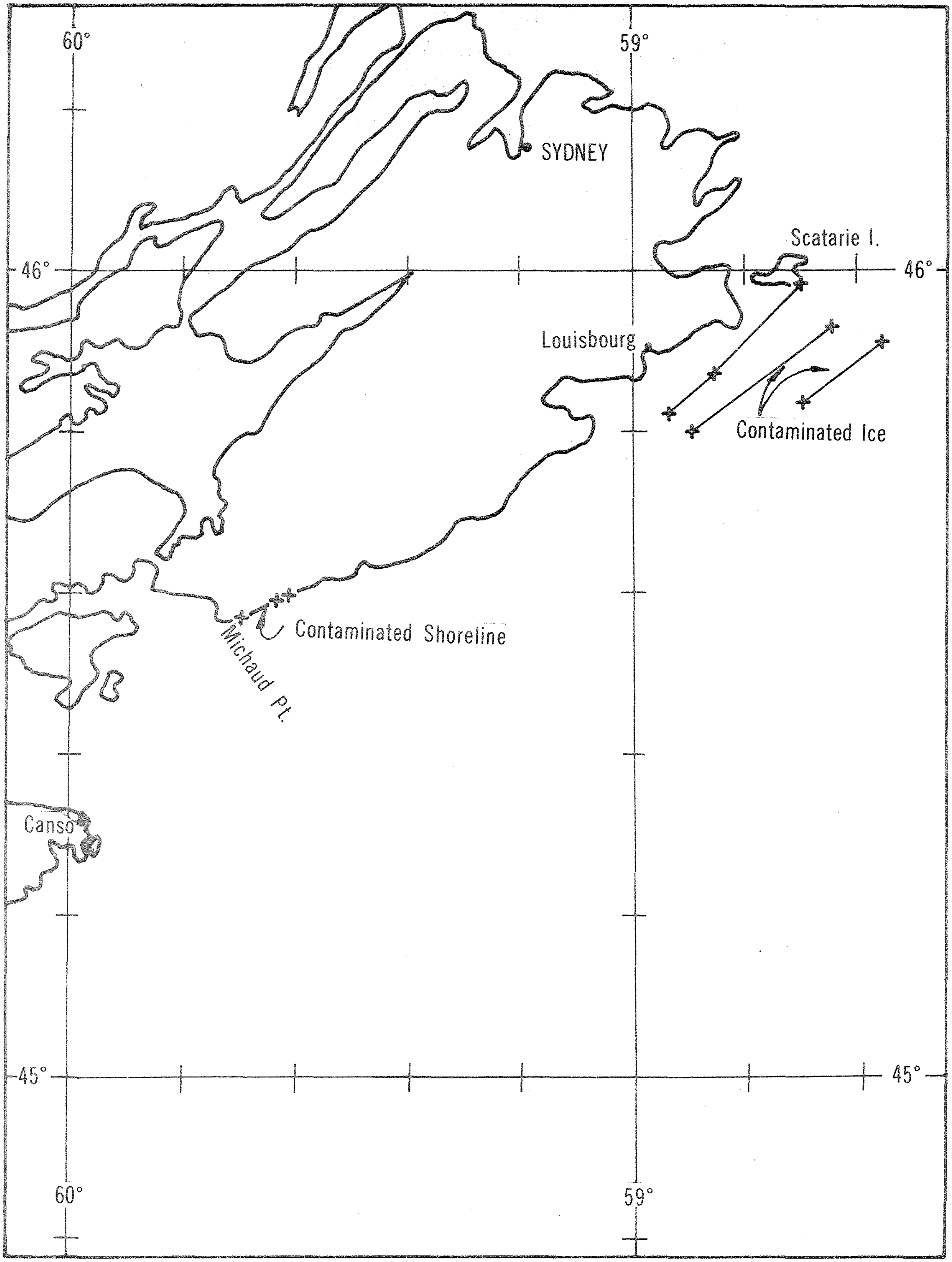


Figure 3. Oil Detected by Remote Sensing Mission Sortie 6, 29 March 1979.

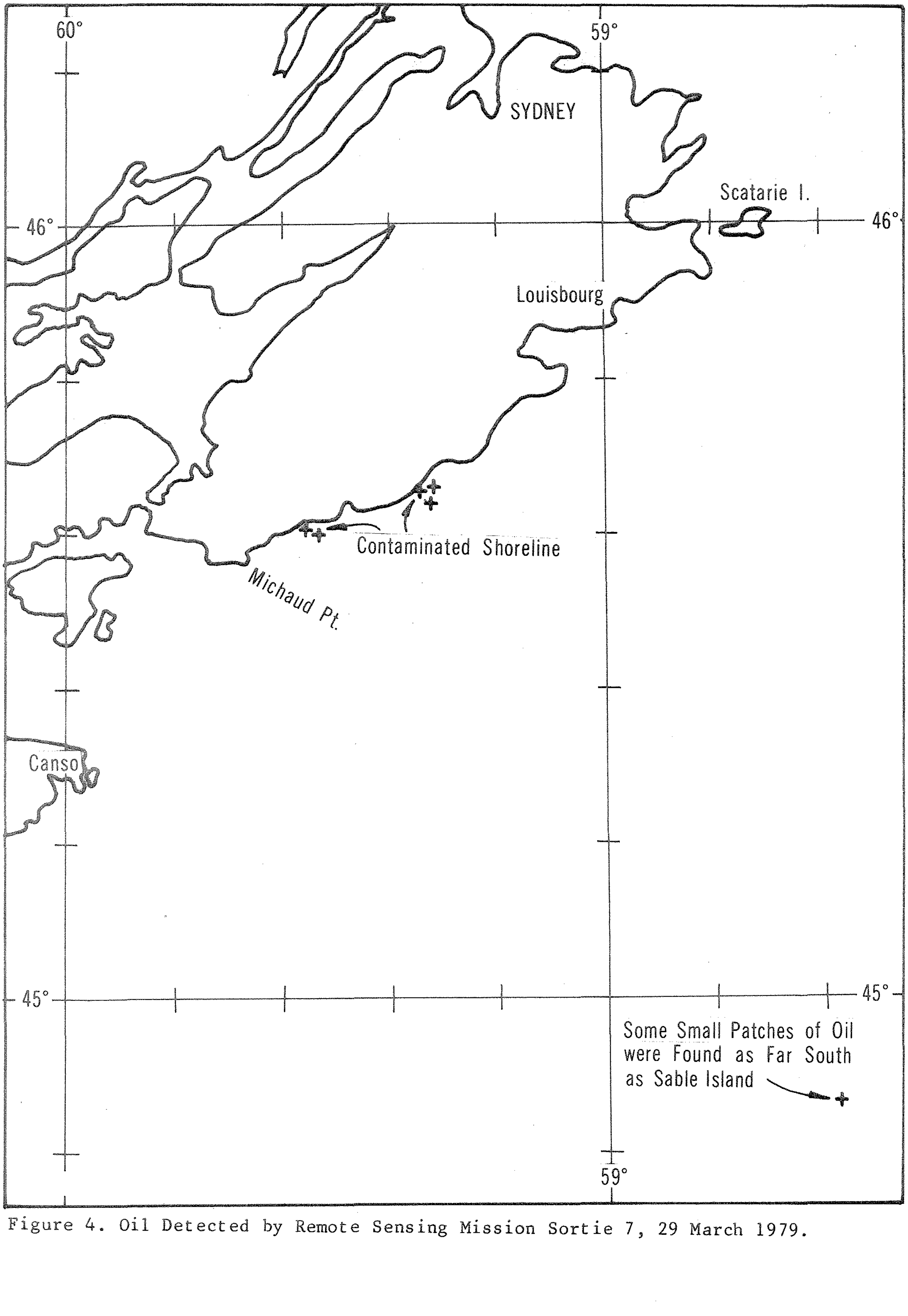


Figure 4. Oil Detected by Remote Sensing Mission Sortie 7, 29 March 1979.

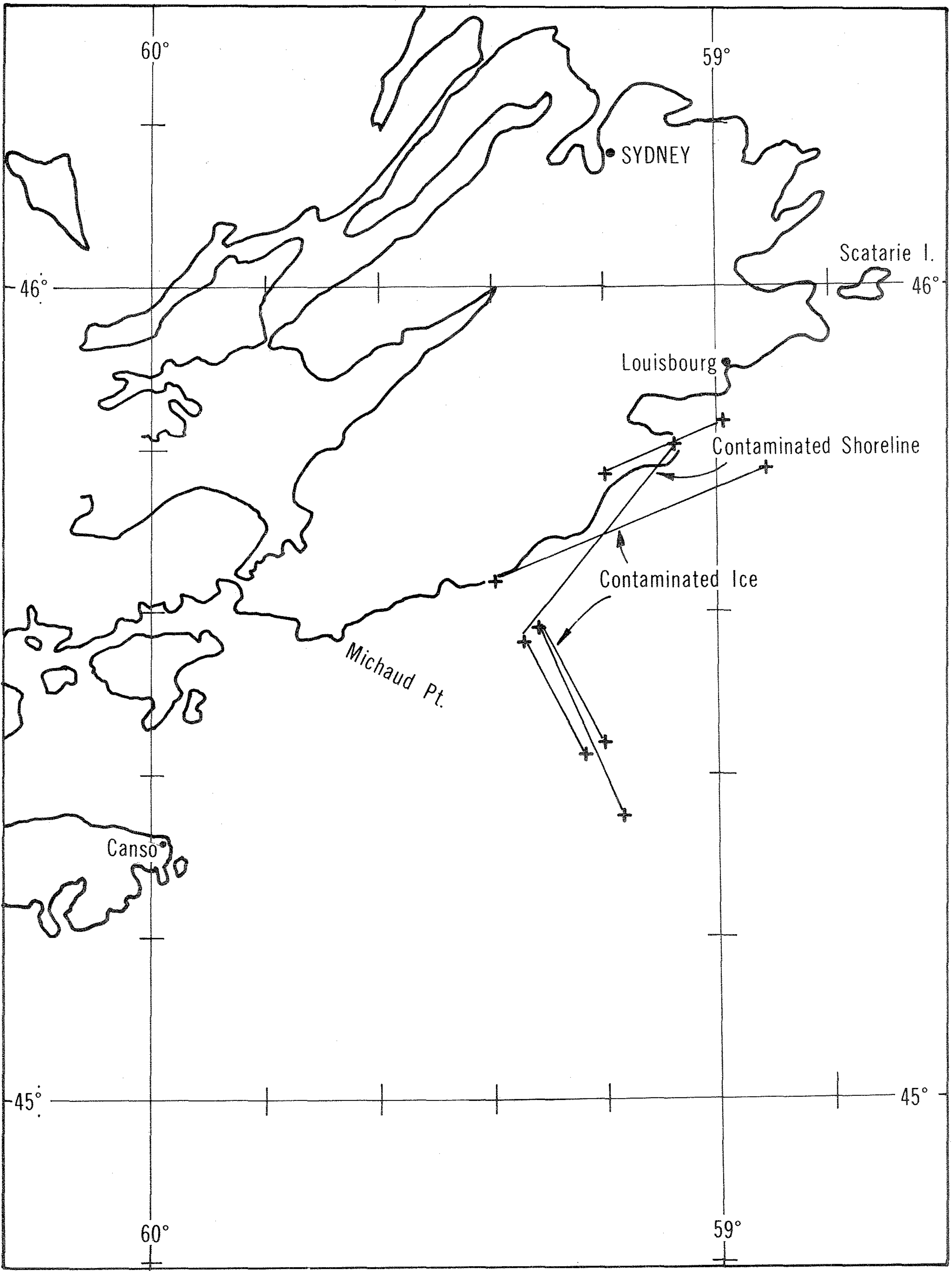


Figure 5. Oil Detected by Remote Sensing Mission Sortie 8, 2 April 1979.

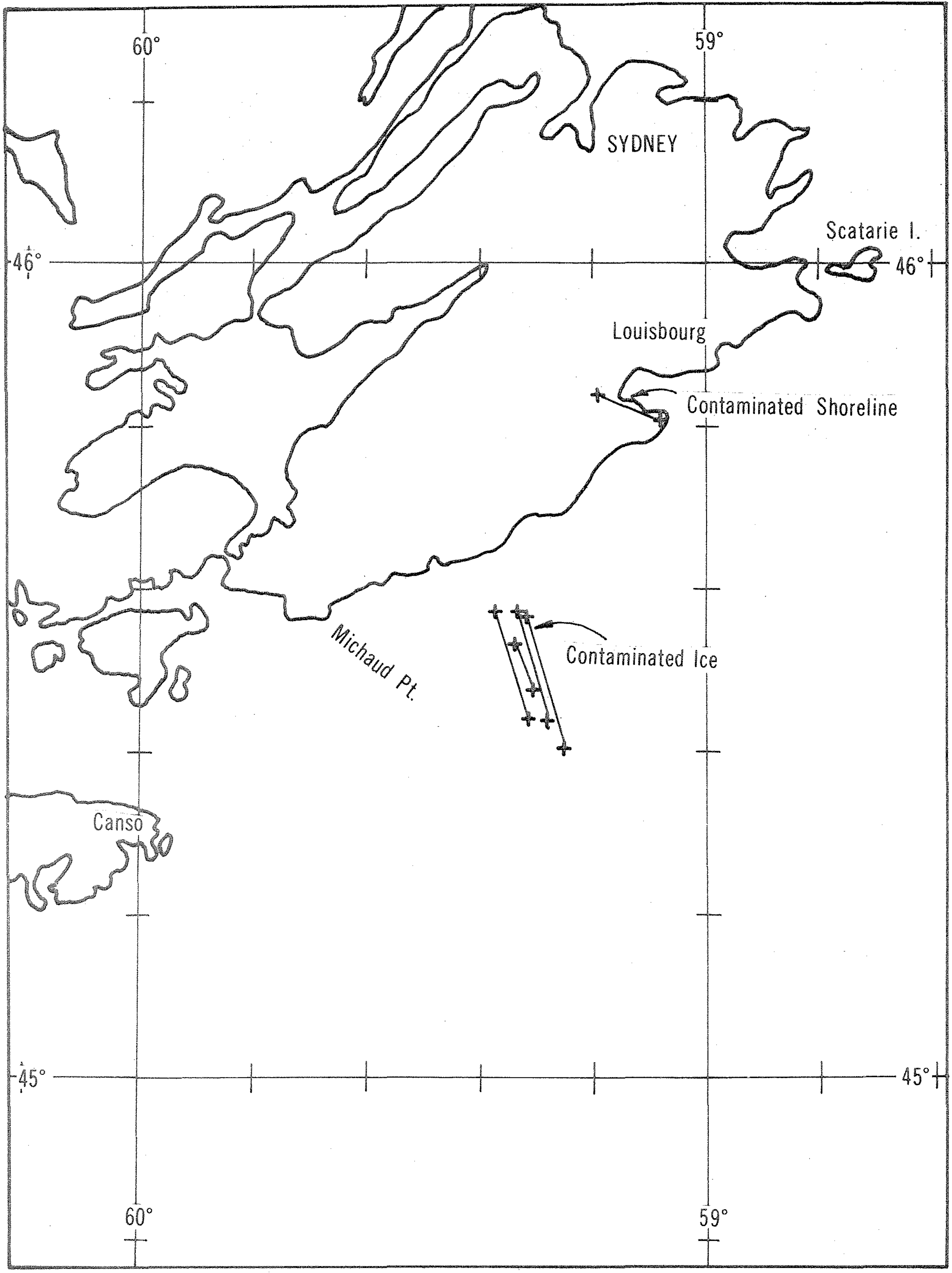


Figure 6. Oil Detected by Remote Sensing Mission Sortie 9, 2 April 1979.

APPENDIX I

Summary of Remote Sensing Missions over the Kurdistan Spill

Day	Aircraft	Sensor Time & Distance total (hrs/min/sec,km)	over oil	Sortie	Notes/Comments
March 17	DC-3	0:1:50 2.25 km	0:00:00	1,2	Preliminary flight over bow and suspected areas - no oil found
March 18	DC-3	1:20:47 308 km	0:00:00 0.25 km	3	A reddish-colored streak was discovered at 46:24.6N 58:58.2W, later suspected to be an oil 'streak'.
March 21	DC-3	0:43:01 170 km	0:00:10 0.7 km	4	Area between the bow and stern was searched approx. midway between these two areas, (45:14.1N 59:01.0W and 45:14.1N 59:43.2W) patches of chocolate mousse were found.
March 23	DC-3	1:29:32 360 km	0:30:51 134 km	5	Large area (approx. 130 x 45 km) of oil found directly east of Port Hawkesbury. Large area consisted of surface sheen, patches of mousse and darker areas (possibly submerged oil). Percentage of surface coverage varied. Patches of oil or oil contaminated ice found parallel to the Nova Scotia Coast as well.
March 29	Falcon	0:28:45 305 km	0:06:36 63 km	6	Large areas of contaminated ice were found offshore between Scatarie Island and Louisbourg. Some contaminated shoreline was found also near Point Michaud.

APPENDIX I (continued)

Day	Aircraft	Sensor Time & Distance total (hrs/min/sec,km)	over oil	Sortie	Notes/Comments
March 29	Falcon	0:13:30 108 km	0:00:20 2.7 km	7	Contaminated shoreline was found on several portions of the Cape Breton Island.
April 2	Falcon	0:30:14 292 km	0:19:17 187 km	8	The shoreline and ice contamination as noted in sortie 7 was observed to have generally drifted southwards - shoreline contamination was evident in the southern portion of many bays. Extensive shoreline and ice contamination was mapped.
April 2	Falcon	0:19:26 131 km	0:05:40 39 km	9	The extensive shoreline and ice contamination noted above was mapped in slightly different areas than noted above.

THE VISUAL IDENTIFICATION OF BUNKER-C OIL IN DYNAMIC PACK ICE

E.M. Reimer

C-CORE, Memorial University, Newfoundland

INTRODUCTION

Subsequent to the Kurdistan oil spill, an unknown amount of Bunker-C oil was entrained in pack ice off the southeast Cape Breton shore in a variety of visually distinctive forms. The visual features associated with oil contamination were in many cases similar to features arising from other phenomena such as organic detritus in and on the ice. These similarities can frequently cause problems in the identification and tracking oil in ice.

As the result of a two-week period of aerial reconnaissance and observation (March 27 - April 7) the following catalogue of visual features has been compiled. The first section deals with the several visually distinctive forms of oil contamination which were observed. The second section itemizes a number of natural phenomena which gave rise to features easily mistaken for one of the forms of oil contamination.

OBSERVATIONS

Oil Contamination

1. In its most commonly observed form, the oil contamination appeared (from distances greater than 100 metres) as a streak or band varying from pale yellow to dark brown. These features had typical dimensions in the order of 100 m to 1 km (Fig. 1).
   On closer inspection a 'streak' would resolve into a yellow-brown 'stain' in the brash between the floes, and into brown stains on the sides and outside edges of floes. Discoloration on floe surfaces usually resulted from contaminated brash thrown up onto the rim of the floes in circumferential dykes, or from spatters of oil extending several metres inward from the edges. Figure 2 shows a ridge of heavily contaminated brash which has been pushed up onto a floe edge. Figure 3 shows the type of oil spattering which was observed extending as much as 10 metres inward from the floe periphery.

Closer inspection of the brash ice revealed blobs and particles of oil ranging in size from several centimetres to less than 100 micrometres. The intensity of coloration in the brash was a direct function of particle size as well as of total oil loading. Thus finely dispersed oil appeared as a tan or yellow stain, while coarser dispersions were darker brown but were visually less intense.

2. Occasionally floes were observed to be totally covered by a layer of oil several millimetres thick. These floes were seen both in areas of clean ice as well as in oil-contaminated areas (Fig. 4). However, positive identification of oil required close inspection, since bottom or shore-derived sediment contamination was also occasionally observed on floe surfaces and has a similar appearance.
3. Storm conditions reduced a sizeable proportion of the ice pack to rubble, with the oil apparently quite uniformly exposed as rich brown streaks (Fig. 5). Mechanical grinding of oiled ice in the nearshore by breaking waves resulted in a very fine oil particle distribution in ice rubble (Fig. 6), giving rise to a very pale yellow hue for oil concentrations in the order of 25 ppm.
4. Oil pancakes averaging about 30 cm diameter were visible at close range on the seaward ice-edge. These pancakes, apparently in the process of being incorporated into the ice, tended to float partially submerged in ice brash. From a few metres distance they appeared as 'holes' in the brash ice. In turbid nearshore waters light scattering and bottom reflection made identification of these pancakes easier.
5. Under some conditions, oil particles and blobs a few centimetres in diameter appeared as a superficial layer over a field of ice pulp (Fig. 7). These often took the form of very dark streaks less than 1 metre across and several tens of metres in length.

Spurious Contamination

1. Much of the ice observed off this part of the Cape Breton shoreline carried a superficial load of reddish clay or sediment which often

appeared as streaks in the pack ice.
Best distinguishing feature: color difference between sediment and oil. Also, discoloration was relatively uniformly distributed over the surface of the floes. As well it was absent in the brash ice.

2. Regular variations in floe size and differences in floe-packing density generated many streak and whorl patterns in the ice field (Fig. 8). Best distinguishing feature: absence of brown or yellow coloration. Further, regular differences in floe sizes are easily recognized from intermediate distances.

3. Organic material (apparently algal pulp) was often seen in nearshore regions as a streak or strain in the ice. The appearance was similar to oil in most respects, including splatters on floe surfaces.
Best distinguishing feature: the hue of this type of stain was slightly purplish as opposed to the yellow hue of oil. In false color infrared photographs these stains typically appeared magenta.

4. Another nearshore phenomenon which might be mistaken for oil was a yellowish band or streak associated with a river outfall.
Best distinguishing feature: absence of staining on floe surfaces. Also distinctive floe size differences were often associated with the area.

5. In the nearshore/onshore zone, stirred up sediments in the water and on the sides and tops of floes were often difficult to distinguish from oil contamination except from close range.
Best distinguishing feature: the characteristic color of the local sediments was perhaps the best clue as to identity, although close inspections was the only reliable method of identification.

DISCUSSION

The visual features described above represent only a few of many possible conditions which can arise from the dispersion of oil on or in ice. In this case the interactions occurred between a heavy residual semi-solid oil (Bunker C) well below its pour-point, and a small, moderately active field of decaying pack ice. Although some of the observations may be extended to other situations, only the more general features such as large scale streaking may reasonably be expected in the case of an oilspill in active ice.

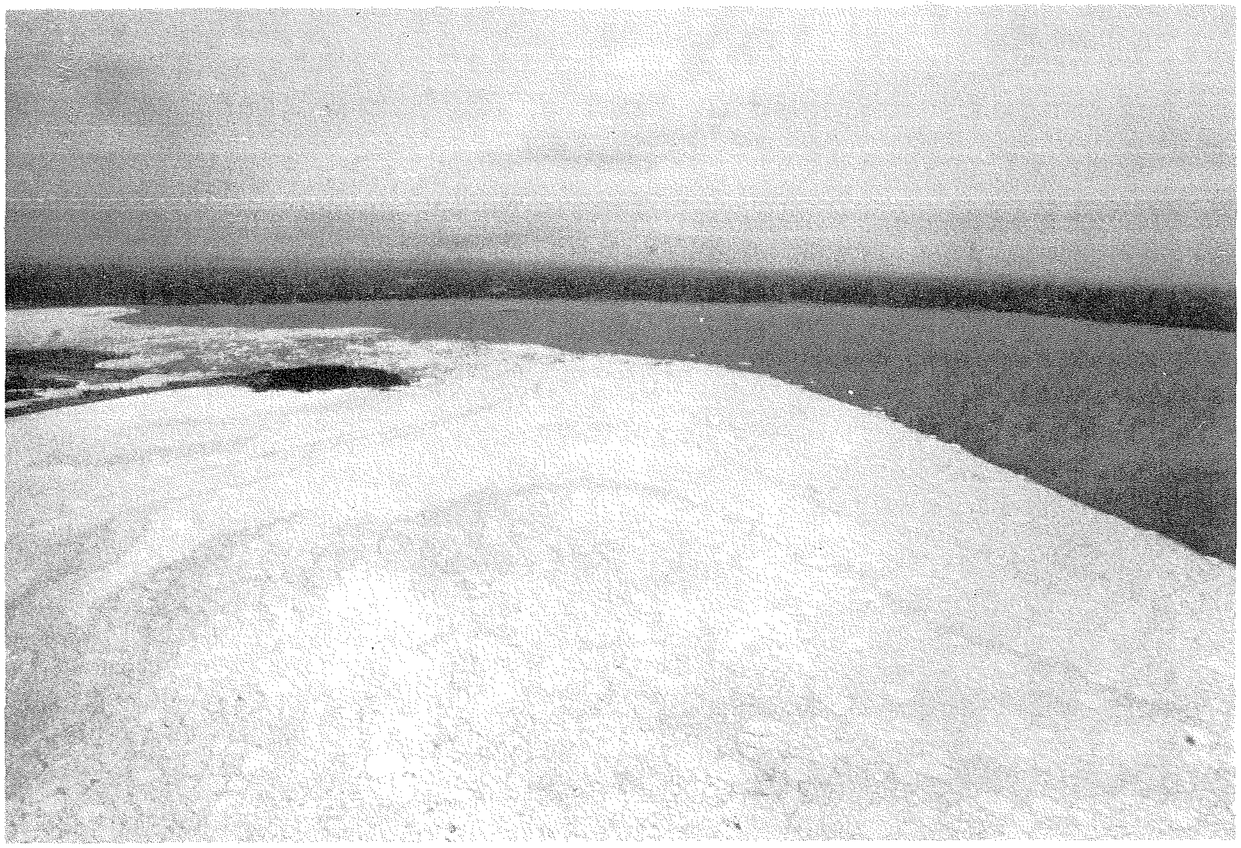


Figure 1. A typical view of oil-contaminated ice in the Cape Breton region. In this case, the pack consisted of 10 m to 20 m floes tightly compacted along shore. The darker streaks running through the pack were the oil contaminated areas.

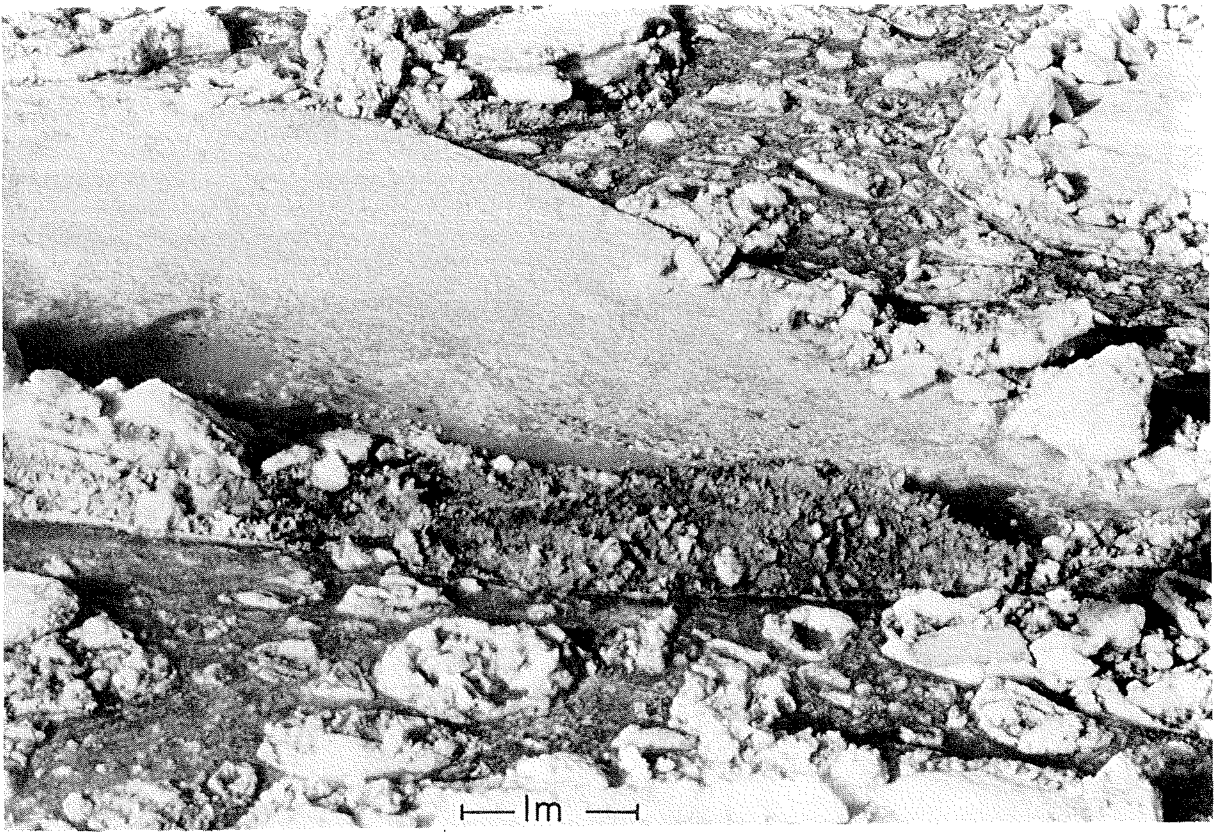


Figure 2. The dark granular mound central in this photo is a ridge of oil-contaminated ice rubble and brash. The coloration of the ridge was such that even from a few metres distance the material could have been mistaken for sand or gravel.

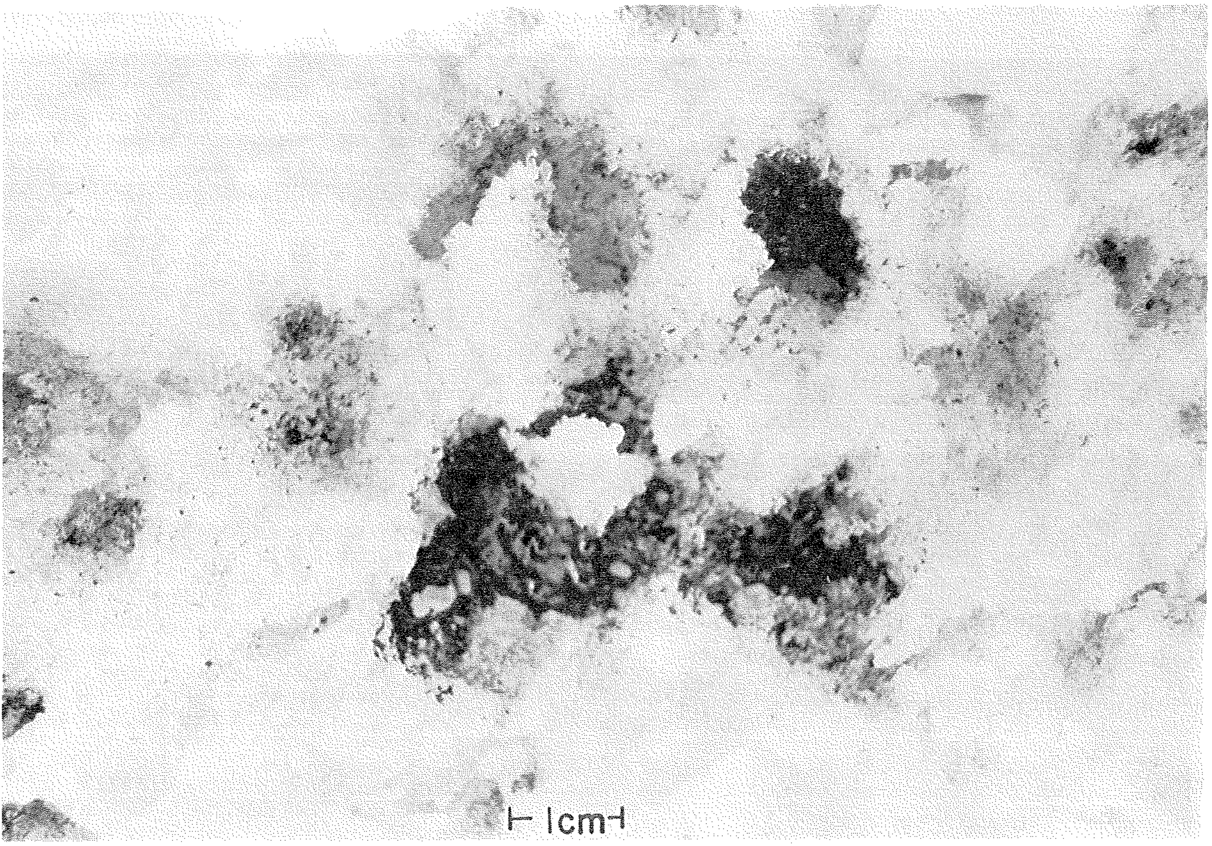


Figure 3. Oil blobs splashed or spattered onto floe surfaces appeared in the form of melt pockets as a result of solar irradiation.

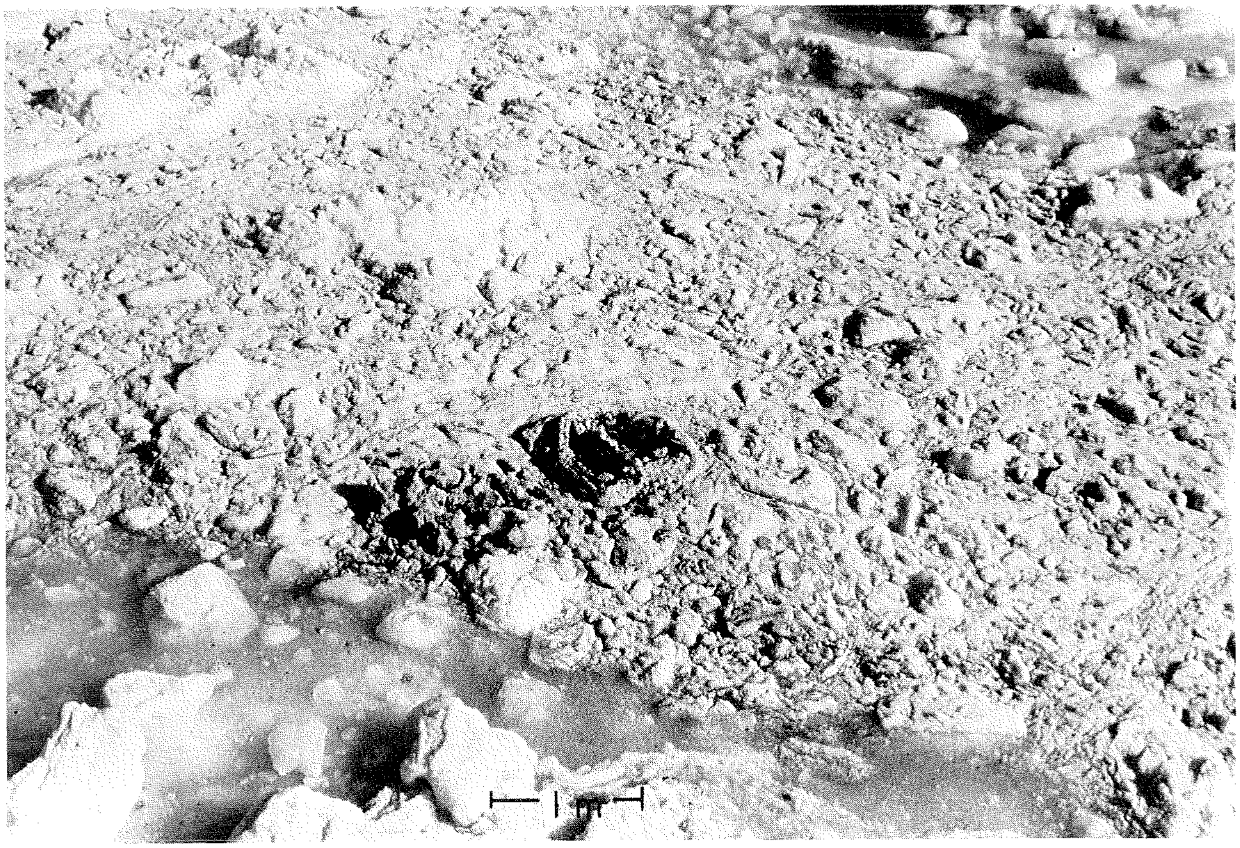


Figure 4. The central floe in this photo carried a complete surface covering of oil. The surrounding brash was mildly contaminated.

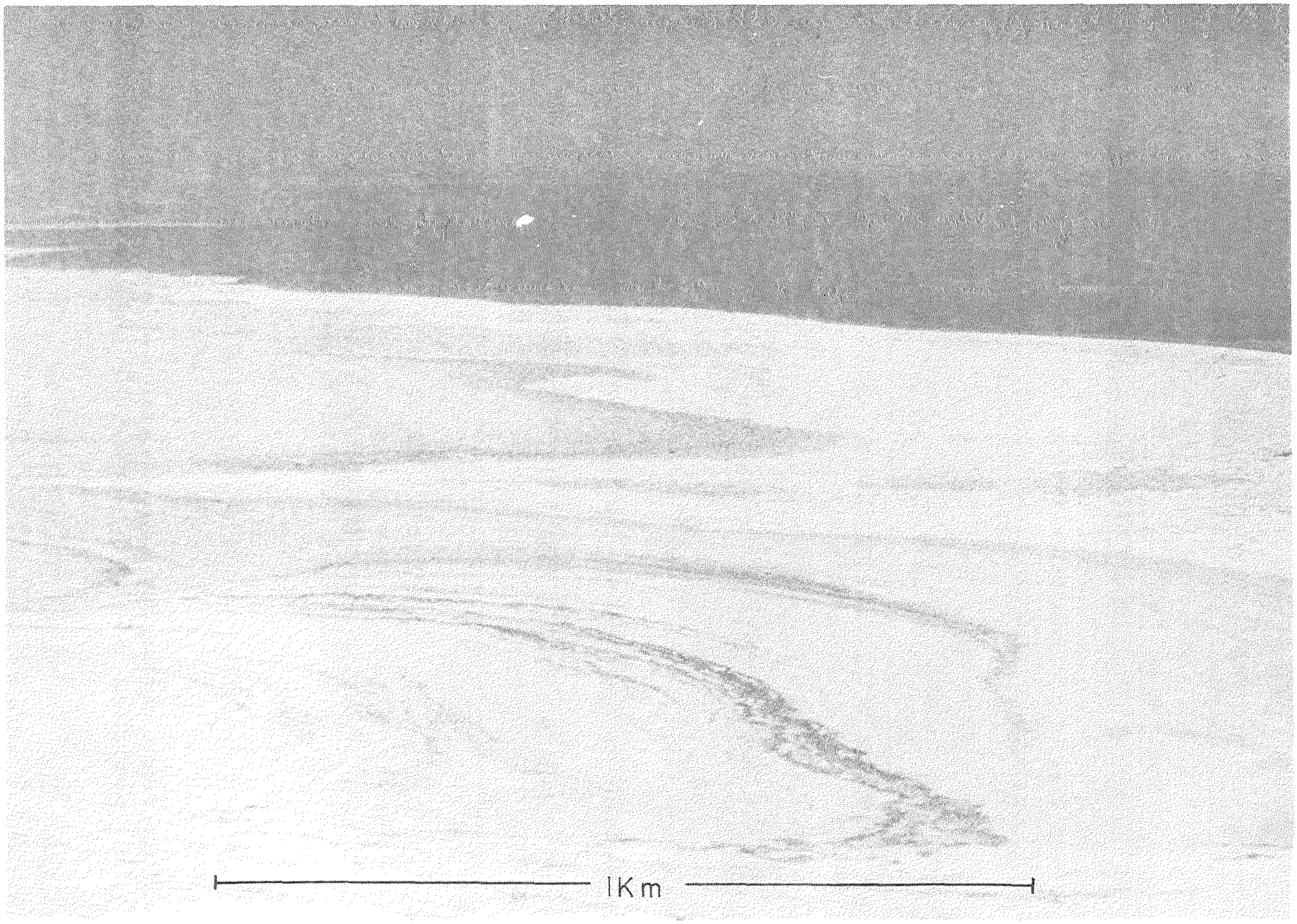


Figure 5. These dark features in the ice pack are 10 m to 30 m in width and several kilometers in length. The darker areas were chocolate brown in hue. Oil concentrations ranged from 50 ppm to 250 ppm in the darkest areas.

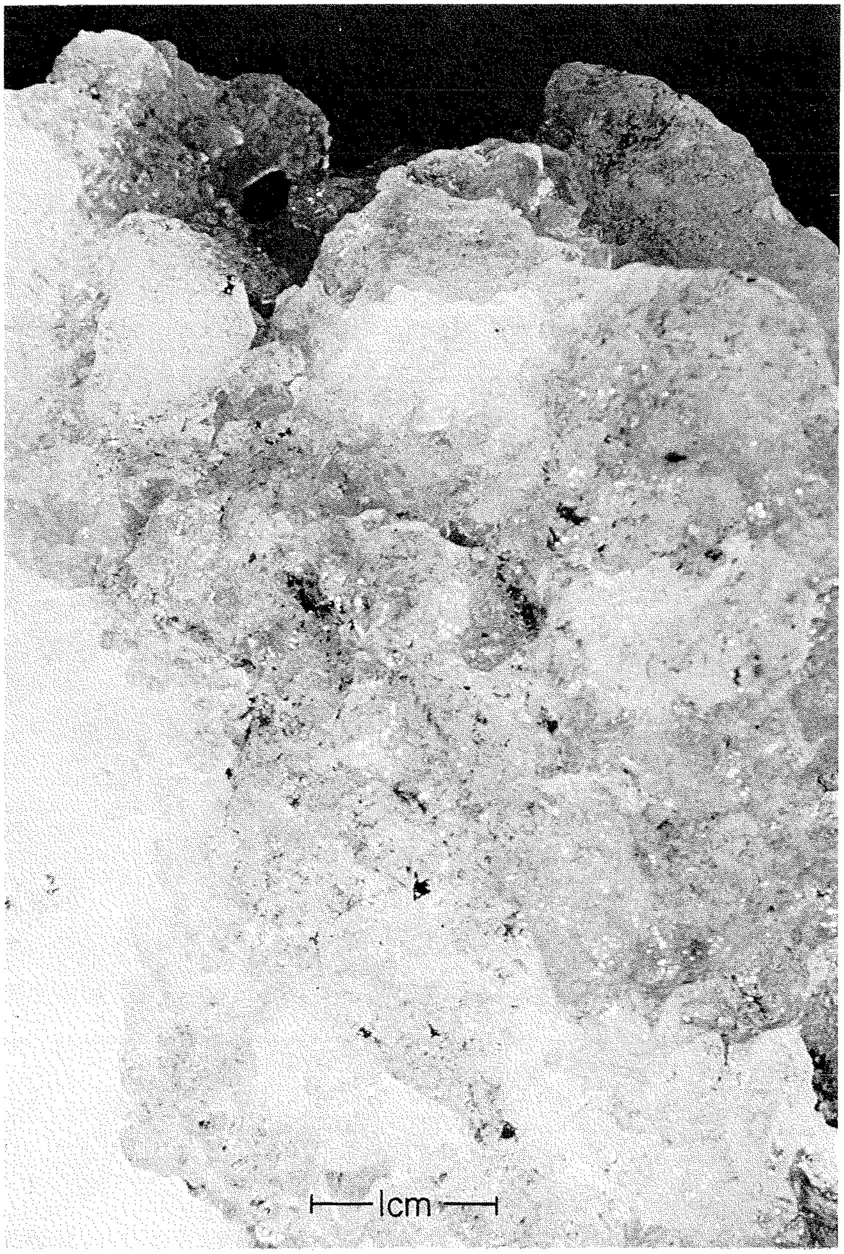


Figure 6. Ice rubble showing a typical dispersion of sub-millimetre size oil particles.

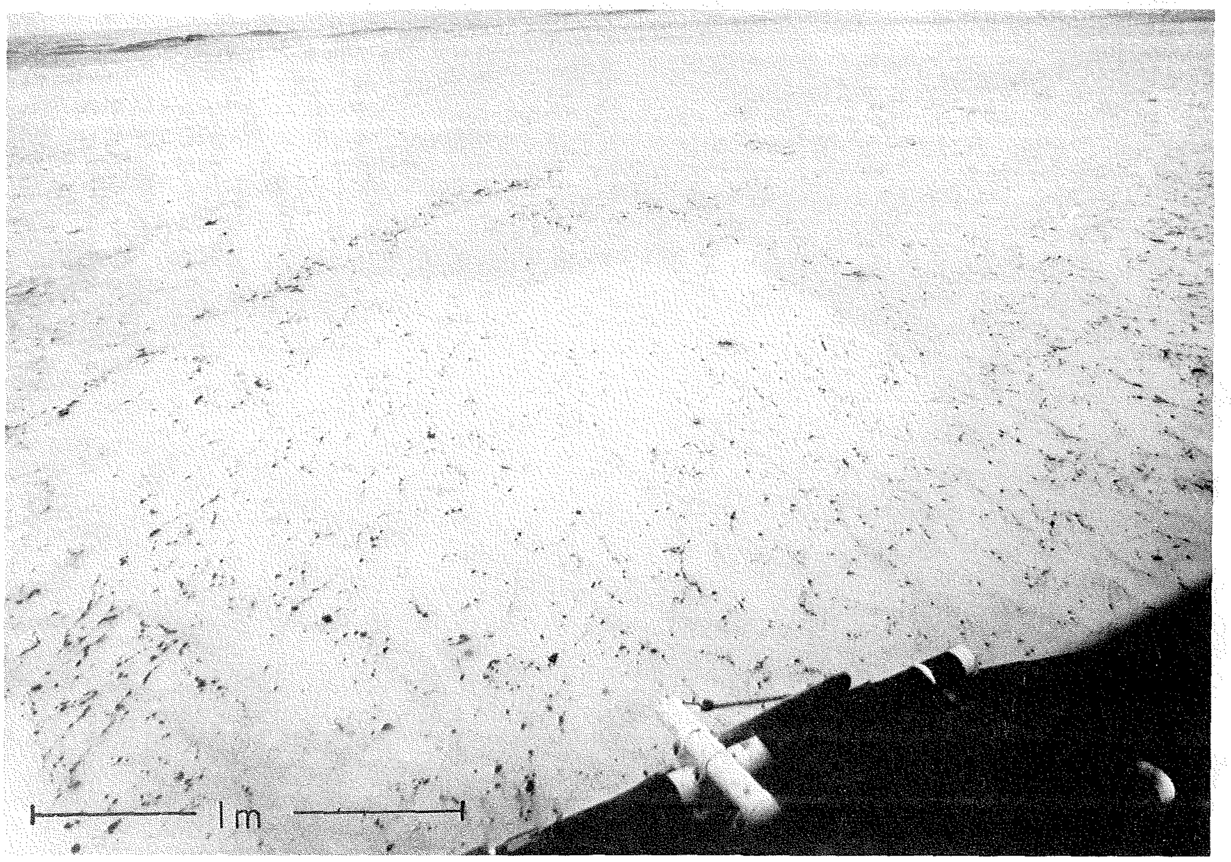


Figure 7. Blobs of oil from 1 cm to 5 cm in diameter appear in the photo as a superficial layer overlying grease ice and pulp.

Figure 8. A monochrome print of a false color infared photograph taken from 4800' ASL. The streak running from centre to right in the ice pack is a size gradation feature. The smaller crescent shaped features in the lower right hand corner were associated with organic material in the ice.

SESSION 2: WATER COLUMN OILING, OIL/SHORE INTERACTION AND EFFECTS ON BIOTA

Chairman: E.M. Reimer

C-CORE, Memorial University of Newfoundland

PETROLEUM RESIDUE CONCENTRATIONS IN SCOTIAN SHELF WATERS FOLLOWING THE KURDISTAN SPILL: PRELIMINARY RESULTS

E.M. Levy

Atlantic Oceanographic Laboratory
Bedford Institute of Oceanography
Dartmouth, Nova Scotia
Canada B2Y 4A2

INTRODUCTION

An intriguing aspect of the *Kurdistan* spill from an environmental point of view was the initial 'disappearance' of the spilled oil. Although several thousand tons were spilled, aerial surveillance of the area failed to locate more than a few small patches of floating oil and surface slicks - certainly nothing approaching even the lower estimate of the amount spilled - and little if any of the oil came ashore during the first few weeks following incident. While it is possible that the oil was somehow shielded from aerial detection by the pack ice or that it had drifted out of the area under surveillance, it is also reasonable to suppose that a portion of the spilled oil had been dispersed by wave action into the water column where it would be present in solution or as dispersed droplets. Both forms were observed during the 1970 *Arrow* incident when about two-thirds of its 17,000 ton cargo of Bunker C were spilled into Chedabucto Bay (Forrester, 1971; Levy, 1971). This report summarizes the preliminary results of cruises by CSS *Hudson* (March 24-26, 1979) and J.L. *Hartt* (May 3-13, 1979) to Cape Breton waters in order to determine the distribution of the oil on the sea surface and in the water column. (This program was subsequently extended over the entire Scotian Shelf, the results of which will be published later.)

SAMPLING AND ANALYTICAL METHODS

During both cruises the sampling program was based on procedures which have been employed by this laboratory in the past. Surface oil samples were collected with a neuston net (Levy and Walton, 1971), water from the surface microlayer with a screen sampler (Garrett, 1965), and samples from the water column with 5-L Niskin samplers.

Quantitative analysis of the surface oil samples was done gravimetrically and that of the surface microlayer and water column samples by fluorescence spectrophotometry (Levy, 1977). Since there was no doubt concerning the source of the oil in this instance, a sample from the *Kurdistan* was used as reference. However, a comparison of its fluorescence characteristics with those of the oil from the *Arrow*, which has been used as the reference material in previous studies of marine oil pollution by this laboratory (Levy, 1971, 1972, 1973, 1979; Levy and Walton, 1973), demonstrated that both oils yielded the same results and therefore the data are compatible with previous results.

CSS Hudson CRUISE (MARCH 24-26, 1979) (viz. Appendix A)

On March 22 oil-stained ice was reported along the south coast of Cape Breton (e.g., 45°40'N 60°13'W; 45°38'N 60°21'W). Accordingly *Hudson* was diverted to the area for a brief reconnaissance to obtain first-hand observations of the oil-in-ice phenomenon and to attempt to define the extent of the oil pollution and its drift.

The locations at which samples were collected during this cruise and the approximate position of the ice edge on March 24 and 25, 1979 are shown in Figure 1. The resulting data base comprised 17 surface microlayer, 82 water column and 14 floating particulate samples taken at 21 stations (Table 1).

Concentrations of dissolved/dispersed petroleum residues in the surface micro-layer ranged from 3 to over 1700 μg/l with most of the values less than 25 μg/l. Since only 14 samples were collected there were insufficient data to establish their frequency distribution. However, previous experience indicates that the data would be distributed log-normally; that is, the frequency distribution will be highly skewed with the majority of values falling in the low concentration range, with only few high values. This seems also to be the case here. Accordingly, the geometric mean of 26.3 μg/l (95% confidence range, 12.9-53.7 μg/l) provides a realistic measure of the level of petroleum residues in the surface microlayer at the time of sampling. Although pre-spill data for the background level in the surface microlayer in this particular area are not available, it would not be expected to exceed 10 μg/l on the basis of data collected in various unpolluted areas (Levy, 1979). Indeed, the 10 μg/l contour was present in the water amongst the pack ice (Fig. 2) which was present along the Cape Breton coastline at the time of sampling. Concentrations increased to the seaward of the ice-edge and a patch of heavy pollution was encountered in the vicinity of station 15. Further offshore the sea surface seemed to be less polluted.

Concentrations of dissolved/dispersed petroleum residues in the water-column were estimated on the basis of 82 water samples taken at standard oceanographic depths at 19 stations (Table 1). Concentrations ranged from 0 to 5 μg/l and had a geometric mean of 0.78 μg/l (95% confidence range 0.69-0.87 μg/l). T-tests demonstrated no significant difference between the geometric means of the concentrations of samples collected in the pack-ice (stations 1-9), at the ice-edge (stations 10-13), and in the areas of open water (stations 14-19). Therefore, it would seem that at the time of sampling there was not sufficient surface energy in the ice field or in the areas that had just become ice-free to result in a large amount of the oil being dispersed into the water column beneath the ice. By comparison these concentrations are very much lower than those observed at the entrance to Chedabucto Bay following the Arrow spill, when ice was not a major factor and where there was an abundance of surface energy (Levy, 1971, 1972).

Floating particulate petroleum concentrations, obtained from surface tows during the Hudson cruise, ranged from zero southwest of Chedabucto Bay and seaward of the ice edge to over 100 mg/m^2 at the ice edge (Fig. 3). By comparison, floating tar was almost never found in the region north of the Gulf Stream during a previous survey of the North Atlantic (Levy and Walton, 1973).

The distribution of the oil floating on the sea surface and the concentrations of dissolved/dispersed petroleum residues in the surface microlayer during late March off the southeast coast of Cape Breton Island can be accounted for by either (or a combination) of two possible mechanisms. Oil which had been spilled amongst the ice off northern Cape Breton Island during the break-up of the Kurdistan may have remained with the ice as the latter drifted southward along the coast and was eventually liberated in southeastern Cape Breton waters as the ice melted. In this case the oil would have been associated with a low-energy environment wherein the surface energy probably would be insufficient to result in high concentrations of oil in the water column. This is consistent with the low concentrations observed, and with the fact that concentrations in the water columns beneath the ice, at the ice edge and in the open water were pretty much the same. Alternatively, the oil was spilled into open water off northern Cape Breton Island and after drifting seaward was carried back to southeastern Cape Breton waters by a clockwise gyre. In this case, it is difficult to account for the oil observed floating on the seasurface and in the surface microlayer within the ice field unless it was somehow swept beneath the ice, and it is even more difficult to account for the observed distribution in the water column. In either case, the effects of wind and surface currents that resulted in the ice hugging the Cape Breton coast would have led to the observed association of the surface oil with the edge of the pack ice. On the basis of the available data, the former mechanism seems more plausible.

J.L. HARTT CRUISE (MAY 3-13, 1979) (viz. Appendix B)

The *Hudson* cruise demonstrated that oil was present in the Cape Breton region as the ice retreated and that shoreline fouling and other environmental impacts could be anticipated. Indeed, by late April extensive fouling of some of the Cape Breton beaches had occurred and tainting of lobsters was reported. At the request of Fisheries Management (Department of Fisheries and Oceans) a survey was carried out to determine the severity of the pollution in the nearshore areas of eastern Nova Scotia and Cape Breton Island.

During the *J.L. Hartt* cruise sampling was carried out on 10 lines of stations extending from as close to shore as it was possible to go with the vessel to the 50-fathom contour offshore (Fig. 4); that is, most of the area involved in the inshore fishery was studied. Oil was found at all but one of the stations sampled along the Nova Scotia coast. During the first phase of the cruise, the oil was present as small particles, lumps of golf ball size, and "paddies" of up to dinner-plate size. At one station two pints of oil were collected, and at all stations it was necessary to wash the net each time to remove the adhering oil. At some stations an estimated several thousand lumps of match-head size were collected.

During the second phase, following two periods of strong offshore winds, the oil was present in much smaller quantities in the nearshore areas of Cape Breton. Either the offshore winds had moved most of the oil seaward out of the sampling area or much of the oil had been transported by currents out of the Cape Breton regions entirely by this time. At one station a tennis-ball sized lump of oil with grains of sand embedded in it was collected. Presumably this particular piece of oil had spent some time on a beach and then moved back to sea under the influence of the offshore winds. A total of 239 water samples and 53 surface tows were collected. Analytical data were not available in time for presentation at this workshop.

CONCLUSIONS

Preliminary results of cruises from Hudson and J.L. Hartt demonstrated that the nearshore waters of eastern Nova Scotia and Cape Breton Island were polluted, in many areas heavily, by oil released during the breakup of the tanker Kurdistan. The impact of the spill was not evident until several weeks after it occurred because of the barrier afforded by the ice. However, with the retreat of the ice from eastern Cape Breton coastal waters the oil was released and a cursory study from Hudson demonstrated the presence of higher-than-background concentrations of floating particulate petroleum residues and of dissolved/dispersed petroleum residues in the sea-surface microlayer. Presumably because of the lack of mixing energy within the ice field, the oil had not penetrated into the water column beneath the ice or near the ice edge.

As the ice barrier retreated, extensive shoreline fouling occurred along eastern Cape Breton and concern over the potential impact of the oil on the inshore fishery led to a survey of oil concentrations in the waters of eastern Nova Scotia andCape Breton Island. The analytical results were not available in time for presentation at the workshop.

BIBLIOGRAPHY

FORRESTER, W.D. 1971. Distribution of suspended oil particles following the grounding of the tanker Arrow. J. Mar. Res., 29, 151-170.

GARRETT, W.D. 1965. Collection of slick-forming materials from the sea surface. Limnol. Oceanogr. 10, 602-605.

LEVY, E.M. 1971. The presence of petroleum residues off the East Coast of Nova Scotia, in the Gulf of St. Lawrence and the St. Lawrence River. Water Res., 5, 723-733.

LEVY, E.M. 1972. Evidence for the recovery of the waters off the East Coast of Nova Scotia from the effects of a major oil spill. Water, Air, Soil Pollut. 1, 144-148.

LEVY, E.M. 1977. Fluorescence spectrophotometry: principles and practice as related to the determination of dissolved/dispersed petroleum residues in sea water. BIO Report Series/BI-R-77-7, July 1977.

LEVY, E.M. and A. WALTON. 1973. Dispersed and particulate petroleum residues in the Gulf of St. Lawrence. J. Fish. Res. Board Can., 30, 261-267.

LEVY, E.M. and A. WALTON. 1976. High seas oil pollution: particulate petroleum residues in the North Atlantic. J. Fish. Res. Board Can., 33, 2781-2791.

TRITES, R.W. 1980. Preliminary observations from CSS Hudson. In: The Kurdistan Oil Spill, March 15/16, 1979. Activities and observations of the Bedford Institute of Oceanography scientific response team. (Vandermeulen, J.H. and D.E. Buckley, eds.) Bedford Institute of Oceanography report Series, BI-R-80-2.

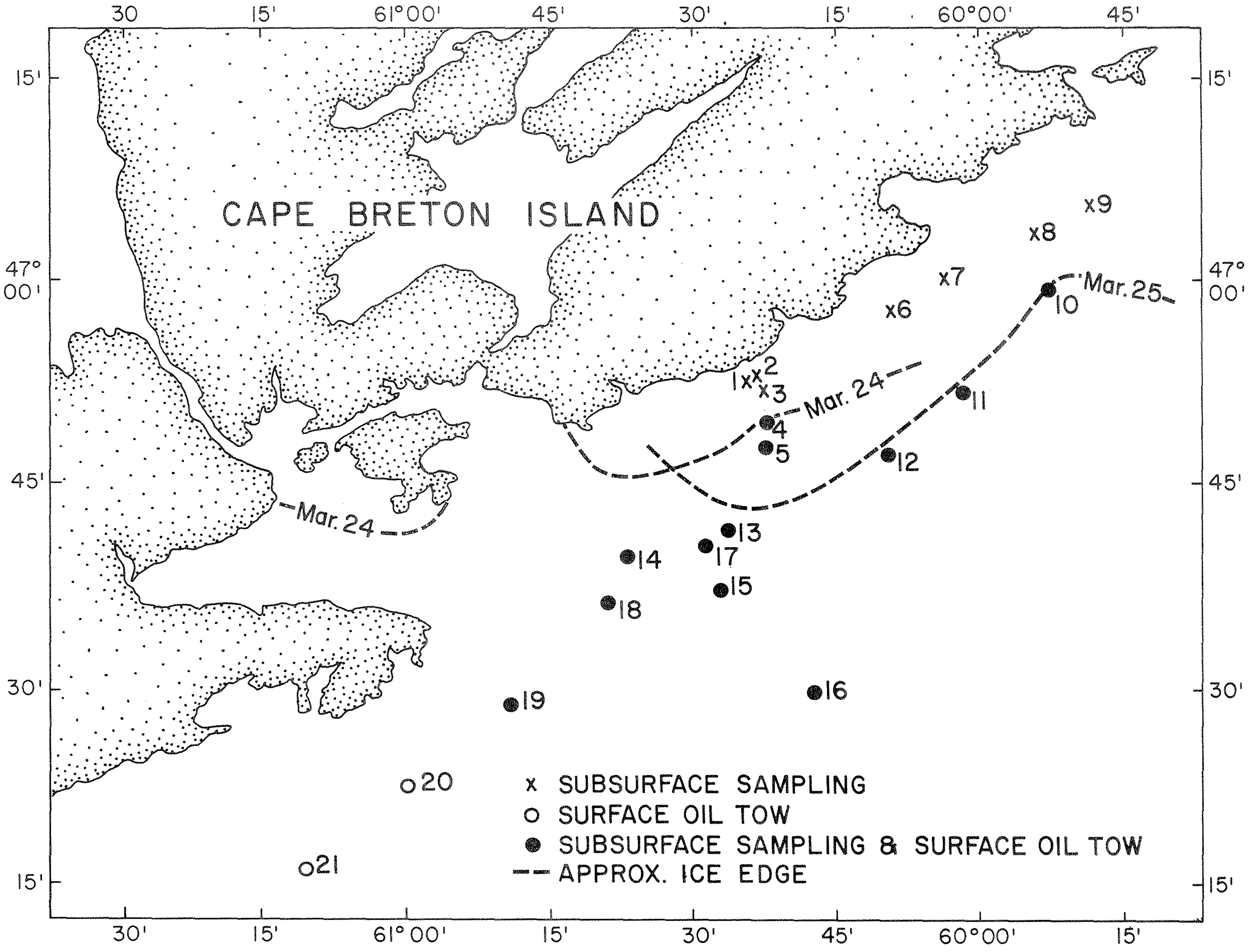


Figure 1. Location of sampling stations, and ship drift sites during period 23 to 26 March 1979. (Cruise 79-001-C, Trites, 1980).

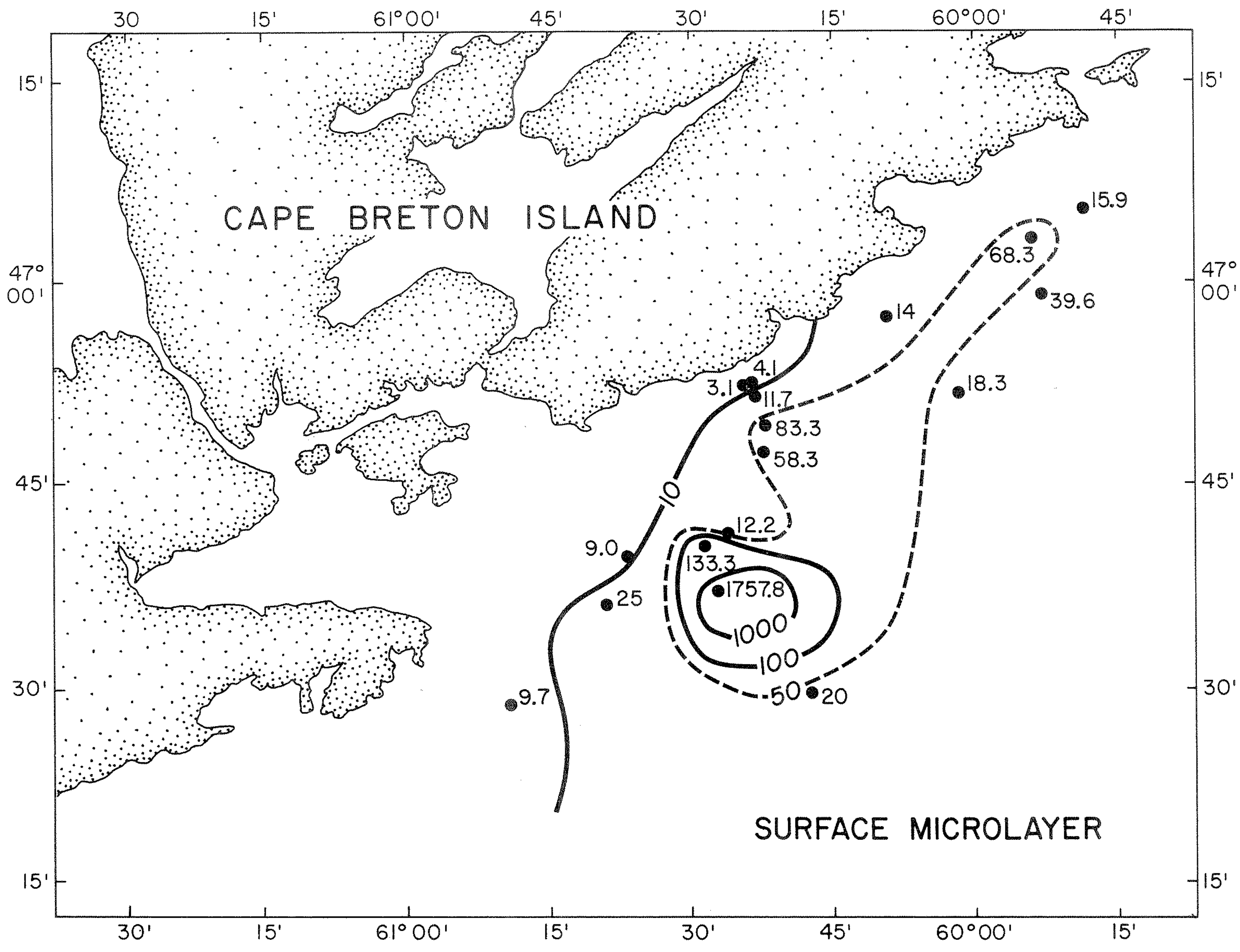


Figure 2. Petroleum hydrocarbon concentrations in surface micro-layer samples from off-shore Cape Breton, March 23 to 26, 1979.

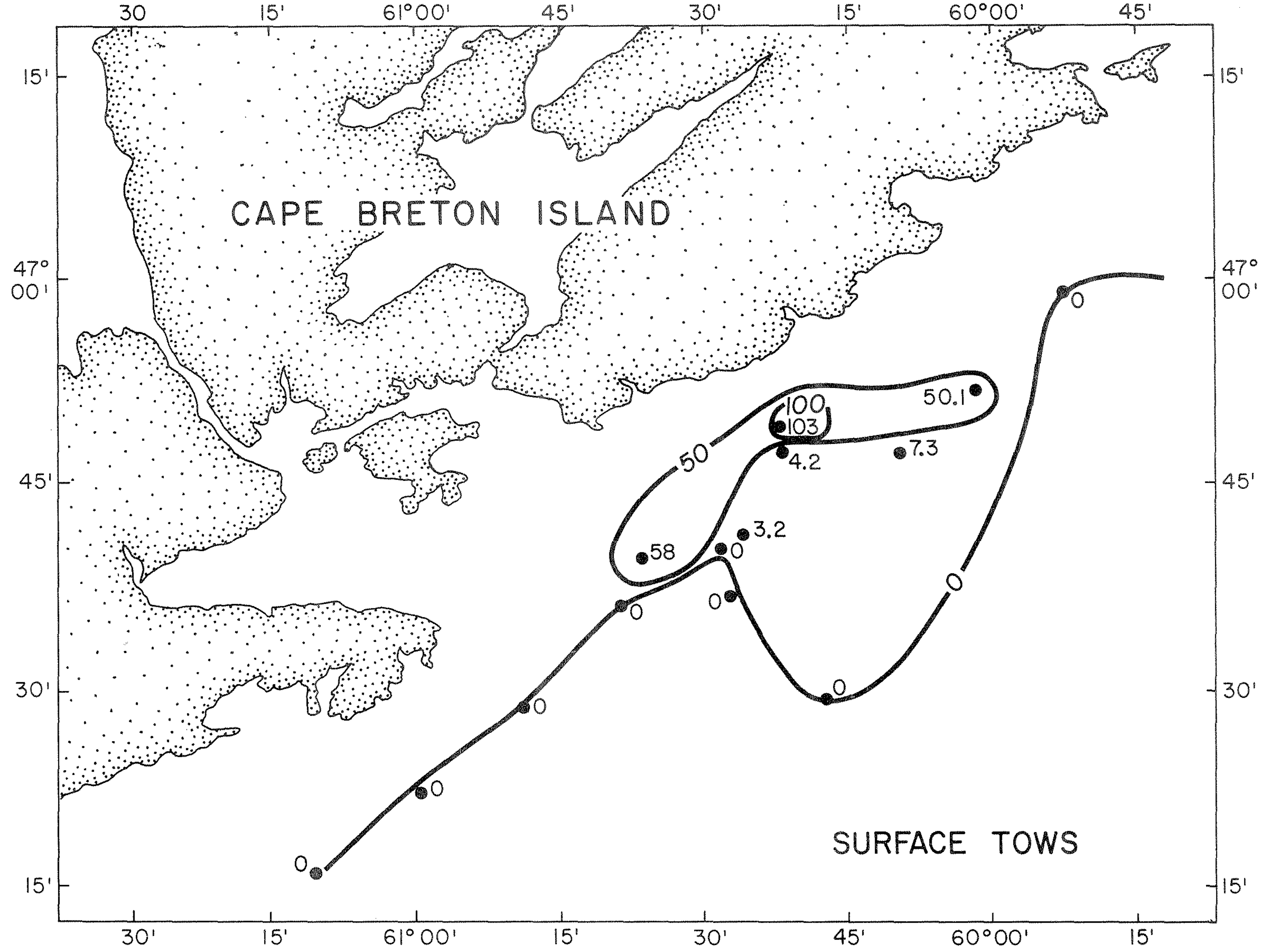


Figure 3. Floating particulate petroleum concentrations from surface tows, CSS *Hudson* cruise March 23 to 26, 1979.

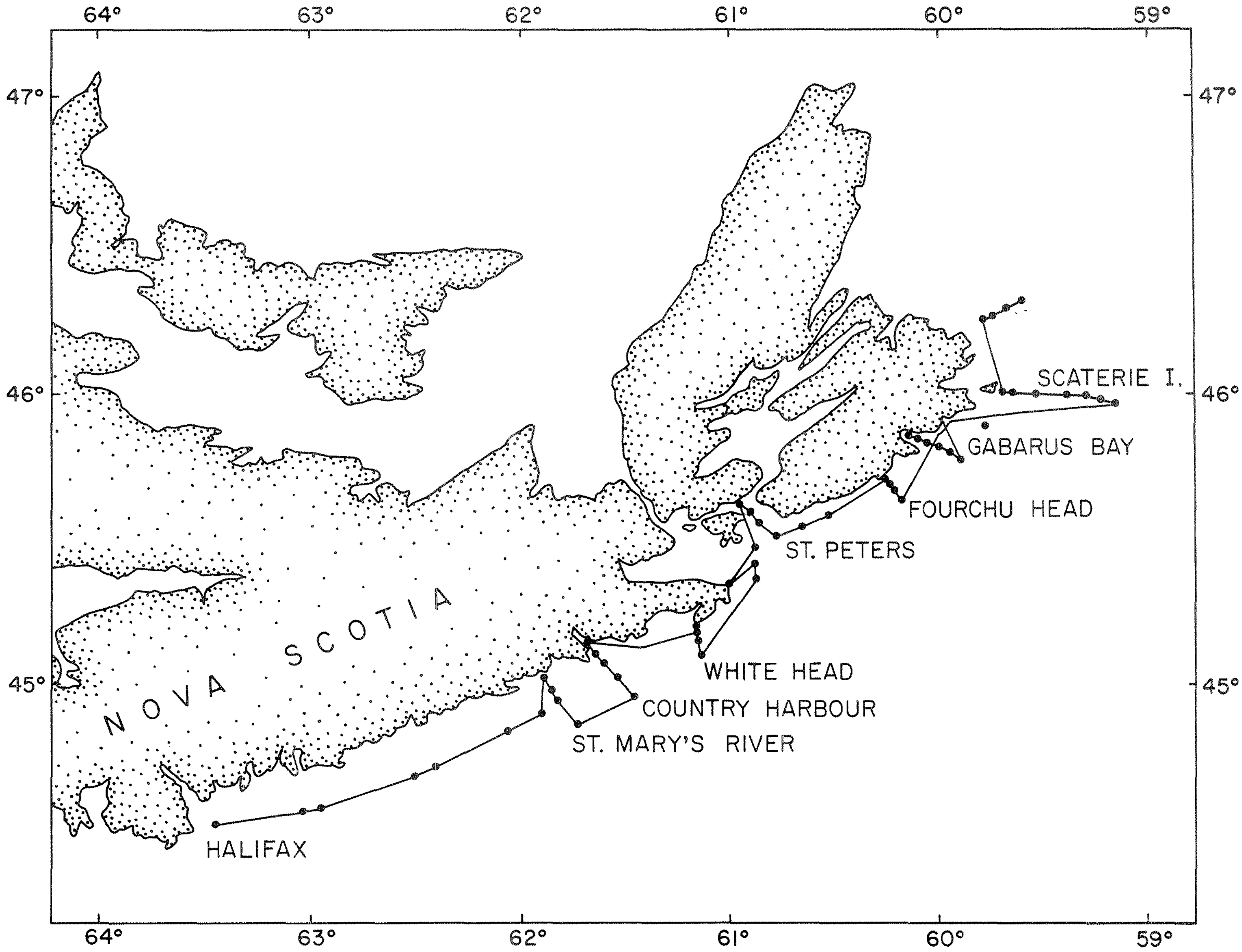


Figure 4. Sampling cruise track of J.L. Hartt, May 3-13, 1979.

TABLE 1

Concentrations of Oil Observed in Cape Breton Waters during *Hudson* Cruise

Station	Surface Microlayer (µg/l)	Floating Particulates (mg/m^2)	Water Depth (m)	Column Concentration (µg/l)
1	3.05	Ice	1	1.0
			10	1.05
			20	1.0
2	4.10	Ice	1	0.90
			10	0.40
			20	0.80
3	17.7	Ice	1	1.00
			10	0.95
			20	0.90
4	83.3	102.7	1	0.85
			10	1.05
			20	1.00
			50	0.65
			70	1.45
			100	0.70
5	58.3	4.2	1	0.75
			10	0.90
			20	0.65
6	14.0	Ice	1	0.20
			10	0.60
			20	0.70
7	-	Ice	1	1.05
			10	0.80
			30	0.75
8	68.3	Ice	1	1.05
			20	0.50
			50	0.70
9	15.9	Ice	1	0.70
			20	0.75
			50	0.55

TABLE 1 (Continued)

Station	Surface Microlayer (μg/l)	Floating Particulates (mg/m^2)	Water Depth (m)	Column Concentration (μg/l)
10	39.6	0.0	1	0.20
			20	0.60
			40	0.60
			50	0.60
			60	0.30
			90	1.00
11	18.3	50.1	1	0.55
			20	0.65
			30	1.00
			50	0.65
			75	0.75
			100	0.95
12	-	7.3	1	1.10
			15	0.15
			30	0.60
13	12.2	3.2	1	0.60
			10	0.00
			20	1.20
			30	-
			50	0.90
			100	0.60
14	7.95	58.0	1	0.50
			20	0.15
			30	0.15
			50	0.70
			75	0.80
			100	1.05
15	1757.8	0.0	1	0.90
			10	0.75
			20	0.65
			50	0.90
			100	0.70
16	20.0	0.0	1	1.05
			10	1.85
			20	0.95
			30	0.85
			50	0.95
			100	0.90

TABLE 1 (Continued)

Station	Surface Microlayer ($\mu g/l$)	Floating Particulates (mg/m^2)	Water Depth (m)	Column Concentration ($\mu g/l$)
17	133.3	0.0	1	0.60
			20	0.80
			30	1.00
			50	1.50
			75	1.75
			100	0.95
18	25.0	0.0	1	1.00
			20	5.00
			50	1.90
19	9.66	0.0	1	0.88
			10	0.90
			20	0.80
			30	1.50
			50	1.00
			100	1.45
20	-	0.0	-	-
21	-	0.0	-	-

APPENDIX A

The following is an extract from CSS Hudson cruise report, March 23 to 26, 1979 (Trites, 1980):

23 March 2000Z: A piece of ice with oil on it (approximately 1' x 4' x 1') was observed at 45°35.38N. A sample of oil was placed in a Mason jar (#3) and a 5 to 10 lb portion placed in a garbage bag. A surface water sample (#1) and an ice-sediment sample (#2) were taken from the same site.

2230: Trites joined ship. Earlier in the day Trites observed slick from helicopter near Pt. Michaud. Ship proceeded to this area.

24 March 1230Z: 1330Z: Nine samples consisting of oil 'plops', ice-oil mixtures, blocks of ice, ice-sediment mixtures and one sample that might have been ice algae were collected from lifeboat (45°35.8'N, 60°26.2'W). Ice cover (10/10) consisted of a spectrum of sizes including slush, brack, blocks, etc. Largest pans about 20 to 25 m in diameter. Thickness varied but mostly 0.5 to 1 m.

1430Z: Proceeded towards Ile St. Esprit along oil streak. Width about 100 m, length about 5 km. Northwest end of streak 45°36.5'N, 60°28.8'W.
1915Z: Chemistry team joined ship.
2130Z: Station 1, in ice-oil stain.
2213Z: Station 2, in ice-oil stain.
2244Z: Station 3, in ice.
2332Z: Station 4, in open water at edge of ice.

25 March 0038Z: Station 5, in open water.
0200-0745Z: Ship drifting with ice.
0805-0950Z: Ship drifting with ice.

APPENDIX A (continued)

25 March 1052Z:

26 March 1052Z: Stations 6 to 21.
2020Z: Arrived at BIO.

APPENDIX B

The following was extracted from the J.L. Hartt cruise report by D. Conrad and J. Moffatt:

Phase 1: (Halifax-Canso)

Station 1 - 25 miles east of Halifax. The surface tow contained small particles of oil.

Station 2 - 4 miles from land. Several hundred tar lumps in tow. Sticky tar on net.

Station 3 - Off Liscomb, N.S. Estimate about 1000 to 1500 tar particles in tow. Net was washed with varsol.

Stations 4-8 - comprised a 13 mile section off the St. Mary's River, N.S. to the 50 fathom edge.

Station 4 - about 1/4 mile offshore, contained about 50 small oil particles in the surface tow.

Station 5 - about 75 small oil particles in the tow.

Station 6 - The surface tow's net was covered with sticky oil to about 15 inches from the end. Floating tar was sighted.

Station 7 - The surface tow contained lumps of oil about the size of peas.

Station 8 - Hundreds of small particles of oil in tow. Lumps of oil about 1 to 5 cm diameter were sighted between Stations 7 and 8.

Stations 9-13 - comprised a 15 mile section off Country Harbour, Guysborough county to the 50 fathom edge.

Station 9 - 50 fathom edge. Hundreds of tiny oil particles in net. Tar lumps as large as fifty cent pieces were sighted.

Station 10 and 11 - Lots of small particles of oil in the tow. No visual observations.

Station 12 - a few small oil particles in tow.

Station 13 - about 60 metres offshore about 50 small particles in tow. A few small particles sighted while on station.

Stations 14-17 - included a 6 mile section off White Head Island.

Stations 14 and 15 - thousands of tiny oil particles in the tow but no visual sightings.

Station 16 - larger lumps of oil collected about 0.5 to 1.5 cm.

APPENDIX B (continued)

Station 17 - 50 fathom edge. Two mason jars filled with oil from tow. Lots of tar balls sighted. Steaming towards Station 18 in Chedabucto Bay hundreds of tar lumps were sighted for about 5 miles, ranging from golf ball size to dinner plate. The weather was foggy.

Station 18 - Chedabucto Bay. Observed floating tar. Some oil in surface tow.

Station 19 - No oil sighted. Only small particles collected in oil tow.

Note: All oil collected by the surface tow was sticky and adhered to the net. Between each station the net was washed with varsol. The amount of oil varied from a few particles (approx. 0.1 g) to over 200 g.

Phase II (Canso - Flint Island - Halifax)

Adverse weather conditions (NW winds of 40-50 kts gusting to 60) on May 6, 7 and 8 kept the ship tied up in Canso, N.S. On May 9 the ship left port and proceeded to Station 20.

Station 20 - Chedabucto Bay. Very little oil was collected here in the surface tow and no oil was sighted.

Stations 21-24 - comprised an 11 mile section between Isle Madame and St. Peter's Island. All neuston tows had tiny oil particles but in small quantity. No visual sightings of oil were made.

Stations 25 and 26 - located about 3 miles off Cape Breton between Michaud and Kempt Points. Both surface tows contained oil but in small amounts. Again no oil was sighted while steaming or on station.

Stations 27-30 - comprised a 6 mile section from Forchu Head to the 50 fathom edge. All surface tows contained oil particles. No large amounts were collected nor were there any visual signs of oil on the surface.

Stations 31-36 - comprised a 12 mile section from Gabarus Bay to the 50 fathom edge. Small amounts of oil were collected in the surface tow. While on station 32 two tar lumps about the size of a tennis ball were sighted. One lump was picked up using a bucket. Particles of sand were noticed adhered to the tar. Strong winds from the NW with gusts to 60 kts forced the ship to stay in Louisbourg on May 11.

APPENDIX B (continued)

Stations 39-43 - comprised a 24 mile section off Scatarie Island to the 50 fathom edge. Small amounts of oil were collected in the tows consisting mainly of fine oil particles. No sightings of oil were made.
Stations 44-47 - comprised a 10 mile section off Flint Island to the 50 fathom edge. Again only small quantities of small oil particles were collected. Station 44 did have one weathered lump about 20 mm long. No visual sightings of oil.
Stations 48-53 - were surface tows only, taken every 25 miles on the return trip to Halifax. These stations were about 4 miles from land. All tows had small amounts of oil except Station 53 which collected no oil. No visual signs of oil were made on the return to Halifax.

Note: Most oil particles were tiny irregular shaped lumps less than 2 mm diameter and were soft to the touch. The majority of the surface tows were estimated to contain less than 1 gram of oil. No visual observations of slicks were reported except the two tar lumps sighted on Station 32. Further, there was no visual evidence of oil in the water column or in the CCl_4 extracts.

PHYSICAL WEATHERING OF *KURDISTAN* OIL: DROPLET FORMATION AND EFFECT ON SHORE-ICE MELTING

J.H. Vandermeulen, B. Amero and T.P. Ahern

Marine Ecology Laboratory
Bedford Institute of Oceanography
Dartmouth, Nova Scotia
Canada B2Y 4A2

INTRODUCTION

Much of the *Kurdistan* oil that came ashore on Cape Breton Island came in, not as fluid oil or as 'chocolate mousse', but as blobs and smaller balls and particles, much of this smaller than twenty centimeters in diameter. At the time much of the Cape Breton coastline was covered with shore-ice, and during our visit to the area we noticed that such oiled ice-cover had a roughened or pitted surface different from that of non-oiled ice.

In this report we present preliminary observations on this phenomenon, including some observations on particle size distribution and on the melting effect of particulate oil on shore-ice.

MATERIALS AND METHODS

Oil, water and ice samples were collected by helicopter on March 28, 1979, thirteen days after the tanker break-up. The samples were collected mainly from St. Esprit Island and from Pt. Michaud. They were stored in an ice-chest aboard the aircraft, and were transported back to the Bedford Institute of Oceanography in Dartmouth for subsequent analysis. Samples of *Kurdistan* cargo oil taken from the deck near the ruptured #3 wing-tanks or directly from the #5 tank served as standards for comparison.

A number of methods have been used to determine particle size of oil in water (Cornillon, 1978). In the end we settled on two methods - direct observation by compound microscope, or indirect observation by projecting an image of the sample contained in a glass dish onto a screen by means of an over-head transparency projector. All particle counts were done in a refrigerated walk-in coldroom (ca. 5°C). Water samples were examined directly. For ice samples a known volume was allowed to thaw in a shallowplastic petri dish. Prior experimentation had shown that under these conditions the oil particles or droplets did not coalesce, but remained apart and distinct, and could be readily counted and measured.

Oil concentrations in the various samples were determined by UV spectrofluorimetry using the method of Gordon and Keizer (1974).

OBSERVATIONS

At the time of the sampling trip patches and strips of floe-ice lay along most of the eastern coast of Cape Breton Island, down to and around Point Michaud at the entrance to Chedabucto Bay. Blobs of oil, ca. 30 to 60 centimeters in diameter, lay on the upper surface of some of the ice-floes. As well the edge of ice-floes frequently were stained a faint brown coloring with smears of oil or smaller oil blobs.

Closer examination of inshore surface water showed the presence of numerous small particles (Fig. 1 and 2). These appeared to be largely oil particles, distinguishable from other suspended matter both by their shape and by their tendency to stick to the walls of sampling vessels. The numbers of these particles increased the closer one sampled near the shore.

Onshore the surface of the shore-ice was contaminated generally with a fine cover or spray of oil blobs and droplets, ranging in size from hand-sized smears and spatters (Fig. 3) down to micro-particulate droplets or nodules a millimeter or less in diameter (Fig. 4). This oiling appeared to be restricted to the ice surface only, and was not found deeper within the one-half to two meter thick ice crust.

Morphologically there were three types or categories of oil contamination - the larger smears and blobs, the numerous fine droplets or particles, and a third group of "cratered" oily deposits (Fig. 5). The latter were almost invariably found within pits or depressions of varying depth, and were often surrounded by or consisted of a fine-veined network of oil particles spreading out over the ice surface (Fig. 7). In some cases these pits had penetrated through the ice (Fig. 8).

Particle size distribution of the fine particulate oil is shown in Table 1. Although there are a large number of particles in the range 1 to

TABLE 1

Particle Size Distribution for Particulate Matter Extracted from Stranded Shore-ice

Mean particle diameter (μm)	Numbers/Litre	ppm (μl/l)
>1871	171.5	-
1871	514.6	1.8×10^3
1493	1,372.2	2.4×10^3
1128	6,861.1	5.2×10^3
892	2,058.3	0.8×10^3
691	15,094.3	2.6×10^3
489	107,375.6	6.6×10^3
<489	1,411,835.3	-

TABLE 2

Hydrocarbon Concentrations in Inshore Surface Seawater and in Stranded Shore-ice

	Hydrocarbon Concentrations (μg/ml)	
un-oiled floe-ice[3]	0.307[1]	0.331[2]
seawater	908.23	812.98
shore-ice sample	2,145.45	2,304.00

[1] Referenced to #5 tank oil sample; [2] referenced to #3 wing-tank; [3] one-litre sample;

2 mm diameter, the bulk of the particulate content of these samples consisted of particles smaller than 0.9 mm in diameter. The largest portion consisted of particles smaller than 0.5 mm diameter. It should be noted here that no attempt was made to differentiate between normal suspended organic particulate matter and particulate oil.

A separate calculation of the total volume of micro-particulate matter in these shore-ice surface samples (based on table 1) showed a concentration of 2.882 grams per litre of ice. This figure is in close agreement with the total hydrocarbon concentration of 2.15 grams per litre determined by chemical analytical means (Table 2).

DISCUSSION

The phenomenon of particle formation of spilled oil at sea is not a new one. Forrester (1971) reported on Bunker C oil particles distributed throughout the water column as a result of the Arrow tanker spill in Chedabucto Bay, Nova Scotia. Particles of that oil were subsequently reported several hundred kilometers from the tanker accident, offshore from Halifax city. The range of particle sizes was similar to the size range observed during the Kurdistan, 5 microns to 1 or 2 mm. Forrester concluded that the particles were formed mainly by wave and surf action, with a negligible role played by ice. While the initial particle observations following the Arrow disaster were made within one week of the incident, oil particles were continually noted up to one month following the spill.

The present observations on oil particles following the Kurdistan are essentially similar to Forrester's, differing only in that much larger numbers of particles were observed in the oiled shore-ice, due probably to the concentration effect of the shoreline with regard to inshore suspended material. This effect was pointed out as well by Forrester.

As for the question of how these various particles were formed, there is the possibility that the presence of the ice at or near the site of the Kurdistan had something to do with this. Presumably an oil slick, through the shearing-grinding action of ice-floes, can be broken up into smaller and smaller blobs and particles. But it is still uncertain whether in fact the Kurdistan's spilled oil was contained within ice or if it escaped entrapment by the ice-field (viz. Trites et al., this volume).

Certainly the weather conditions and sea-state at the time of the tanker break-up and for the two or three weeks following were violent enough that much of the particle and droplet formation can be accounted for just on the basis of wave action and water-column turbulence. Droplets can also be formed onshore by spattering of oil blobs onto ice or rock surfaces (Fig. 3).

While there was no attempt made to differentiate between normal suspended material and oil particles in the analysis there is little doubt in our minds that the bulk of the particles were in fact oil. Firstly there is the close agreement between the total volume of particulate matter (2.882 grams per litre of ice) and the total volume of hydrocarbons (2.15 grams per litre of ice), there being a circa 25% difference. Also the particle range, both with respect to size and numbers, was far greater than found normally in similar nearby waters (Strait of Canso, Nova Scotia, Kranck, personal communication).

A rather surprising aspect of this shoreline oiling by particulate oil is the unexpectedly large amount of oil that is represented by what, at first glance, appears to be a very fine cover of spray. If we assume that the oiled, shore-ice sample in Table 2 represents one square decimeter of ice surface then a beach 10 m wide and 1 km long can accommodate 2,250 kgms of stranded oil in particulate form. This figure is at best a near guess of course, but it nonetheless serves to illustrate the amount of oil contamination that can occur due to particulate oil only. This also highlights the very significant role of droplet or particle formation and potential contamination from this source during a spill.

The other more curious aspect of such particulate oil is the potential role such stranded oil may play in the melting rate of stranded ice. Most of the oiled shorelines examined had a heavily eroded pitted ice surface differing markedly from the smoother ice surfaces of non-oiled beaches. Probably this is a case of the oil particles and lumps acting as dark-bodies or heat-sinks for solar radiation, this in turn accelerating the melting rate of the underlying ice surface. This was observed out at sea as well, where large flattened blobs or discs of oil lying on floe surfaces were floating in a water-filled crater in the floe-surface. Occasionally one sees the same thing occurring under a piece of kelp or a sea-urchin skeleton, where with time the material becomes embedded within the ice as it melts the ice underneath by reradiating absorbed solar heat.

There is one difference, however, between the melting effect of an oil droplet and that of a sea-urchin test, and that is the spreading effect of the oil droplet as it warms up under the sun. As the droplet spreads, its diameter increases and concommittantly its net heat gain (absorptivity minus emissivity) available for ice melt also increases. Therefore each of the oil droplets or particles act not as single point sources of constant area, but have to be treated as expanding black bodies with an area increasing as a function of time. This phenomenon is best illustrated by Figures 7 and 8, in which the network of oil 'veins' probably represents the greatest extent of oil droplet spreading before breaking up into smaller droplets. Taking this process one step further, it seems likely that some of these 'veins' will in time coalesce in turn, and again give rise to smaller droplets and particles (viz. Fig. 7). Thus this as well is a part of the microparticularization of spilled oil.

SUMMARY

1. Observations of inshore surface waters and of shore-ice stranded on St. Esprit Island, Cape Breton Island, showed the presence of numerous oil blobs and particles.
2. Particle size range varied from ca. one or two decimeter in length, down to numerous particles smaller than one centimeter in diameter. By far the largest proportion of oil particles was in the size range 500 microns and smaller.
3. The contamination by oil of the shore-ice enhanced the melt-rate of this shore-ice, through the heat gain of the oil droplets acting as black bodies. This effect was further enhanced by the spreading of the oil blobs during heat gain, thereby increasing the effective melting diameter of the oil drops.

ACKNOWLEDGEMENT

We acknowledge the assistance of Mr. G. Donaldson of the Canadian Coast Guard in collecting of field samples and cargo samples from the wreck of the Kurdistan. We also appreciate very much the discussions on ice melt with D. Jenkins of D. Jenkins and Associates, Dartmouth, N.S.

BIBIOLGRAPHY

CORNILLON, P. 1978. Oil droplet measurements made in the wake of the Argo Merchant. In In the Wake of the Argo Merchant. Proceedings of a Symposium Held January 11 to 13, 1978. Center for Ocean Management Studies, Univ. of Rhode Island pp. 43-47.

FORRESTER, W.D. 1971. Distribution of suspended oil particles following the grounding of the tanker Arrow. J. Mar. Res. 29 (2): 151-170.

GORDON, D.C. Jr. and P.D. KEIZER. 1974. Estimation of petroleum hydrocarbons in seawater by fluorescence spectroscopy: improved sampling and analytical methods. Fish. Mar. Serv. Res. Dev. Tech. Rep. 481: 24 pp.

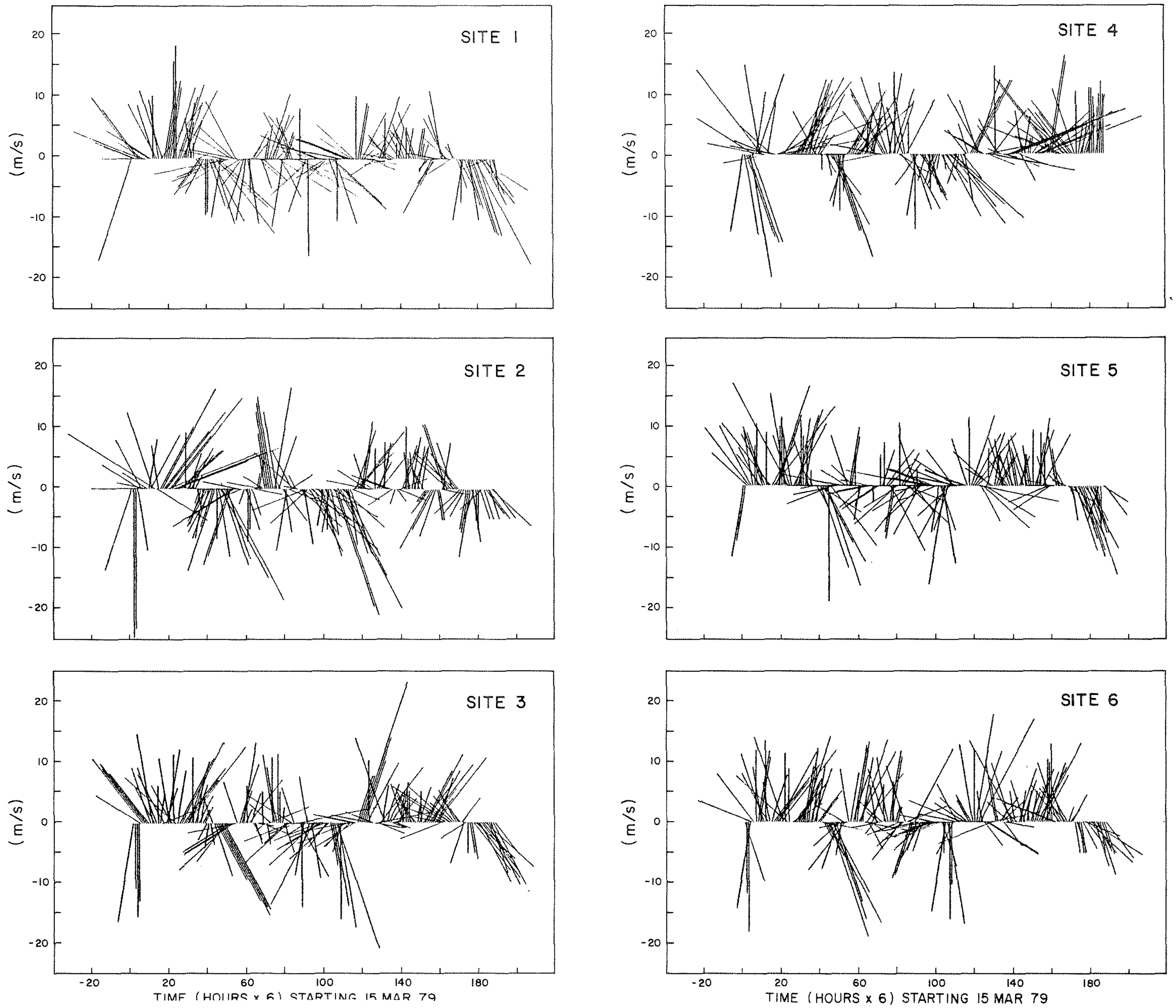


Figure 1. Water samples of inshore surface water (ca. 10 m from shore) near St. Esprit Island, Cape Breton Island showing particulate oil contamination.

Figure 2. Contaminated ice-lead near St. Esprit Island, Cape Breton Island containing particulate oil.

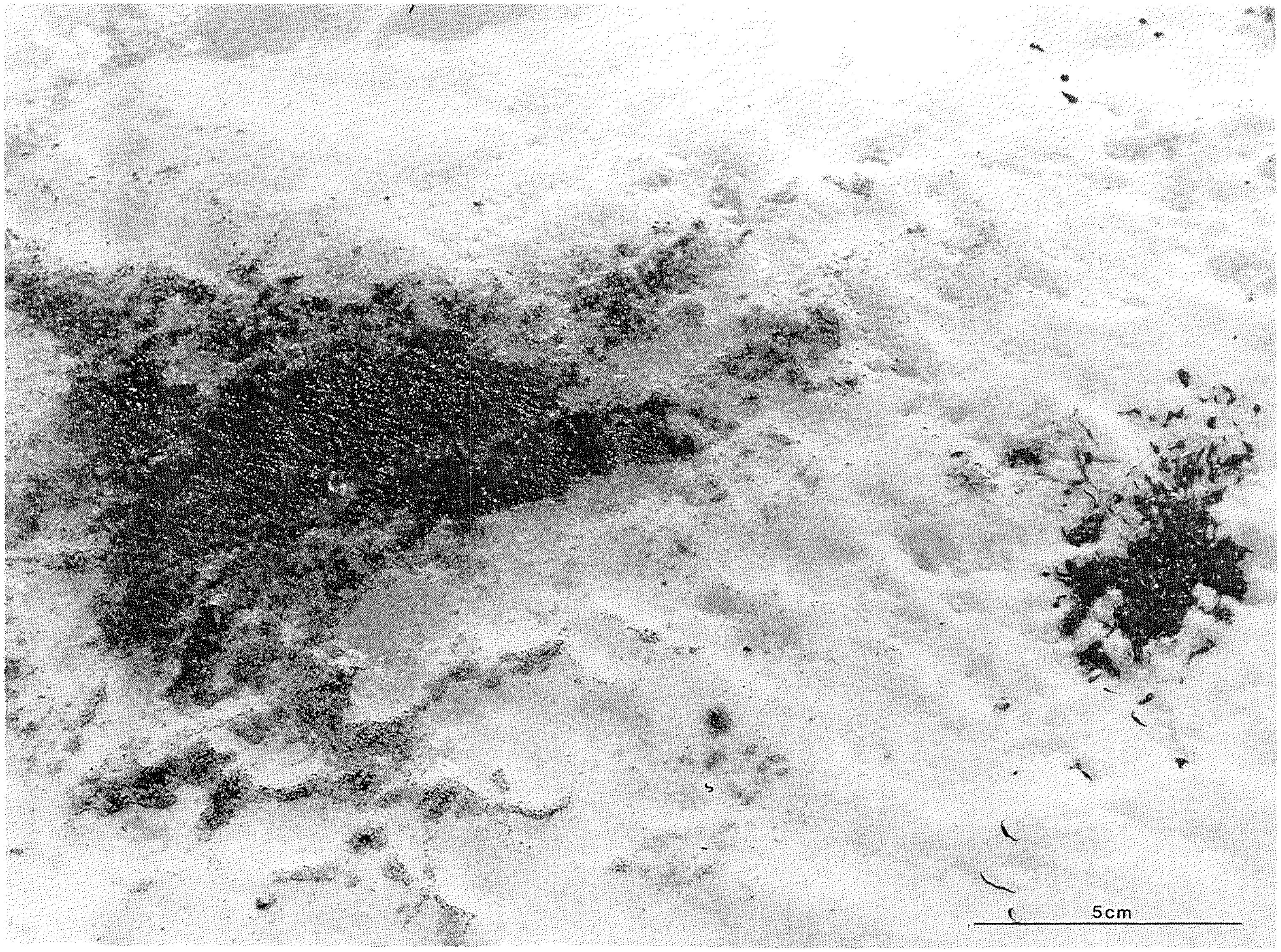


Figure 3. Surface stranded oil on shore-ice of St. Esprit Island, Cape Breton Island. Note oil droplets resulting from oil spatter.

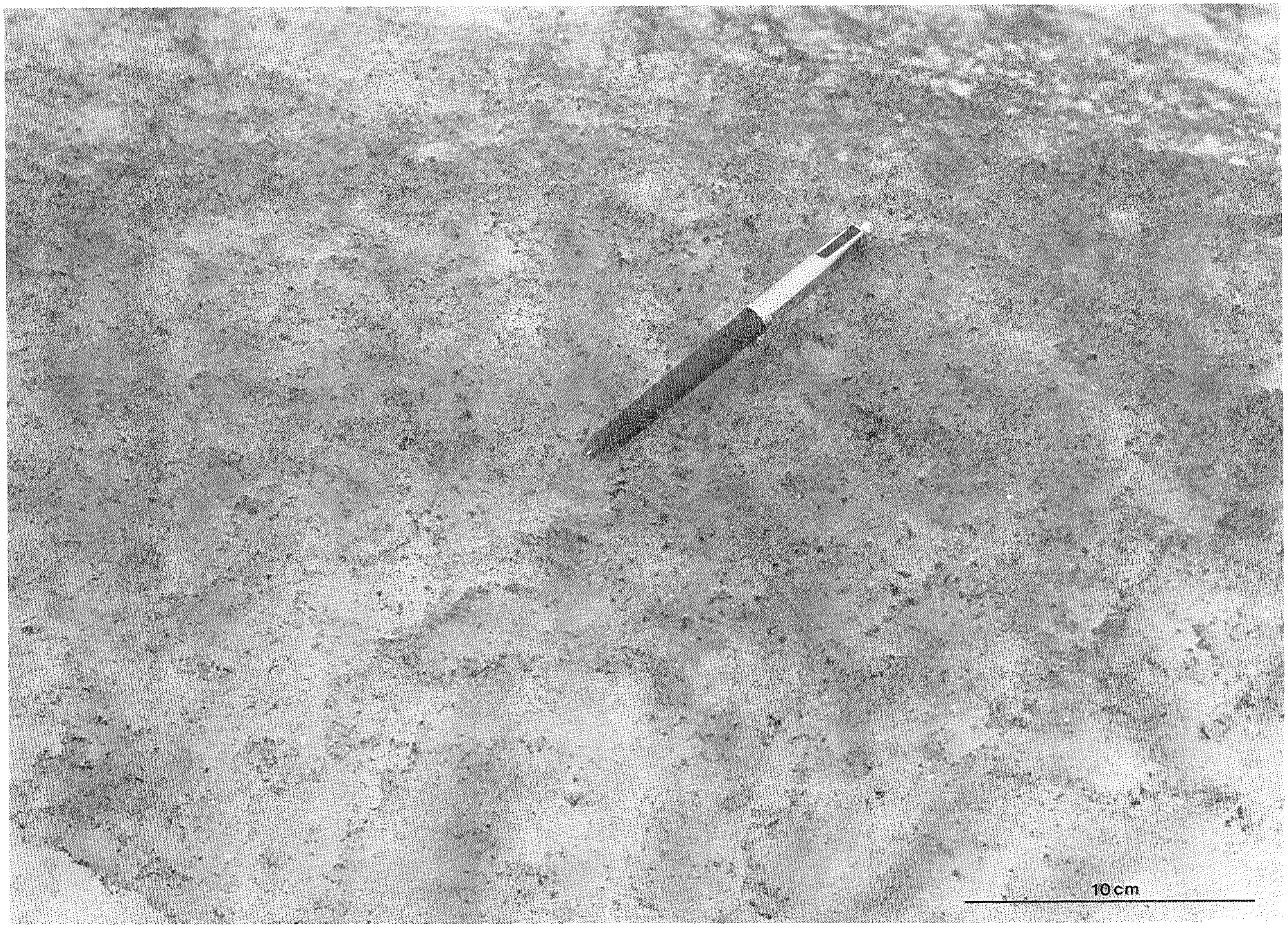


Figure 4. Fine particulate oil on surface of shore-ice bounding ice-lead near St. Esprit Island, Cape Breton.

Figure 5. Oil pitted shore-ice surface of St. Esprit Island, Cape Breton.

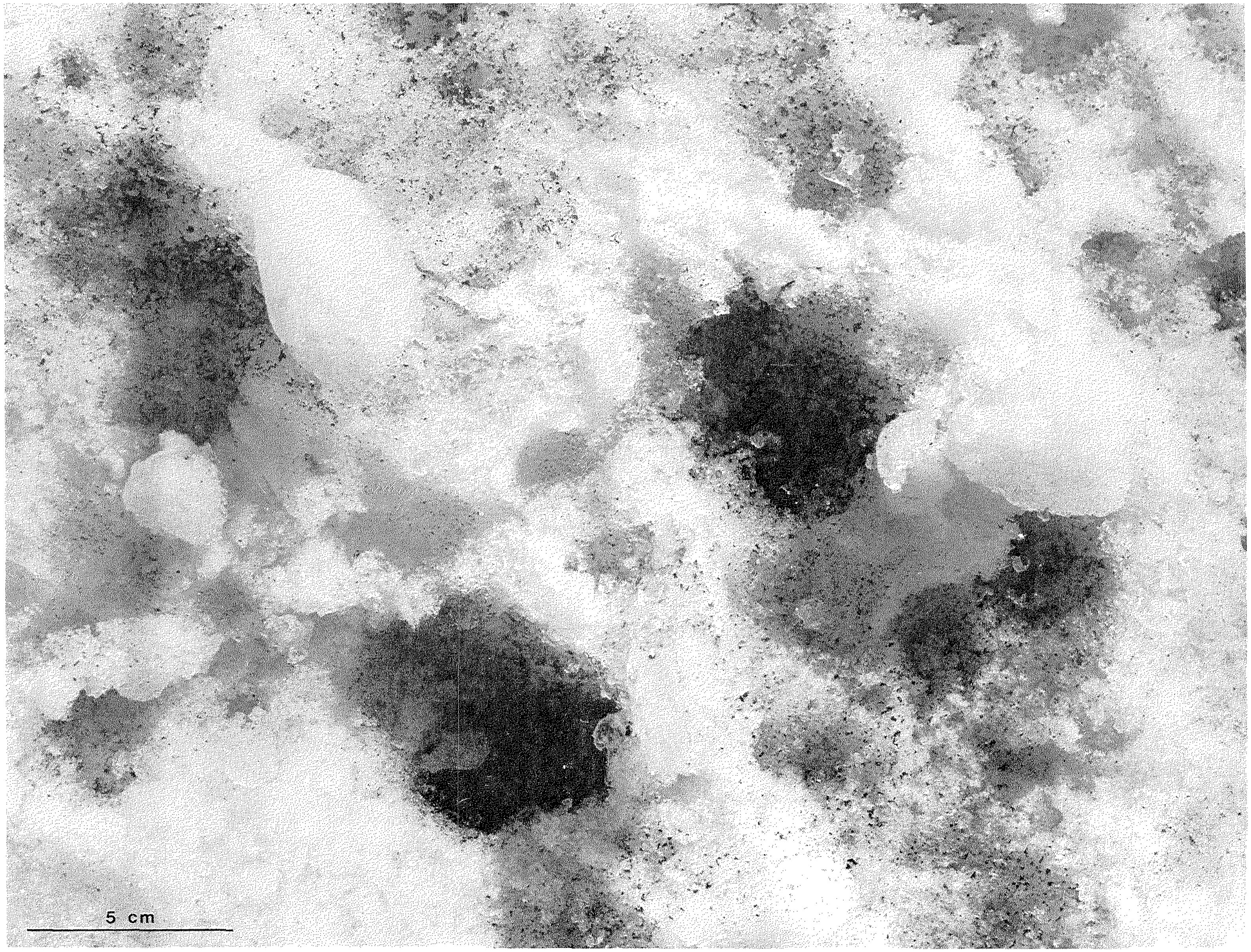


Figure 6. Detail of oiled shore-ice surface. Note particulate oil.

Figure 7. Detail of shore-ice surface showing small cratered depressions and dimples containing network of oil 'veins' and fine droplets.

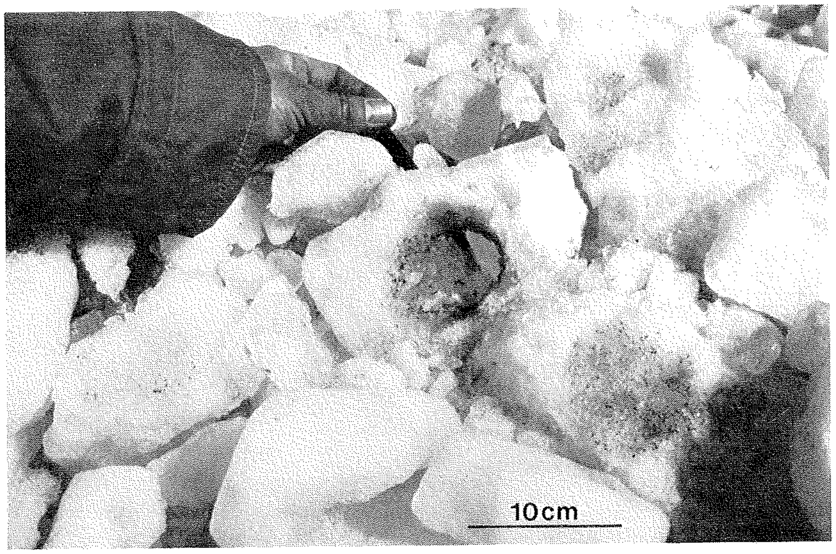


Figure 8. Melt-hole through ice lump filled with oil remnants.

OBSERVATIONS ON THE OCCURRENCE OF 'BUNKER-C' OIL ON THE CAPE BRETON SHORELINE' MAY 1979

G.E. Reinson, D. Frobel, R.B. Taylor, and K. Asprey

Atlantic Geoscience Centre
Geological Survey of Canada
Bedford Institute of Oceanography
Dartmouth, Nova Scotia

INTRODUCTION

Some weeks following the breakup of the Kurdistan oil tanker, Bunker-C oil began appearing on the shoreline along the Atlantic coast of Cape Breton and Chedabucto Bay. There were numerous and repeated incidents of shoreline oiling, and in nearly all cases the oil approached the shore as discrete, circular 'paddies' or 'pancakes', ranging in diameter from a few centimetres to a few metres. We had the opportunity to examine the oil-shoreline interaction in detail on two separate occasions, May 1 to 7 and again May 23 to 30, 1979. On both occasions we observed that the oil occurred in a limited number of physical forms and that there was a definite correlation between certain of these forms and specific shoreline types. The objectives of our paper are to expand on these observations of modes of occurrence of stranded oil, and to delineate the relationships between the forms of oil present on the shore, the type of shoreline environment in which the forms occur, and the mechanical dispersal path of the oil in the littoral zone.

MODES OF OCCURRENCE

The forms in which oil occurred on the shore (morphological state in which we observed it on the shoreline) can be grouped into four broad classes (Table 1): 'molasses', oil-detritus mixtures ('cowpies'), stains, and specks. The above terms were selected purposely because they are very descriptive and convey a fairly acurate picture of how the oil appears on the shoreline. 'Molasses' oil (Fig. 1) is considered to be the primary form in which oil first impinged on the shore. Within the context of our study, it is the 'original oil'; that is, it is original in terms of initial interaction with the shore zone. Conversely, oil-detritus mixtures consist of recycled oil that has been reworked in the swash and surf

Table 1
Classification of shore-line stranded oil, based on field observations following *Kurdistan* spill.

Form of Stranded Bunker C	Description (size, detritus, content, location)
Molasses oil (original oil*)	Gooey blobs and patches, a few centimetres to a few metres in diameter.
Oil-detritus mixtures ('cowpies')	1. Oil-organic** patches and blobs. 2. Oil-sediment patches*** with positive buoyancy. 3. Oil-sediment patches with negative buoyancy. Size range from a few centimetres to a few metres in diameter.
Stains	Oil splattered on bedrock and boulders
Specks	Minute oil particles in suspension in inshore water, or on rocks, cobbles, etc.

* 'Original' oil describes freshly stranding oil, not yet effected or reworked by beach processes.

** Containing algal detritus.

*** Oil/sediment patches contain 75 to 85% sediment.

zones. Oil-organic mixtures are those deposits that incorporated seaweed, kelp, or dead birds as a nucleus. Oil-sediment mixtures occur basically as two types; those that are flat, pancake-shaped and can float (Fig. 2), and those that are more three-dimensional in appearance and do not readily float (Fig. 3). The latter types act more as a bedload sediment clast, moving as intermittent suspension, saltation or traction load, depending on their size, amount of incorporated sediment and wave-energy conditions. Oil-sediment forms display some coherence and consistency and can be manually removed rather easily from the beach face, whereas 'molasses' forms tend to break up and adhere to the sediment surface upon removal.

The term 'stains' is used to refer to oil which has splattered onto bedrock and boulder surfaces, probably by hydraulic action of wave impact. Preliminary chemical analyses indicate oil stains are similar to the molasses type in composition, suggesting that stains are probably 'original' in terms of primary shoreline impingement. The term 'specks' refers to minute oil particles that occur in suspension in the swash zone, or adhere to boulders, cobbles, bedrock, etc. (Fig. 4). They are more like tiny globules rather than mini-stains.

SHORELINE TYPES AND OIL OCCURRENCE

There are four main shoreline types on the Cape Breton coastline extending from Point Michaud to Glace Bay: cobble-boulder beaches, sandy beaches, bedrock shores, and marshlands. Beaches are the prevalent type of shoreline (comprising almost 50%) in the coastal segment from Point Michaud to Gabarus Bay, whereas from Gabarus northward to Glace Bay, beaches comprise only 25% of the coastline and bedrock shores predominate (Reinson, 1980).

We found that there was a strong relationship between shoreline type and mode of oil occurrence. This was particularly evident when comparing the cobble-boulder beaches with the sand beaches. On cobble-boulder beaches, such as Main à Dieu and Kempt Point, oil was present primarily as stains and specks on boulder and cobble surfaces (Table 2). The stains were largest near the high-water line and diminished in size seaward across the beachface. Specks occurred more frequently in the wetted zone of the beachface and oil swash lines were marked by rows of specks on the beach

Table 2

Shoreline Environments and Stranded Oil Occurrence

Shoreline Type	Forms of Occurrence	Dominant Dispersal Path	Fate
Cobble-boulder beaches	Stains, specks (oil-detritus mixtures)	Mechanical weathering	Disintegration (penetration, burial)
Sandy beaches	Oil-sediment mixtures and molasses	Sedimentation	Burial and disintegration through reworking
Bedrock coasts	Stains, large agglutinated patches on rock platforms	Mechanical weathering	Disintegration
Marsh	Any oil with positive buoyancy	Arrested sedimentation cycle	Long term persistence

surface. In the active swash zone and surf zone, the water was filled with suspended oil specks. Some specks were impacted on rock surfaces with each swash, while others were resuspended by subsequent swash action. Sheen oil was also observed in the water where oil specks occurred.

A secondary form of oil on cobble-boulder beaches is that of oil in the form of large oil-detritus mixtures with enough incorporated granules and pebbles to resist resuspension. In a few cases these oil-conglomerate 'cowpies' were found in the process of being buried in the beachface by pebble-cobble traction load. Where the oil-detritus patches were initially deposited above the mean high-water line, oil penetration was occurring through solar heating effected melting.

On sandy beaches, such as at Point Michaud and Big Glace Bay Lake, oil occurred as blobs and patches of 'molasses' and as oil-sediment mixtures in the form of discrete paddies and 'cowpies'. Some of the oil-sediment forms were positively buoyant, whereas others had incorporated enough sand to lose their buoyancy and act as sedimentary clasts. The oilsediment mixtures were undergoing reworking in the swash zone, and some were found buried in beach cusps or sandy berm deposits some 10 to 20 cm below the beach surface. On most sandy beaches 'molasses' oil was not present in as great amounts as oil-sediment forms; where the former did occur it was confined to the upper part of the beachface at the top of the intertidal zone.

On bedrock shorelines oil was present largely as stains and specks, but oil-sediment patches and oil-organic mixtures were also found adhering to intertidal rock platforms as large agglutinated patches of seaweed, sediment, and other debris (Figure 5).

In marsh areas adjacent to tidal creeks and channels, such as at Big Glace Bay Lake, oil occurred as 'molasses' and as oil-detritus mixtures. Any form of oil that floated was accessible to marsh environments. Once deposited it adhered to the marsh vegetation and was not resuspended or reworked (Figure 6).

MECHANICAL DISPERSAL PATHS

It was evident from our observations in different shoreline environments that when the oil first impinges on the shoreline (as 'molasses'-

type patches) two dispersal paths become available - mechanical weathering and that of sedimentation (Table 3). Mechanical weathering of oil occurs primarily on boulder-cobble and bedrock shores, with the end result ultimately being disintegration. This disintegration results through a progressive breakdown of oil stains into oil specks and is achieved through a hydraulic process of wave impact and recycling of stain-derived oil through the water column and back onto rock surfaces on shore. Most of this reworking occurs in the swash and surf zone where hydraulic turbulence on cobble-boulder and bedrock shorelines is most intense.

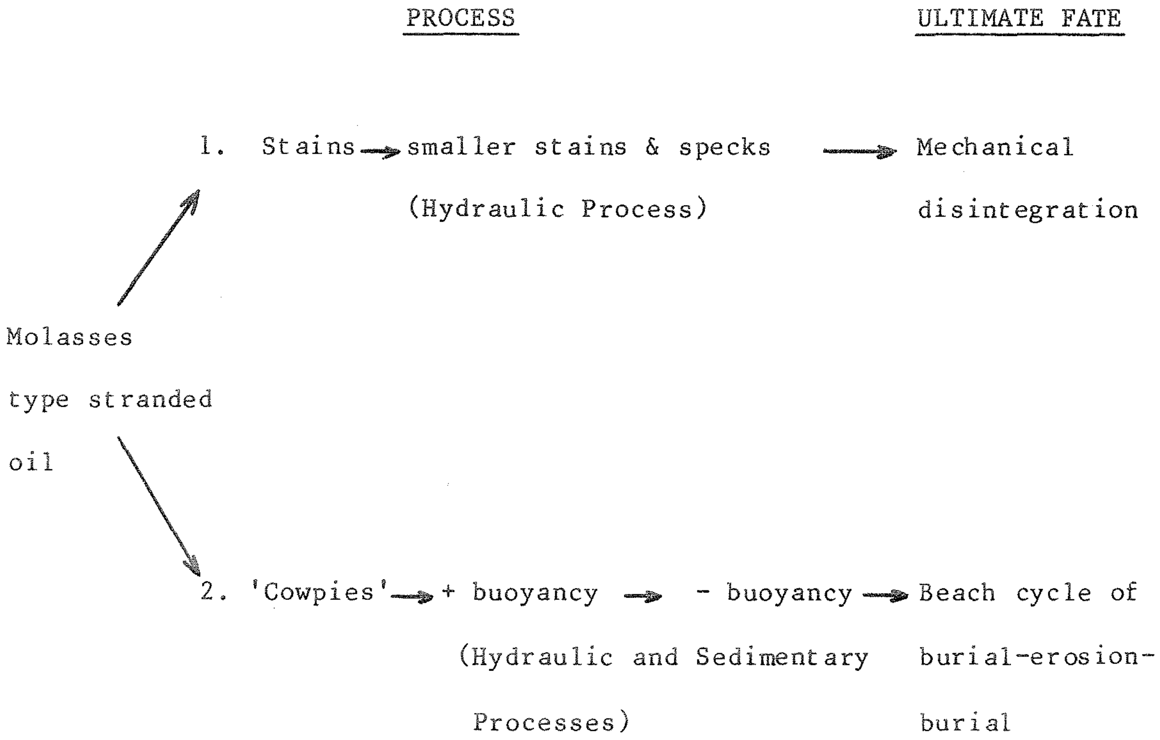
The sedimentation-dispersal path is operative mostly on sandy beaches where oil becomes part of the beach sedimentary cycle (Table 3). The oil-sediment clasts which behave much like the surrounding beach detritus are formed by the hydraulic and sedimentation processes operating on the beachface. The cycle of resuspension, deposition, and resuspension continually increases the amount of sand incorporated within the initial 'molasses' oil, to the point where the oil-sediment mixture becomes part of the sediment substrate rather than simply lying on top of the beachface. At this point the oil enters the burial-erosional-burial beach cycle, whereby the short-term fate may be deposition and burial during phases of beach accretion. During phases of beach erosion, these buried clasts may again be exposed to reworking on the beachface. Repeated cycles of beachface erosion and accretion will probably lead to gradual mechanical disintegration of the oil-sediment clasts through abrasion, although recent studies of spilled crude oil on sandy beaches in France suggest that such buried oil can probably persist for several years and may become part of the beach structure (Vandermeulen *et al.*, 1979; Long *et al.*, in press).

CONCLUSIONS

Oil found on the shoreline of Cape Breton in May 1979 was being dispersed by natural means through two main processes: (1) by mechanical weathering through wave impact, and (2) through erosional-depositional processes associated with the beach sedimentary cycle. Mechanical weathering was the prevalent dispersal path on cobble-boulder beach and bedrock shorelines. On sandy shorelines oil has entered the beach sedimentary cycle and

Table 3

Mechanical Dispersal Paths of Stranded "Molasses" Oil



undergone deposition, burial, and reworking in response to beach accretional and erosional phases. In marsh environments, mechanical dispersal of oil was impeded because high-energy hydraulic impact processes and cyclic depositional processes are absent. The oil thus persists in marsh environments for relatively long periods compared to the other environments where it is being dispersed through mechanical disintegration and burial.

Based on our observations of the relationship between oil occurrence and shoreline type, we would make the following suggestions with respect to cleanup strategies. On cobble-boulder beaches, particularly in the intertidal zone, it is futile to attempt removal of stained and specked oil; this will eventually be achieved naturally through mechanical disintegration. Oil-detritus mixtures should be removed from cobble-boulder beaches, especially if they are near the high water line, so that penetration after solar heating will be minimized. The cleanup strategy with respect to bedrock shorelines should be the same as cobble-boulder beaches. On bedrock shores larger masses of oil are often found adhering to intertidal rock platforms (Figure 5); these will break up into "paddies" by wave action and may then be transported to other adjacent beaches (i.e. in the Glace Bay-Port Morien region).

In the case of sandy beaches the easiest and probably most effective cleanup strategy is to manually pick up the 'molasses' patches and oil-detritus 'cowpies' as they appear, and this in fact is what has been done along the Cape Breton coastline. Manually removing these forms of oil from the beachface lessens the oil-sediment depositional process, thereby reducing the amount of oil that is retained in the system through sedimentation and burial.

Oil in marsh environments poses a special problem because of its relatively long-term residence time if manual removal is not attempted. However, it is often difficult to decide which may be more harmful to the marsh environment, the oil itself or the ensuing cleanup operations.

REFERENCES

LONG, B.F.N., J.H. VANDERMEULEN et D.E. BUCKLEY. In Press. Les processus de la migration du petrole échoué dans les estrans sableux: contamination des nappes phréatiques. In: Amoco Cadiz: Fates and Effects of the Oil Spill. Proceedings of an International Symposium, November 1979, Centre Oceanologique de Bretagne, Brest. Centre National pour l'Exploitation des Oceans (CNEXO). (In French).

REINSON, G.E. 1980. Assessment of the Nova Scotia shoreline for potential impingement of KURDISTAN oil: 1. Glace Bay to Point Michaud, March 21, 1979; 2. Hartlen Point to Cape Canso, March 28, 1979. In The Kurdistan Oil Spill, March 15/16, 1979. Activities and observations of the Bedford Institute of Oceanography scientific response team (Vandermeulen, J.H. and D.E. Buckley, Eds.) Bedford Institute of Oceanography Report Series, BI-R-80-2.

VANDERMEULEN, J.H., D.E. BUCKLEY, E.M. LEVY, B.F.N. LONG, P. MCLAREN and P.G. WELLS. 1979. Sediment penetration of Amoco Cadiz oil, potential for future release and toxicity. Mar. Poll. Bull. 10: 222-227.

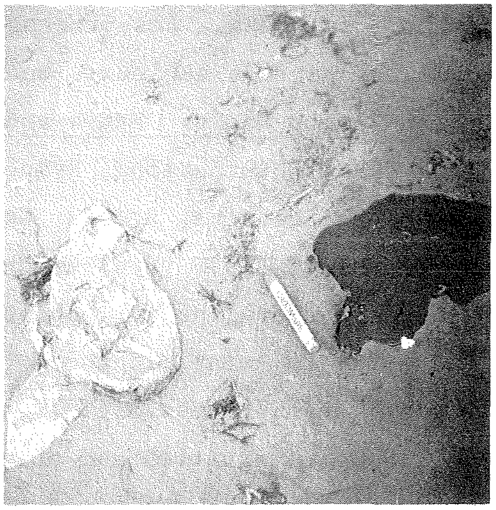


Figure 1. 'Molasses' oil is considered to be the primary form in which oil first impinges on the shore. This is an example of molasses type oil found at the high water swash line, Point Michaud beach, May 28, 1979.

Figure 2. Oil-detritus mixtures consist of recycled oil having been reworked in the swash and surf zones. Positively buoyant oil-sediment 'cowpies' were most commonly observed on sand beaches (Point Michaud beach, May 28, 1979).

Figure 3. Oil-sediment mixtures which became negatively buoyant often acted as sedimentary clasts moving by saltation or traction load. These clasts (arrows) were photographed near Big Glace Bay Lake beach adjacent to the bedrock shoreline, May 29, 1979.

Figure 4. Specks of oil on cobbles, Main à Dieu beach, May 29, 1979.

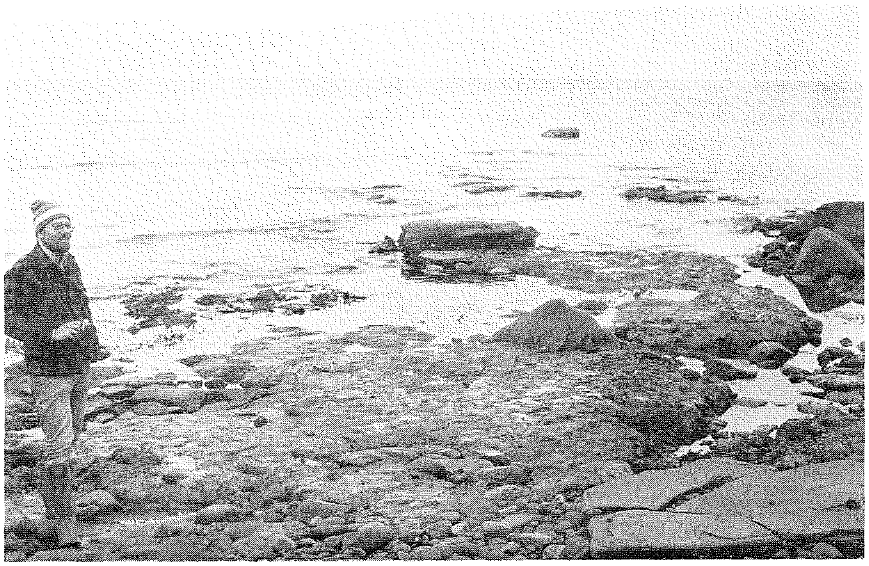


Figure 5. Large agglutenated patches of oil, seaweed, and sediment adhered to the cobble-covered intertidal bedrock platform, Dominion beach, May 29, 1979.

Figure 6. Big Glace Bay Lake marsh. Note the marshbank at the edge of the tidal channel is covered with oil. The oil was left adhering to the marsh vegetation after the tide receded (May 29, 1979).

VISUAL OBSERVATIONS ON THE BEHAVIOUR AND FATE OF OIL ON SHORELINES IN THE CAPE BRETON AREA, NOVA SCOTIA, CONTAMINATED AFTER THE KURDISTAN OIL SPILL

B.M. Fowler[1] and C.J. Noll[2]
NORDCO Ltd., St. John's, Newfoundland

1. Present address: Petroleum Directorate, Government of Newfoundland and Labrador, Newfoundland A1G 5T7
2. Present address: Hydrospace Marine Services, St. John's, Newfoundland

INTRODUCTION

Following the breakup of the 32,530 DWT British tanker *Kurdistan* on March 15, 1979, during heavy seas in the vicinity of pack ice, an estimated 7900 tons of Bunker C fuel oil was released into Cabot Strait. Much of the oil became intermixed with the pack during the following weeks. The ice and oil eventually began to come ashore on the south shore of Cape Breton Island and in Chedabucto Bay on Isle Madame. Tightly-packed first-year ice floes were stranded on the shores until mid to late April 1979.

A preliminary investigation was carried out on Isle Madame and south-east Cape Breton shorelines primarily to determine the physical fate and behaviour of the oil on various shore types, and to make preliminary observations on the distribution of the oil in the intertidal sediments. Results of hydrocarbon analyses will be reported at a later date when these have been completed.

This area was heavily oiled during the *Arrow* grounding of 1970 (Anon., 1970), and in fact *Arrow* oil can still be found in many places (Vandermeulen and Gordon, 1976; Keizer *et al.*, 1978; Thomas, 1978; Gilfillan and Vandermeulen, 1978). The arrival of *Kurdistan* oil in this same area, nine years later but at the same time of year and involving the same type of oil, gave us an opportunity to compare the stranding processes and confirm some of the earlier stated principles of oil degradation as a function of shoreline energy (Thomas, 1973; Vandermeulen, 1977).

METHODS

The area visited consists of a sheltered, low-energy zone with undeveloped beaches (north Isle Madame), and an exposed zone with beaches consisting mainly of boulder, cobble and pebble (south Isle Madame and Petit de Grat). Beach profiles in the latter region are steeper in winter than summer, the more gently sloping accretional summer profiles having increased amounts of coarse sand and gravel in the intertidal zone (Owens, 1971). Chedabucto Bay is exposed to the full force of waves from the east and south, and the shores which are directly exposed to these waves have high energy littoral environments.

Observations were limited to visual examination of beaches and shores accessible by road or involving short walks. Observations were made on the distribution and relative abundance of oil on the shoreline and notations were made on the surficial sediments, shoreline type, and wave exposure. Most of the observations were of a qualitative nature, though representative patches of oil were measured to give an indication of the size-distribution of deposits. The sites were also photo-documented.

OBSERVATIONS AND DISCUSSION

General Distribution and Relative Abundance of Oil

Eighteen sites were visited during the two-day reconnaissance, 14 on Isle Madame and Petit de Grat Island, and 4 along the south shore of Cape Breton Island between Michaud Point and Fourchu Head. The relative abundance of oil at the sites surveyed is summarized in Figure 1.

Thick, viscous deposits were found at all but two sites. However, in general the oil was greatly dispersed and the distribution very patchy and highly variable, making estimates of percent coverage impractical.

The key for relative abundance of oil given in Figure 2 attempts to quantify to some extent the density and size of oil deposits at each site. 'Traces' of oil indicates that small stains (1 mm - 1 cm) and/or small cakes (approximately 3-5 cm) were sparsely distributed on the shore. 'Light' abundance of oil indicates a more dense, evenly distributed cover of small oil spots forming a band on the shore or of small cakes more frequently scattered over the shore. A 'moderate' oil cover indicates that larger cakes in the range 5 cm to larger than 1.0 m were distributed frequently over the beach, or in the case of rocky shorelines the presence of oil pools in crevices on the upper shore. Since the oil was present in a patchy distribution in all cases, never forming a continuous cover or band on the shore, the oil deposit was never considered 'heavy' at any location.

The more exposed sand, gravel, and boulder coasts of south Isle Madame and Petit de Grat Island were moderately contaminated with oil. In contrast, the sheltered north shores of Isle Madame and of Chedabucto Bay east of the Strait of Canso showed only traces of oil at the sites visited. Only traces of relatively fresh oil were found in Arichat Harbour, which is sheltered from impact from the east and south.

The exposed sand beaches of Point Michaud, Kempt Point, and Framboise Cove along the south shore of Cape Breton Island were found to be only moderately contaminated with oil pancakes at the time of our survey (April 19, 20).

Detailed Site Description (Figure 2)

Site 1. The site consists of a moderately sloping, mixed cobble, gravel, and sand beach extending approximately 60 m between upper high water and low water. There was a moderate degree of sorting with coarser gravel and pebble on the backshore. First-year ice floes (1-3 m diameter, 40-50 cm thick) were stranded on the beach in a 15-m wide band between 6 and 21 m from high water mark.

Oil stains and particles (1-2 cm) were observed on the cobble and pebble throughout the intertidal zone and oil particles mixed with sediment were found entrained in the sides of stranded ice floes. Larger cakes ranging between 2 to 4 cm and up to 30 cm in diameter lay on and between the ice pans stranded on the shore, with a density of approximately three oil cakes per square metre on the stranded ice.

The incoming tide washed in particles and cakes of oil (Figure 3) ranging in size from particles less than 1 cm to large cakes or plagues, up to 50 cm diameter by 2 cm thick. The oil appeared to be splattered on the ice as the incoming tide surged over the ice pans (Figure 4). There was also evidence of oil cakes entrained in the ice floes (Figure 5). Deterioration of the ice through wave action and solar radiation, particularly around oil cakes, was evident.

A dense deposit of oil was found in the debris at the berm below the storm ridge at this site. Traces of oil were also found beyond the storm ridge, probably brought in by overwash during times of storm surges or high wave-energy levels. This oil, protected from the constant abrasion of wave activity, probably will be only slowly eroded and degraded.

Site 2. Site 2 lies southeast of Site 1, and is a high energy rock outcrop and boulder shore with cobble and gravel on the backshore. Small oil particles and larger cakes of oil were evident in the waves breaking on the rocky shore. Large pancakes of tarry oil 10 to 30 cm in diameter were scattered throughout the intertidal zone, while at the back shore dense deposits of oil formed a discontinuous band 1 to 2 m wide (Figure 6). The rock outcrop shown in the centre of Plate 4, as well as the cobble below, was coated with tar.

Site 3. An exposed beach consisting of moderately sorted cobble, pebble, and sand. Oil cakes 10 to 50 cm in diameter were scattered throughout the intertidal zone. Above high water at the berm oil was concentrated in a more or less continuous band (Figure 7).

Two tarry clumps of oil (15-20 cm diameter) were found buried in the sediment at the berm, one at 5 cm depth, another at 10 cm depth. Such oil probably was buried during a time of beach accretion when sediments were being moved upwards towards the berm. Whether this was Kurdistan oil is not known. However the oil was quite viscous, similar to the cakes deposited on the lower intertidal. This oil may become exposed again during the next period of beach erosion.

Cakes of oil stranded throughout the intertidal zone on this mixed beach were found to have penetrated the sediments to depths of 1 to 2 cm. Oil penetration as a process appears to be related to viscosity and sediment compactness. This is evident from Figure 8 showing the backshore behind the berm. In this case the oil had penetrated into the sand 2 to 3 cm. In comparison (Figure 9) oil stranded on sand in the lower intertidal was covered with water much of the time and had not penetrated into the substrate, although the sediment particles appeared less compact.

Oil stranded in the intertidal zone was eroded and degraded constantly by the mechanical action of waves and abrasion by sediments in the swash and backwash. In contrast oil stranded above high water remain appeared to physically unchanged, possibly because it is less affected by the mechanical processes of wave action.

Site 4. This cove, north of Red Head, presented an opportunity to observe the behaviour and fate of oil on a number of different shore types. The cove is approximately 500 m in length, exposed to the east and southeast. A small cove (approximately 100 m in length) consisting of bedrock shoreline lies at the northern end of this shore. Rugged, irregular rocky outcrops create many crevices and pools where oil can collect both in the intertidal and above the normal high tide line. Pools of oil similar to the one shown in Figure 10 covered approximately 50% of the shore above the normal high water line. The depth of oil in the pool shown in Plate 8 was approximately 7 cm. These deposits of oil are available for recontaminating the shore and adjacent shorelines when washed out during periods of high water, as at spring tide or during storm surges. Crevices within the intertidal also contained substantial deposits of oil.

Adjacent to the rocky shore at Site 4 lies a loose cobble beach approximately 250 m in length and 100 m wide with a 5 to 20 degree slope. Patches of oil were dispersed evenly and frequently throughout the beach from the berm to low water. At first sight the oil patches appeared to be small cakes scattered over the beach, but closer inspection showed that they were substantially larger patches (20-30 cm diameter) which had become buried down into the loose cobble, some to depths greater than 20 cm (Figure 11).

Adjacent to the cobble beach at Site 4 is a medium-grained sandy beach approximately 250 m x 100 m with a slope approximately 5 to 10 degrees. Large cakes of oil (40-60 cm diameter, 2-3 cm thick) as well as numerous smaller ones (5-20 cm diameter) were scattered intermittently over the surface of the beach face.

Site 5. Jersey Point, south end of Petit de Grat Island. This site is an exposed shoreline of bedrock and till deposit including boulder, cobble, and pebble with a grassy terrace (height approximately 1.5 m) at the backshore. Oil was present in a patchy distribution of viscous, tarry patches (approximately 10-20 cm diameter), concentrated primarily between mid-tide and above the high water mark, frequently mixed with seaweed debris (Figure 12). Overwash had deposited patches occasionally patches onto the grassy terrace above the beach.

Site 6. Petit de Grat inlet. The shoreline investigated was the west side of Petit de Grat Island north of the causeway. The inlet was covered approximately 5/10 to 8/10 with brash ice and ice floes ranging from small pieces to pans approximately 5 m diameter. The ice was stained a light brown at and below the waterline with a mixture of sand and oil particles. Scattered patches of black oil stained the surface of the ice floes. This oil appeared distinctly different from the shiny oil seen on ice at Site 1, having a dull and gritty-looking appearance due to the entrainment of sediment particles in the oil.

Light brown colored water-in-oil emulsions ringed the ice floes. A film of oil, clearly emanating from the emulsion, formed on the open water between the floes showing the potential for delayed contamination.

The shoreline in this sheltered inlet was narrow and steep, composed of bedrock and till deposits, boulders, cobbles, and pebbles. The sediments in the intertidal zone were densely speckled with oil stains (2 mm - 2 cm) which did not refloat at high tide (Figure 13). It is unlikely that these small oil stains originated in this low energy environment. Rather the oil, mixed with ice, may have been dispersed elsewhere in high-energy wave environments and was then eventually carried by currents to this sheltered environment and deposited on the shore as the tide receded.

Site 7. Arichat Harbour. The harbour is sheltered from wind and waves from the east and south and, although it was heavily contaminated after the Arrow spill (Anon., 1970), it had not been significantly affected by the Kurdistan oil spill up to the date of this survey. An occasional small (3-5 cm) cake of viscous, tarry oil was observed above the normal high-water mark as well as a very sparse scattering oil specks. Evidence of the Arrow oil contamination was still apparent. High on the beach there was a discontinuous band of asphalt material, hard and brittle, presumed to be Arrow oil, as well as scattered clumps and small pieces.

Site 8. Mousseliers Passage, Haddock Harbour. This sheltered beach in a low-energy environment showed no visible sign of recent oil contamination. It had been contaminated with oil from the Arrow spill (Anon., 1970; Vandermeulen and Gordon, 1976).

Site 9. Mousseliers Passage, south side of the causeway, opposite Site 8. Scattered spots (1-2 cm) of tarry oil were found about mean high tide mark. Some remains of the Arrow oil contamination were evident, such as large clumps (15-20 cm) of asphalt scattered in a band high up on the beach face.

Site 10. Poulamon Bay. The site is a narrow, sheltered low-energy beach with till deposits of cobble, gravel, and sand. The intertidal was speckled with small oil stains similar to the situation at Site 6 (Figure 14) but not quite as dense a distribution.

Sites 11 and 12. Cap la Ronde. Site 11 is located on a barachois * (see footnote) behind a beach (Site 12) at Cap la Ronde. The beach is a high-energy, steeply-sloping (20-25 degree) well-sorted cobble beach with some gravel and sand between mid and low tide lines. There was no evidence of oil deposition anywhere on the beach. The narrow shore of the barachois consists of an angular rock and shale substrate and has a gentle slope. The lower shore of the barachois just behind the steep cobble beach was very densely speckled with numerous small oil stains (1-5 mm), apparently sprayed onto the shore (Fiugre 1).

The lack of any obvious signs of oil on the exposed high-energy barrier beach may reflect the high rate of physical degradation and dispersion of oil in this type of environment, although it is not known if this area was oiled to any degree.

Site 13. Rocky Bay. This site is a low to moderately sloping fine sand beach approximately 50 m wide with scattered cobble throughout the beach sediments and at the berm. An occasional small cake (4 cm) of oil was found near the high tide mark. Particles of oil were sparsely distributed on the cobble at the berm. Attempts to locate buried oil above the high-water line were unsuccessful.

Site 14. Pondville. A low-sloping, fine sand beach just south of Shaw Point. A band (approximately 10 m width) of tightly-packed first-year ice floes was stranded on the beach at high water. The floes were discoloured with sand and particles of oil at and below the waterline. Particles of oil (approximately 1-2 cm) were distributed on the beach between normal and high water lines.

---

* Barachois is a small backshore pond or embayment.

CAPE BRETON ISLAND, SOUTH SHORE

Michaud Beach

This extensive fine-grained sandy beach had already undergone cleanup operations at the time of the survey, and the backshore was lined along its entire length with plastic bags filled with oil and oil-contaminated debris and sediments. Still, large pancakes of viscous oil (0.5-1.0 m) with small spots and specks intermixed were frequently found distributed along the upper shore and in the intertidal.

Kempt Point and Framboise Cove

Deposits of moderate sized oil cakes (15-30 cm) and oiled seaweed and debris were relatively abundant on the sandy beaches in these two areas. Cleanup operations had been undertaken at Framboise Cove.

Fourchu Head

The harbor and headland at Fourchu had been apparently heavily contaminated. Extensive cleanup operations had been undertaken as evidenced by the numerous plastic bags that lined the entire length of the harbour. The low-energy, narrow, till deposit shore was still moderately oiled with medium size cakes (10-20 cm) and oil particles.

SUMMARY

Offshore oil was greatly dispersed into cakes and particles, the latter ranging from several centimetres in diameter down to less than a millimetre. Particles of oil were also entrained in and adhered to the sides of the floes. Occasionally larger oil cakes were washed up on top of the floes. Oil and sediment particles entrained in the sides of ice floes stained the ice a light brown. However, it is difficult to distinguish between oil/sediment contamination and discolouration due to sediment alone without close examination.

All shores visited on Petit de Grat Island in Chedabucto Bay and shores between Point Michaud and Fourchu Head were moderately contaminated with oil. The oil was greatly dispersed, never forming a continuous cover, and was distributed randomly as blobs and pancakes over the shores. However, oil deposits did tend to be concentrated at the berm of exposed beaches, and in tide pools and in crevices above the high water line.

Oil penetrated (was buried) deeper into coarse sediment beaches than into fine sediment beaches. Depth of oil penetration was seen to depend in part on the viscosity of the oil, especially where oil particles had heated up with solar radiation.

The fate and behavior of oil on the various shorelines was seen to be greatly influenced by the physical characteristics of the site, by the sediment type and exposure to wave action. The energy level of the beach determined the rate of physical breakdown of the stranded oil. However, it appeared that some of the oil had already been dispersed and weathered elsewhere before becoming deposited on these shorelines.

LITERATURE CITED

ANON. 1970. Report of the Task Force - Operation Oil. Vol. I, II, III, IV. Canadian Ministry of Transport 1971.

GILFILLAN, E.S. and J.H. VANDERMEULEN. 1978. Alterations in growth and physiology in oiled soft-shell clams, *Mya arenaria,* chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-76. J. Fish. Res. Board Can. 35: 630-636.

KEIZER, P.D., T.P. AHERN, J. DALE and J.H. VANDERMEULEN. 1978. Residues of Bunker C oil in Chedabucto Bay, Nova Scotia, 6 years after the ARROW spill. J. Fish. Res. Board Can. 35: 528-535.

OWENS, E.H. 1971. The restoration of beaches contaminated by oil in Chedabucto Bay, Nova Scotia. Marine Sciences Branch, Department of Energy, Mines and Resources, Ottawa.

THOMAS, M.L.H. 1973. Effects of Bunker C on intertidal and lagoonal biota in Chedabucto Bay, Nova Scotia. J. Fish. Res. Board Can. 30: 83-90.

THOMAS, M.L.H. 1978. Comparison of oiled and unoiled intertidal communities in Chedabucto Bay, Nova Scotia. J. Fish. Res. Bard Can. 35: 707-716.

VANDERMEULEN, J.H. 1977. Self-cleaning and biological recovery of an oiled marine environment: ARROW 1970-1977. Oceanus 20 (4): 31-39.

VANDERMEULEN, J.H. and D.C. GORDON, JR. 1976. Reentry of 5-year old stranded Bunker C fuel oil from a low-energy beach into the water, sediments, and biota of Chedabucto Bay, Nova Scotia. J. Fish. Res. Board Can. 33: 2002-2010.

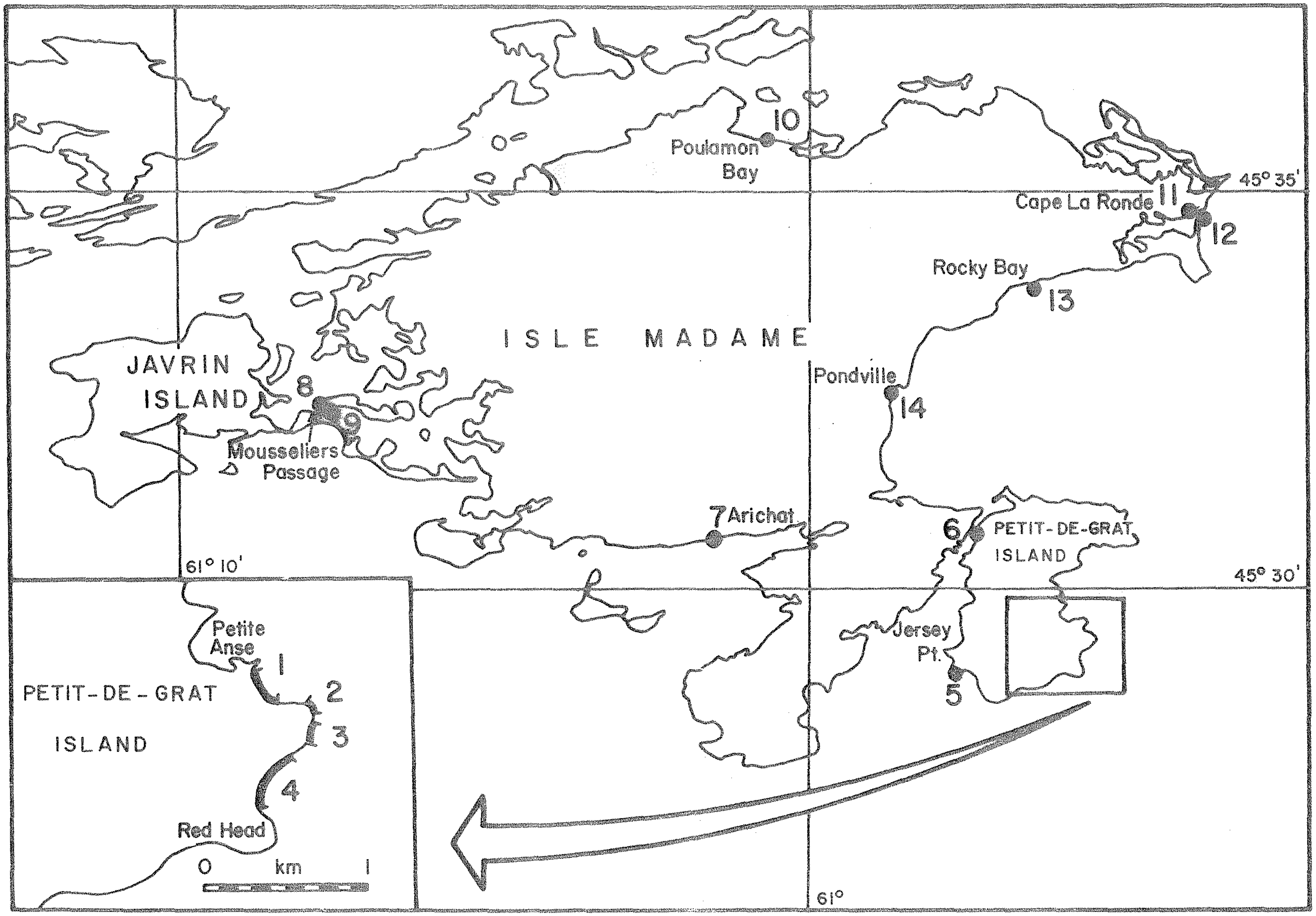


Figure 1. Site locations on Isle Madame and Petit-de-Grat Island, for stranded oil observations described in the text.

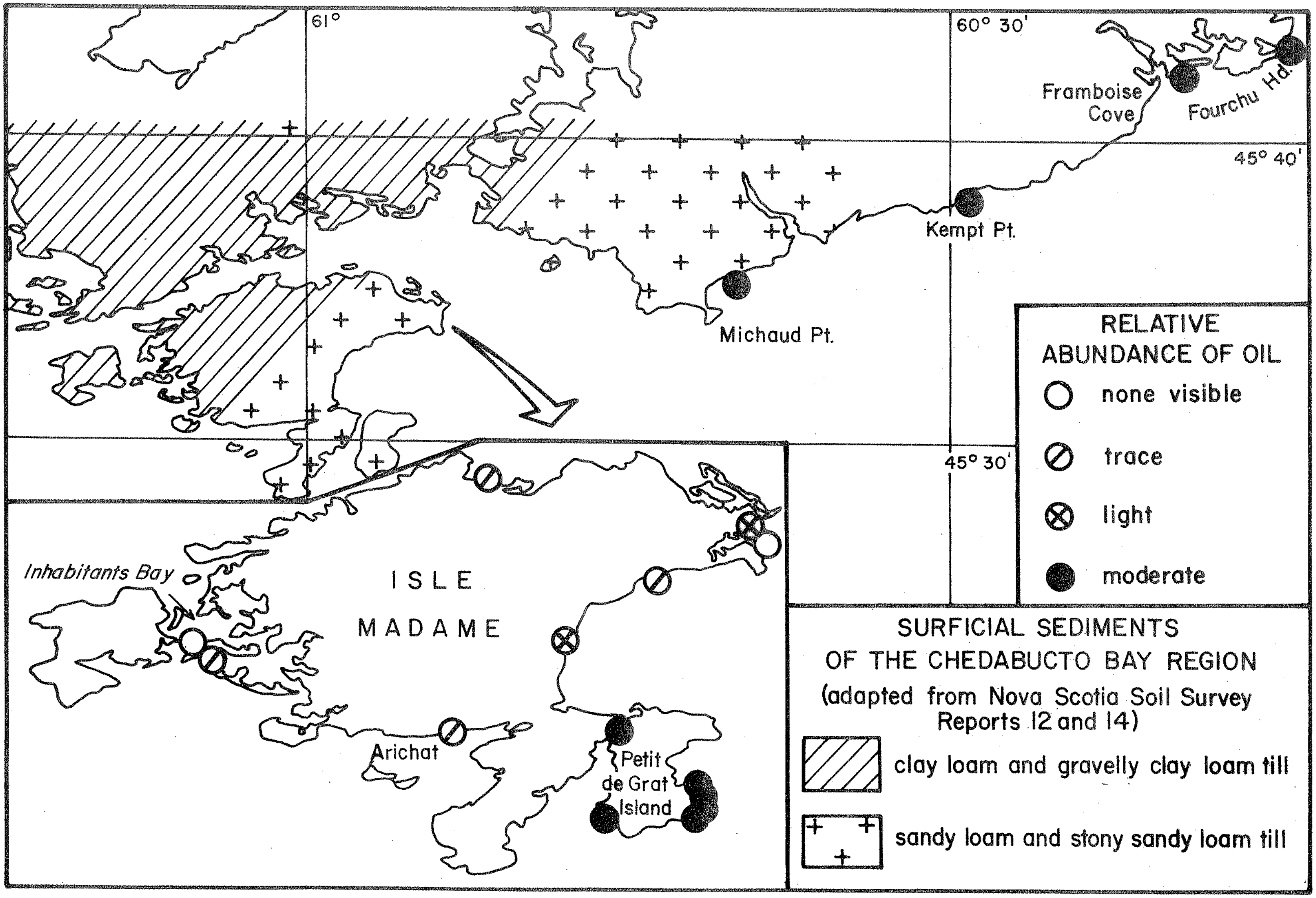


Figure 2. Relative abundance of oil on Isle Madame and adjacent Chedabucto Bay shorelines, April 19 and 20, 1979.

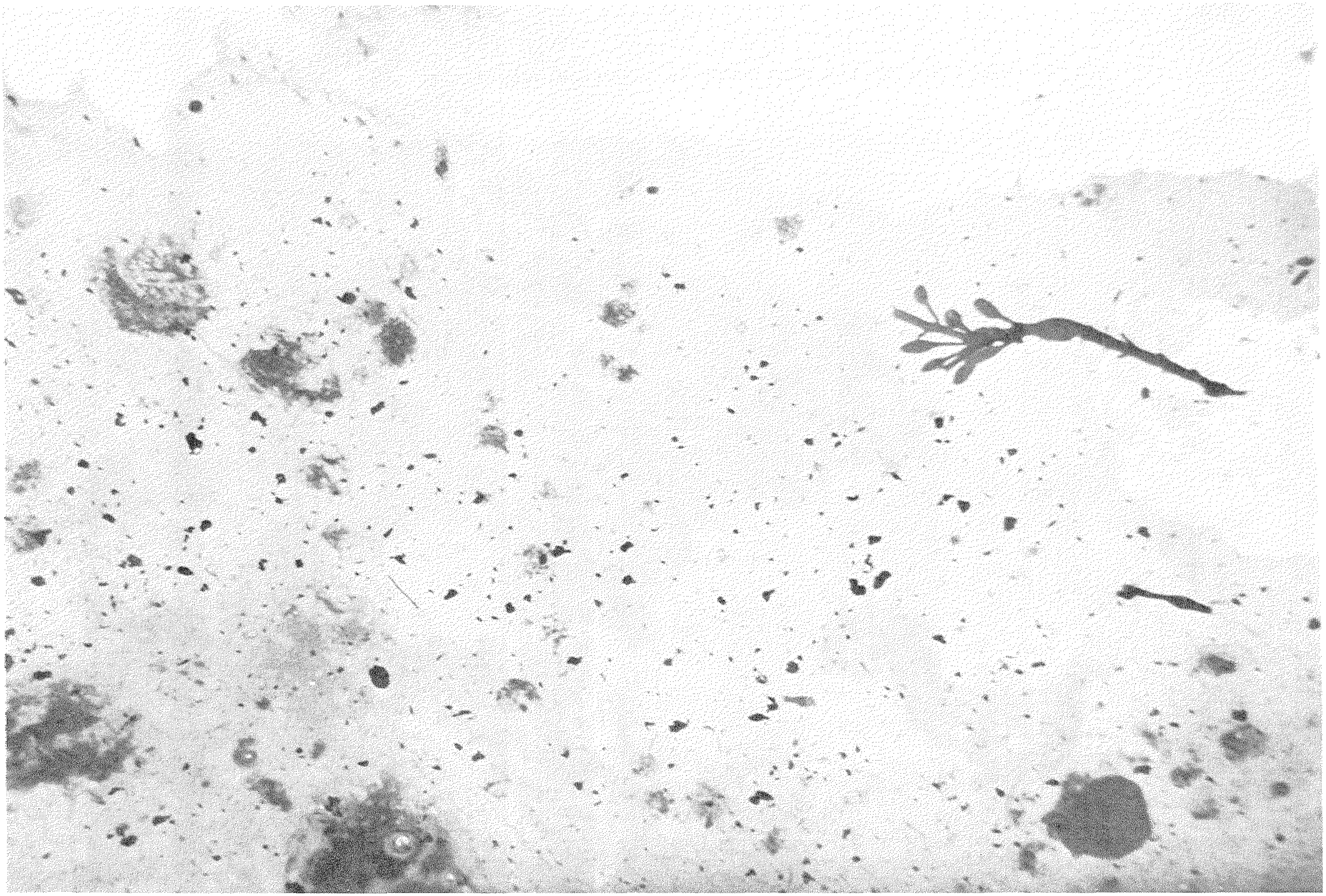


Figure 3. Oil particles and cakes washing ashore around ice floes stranded on the foreshore (scale 1 cm = 2.5 cm).

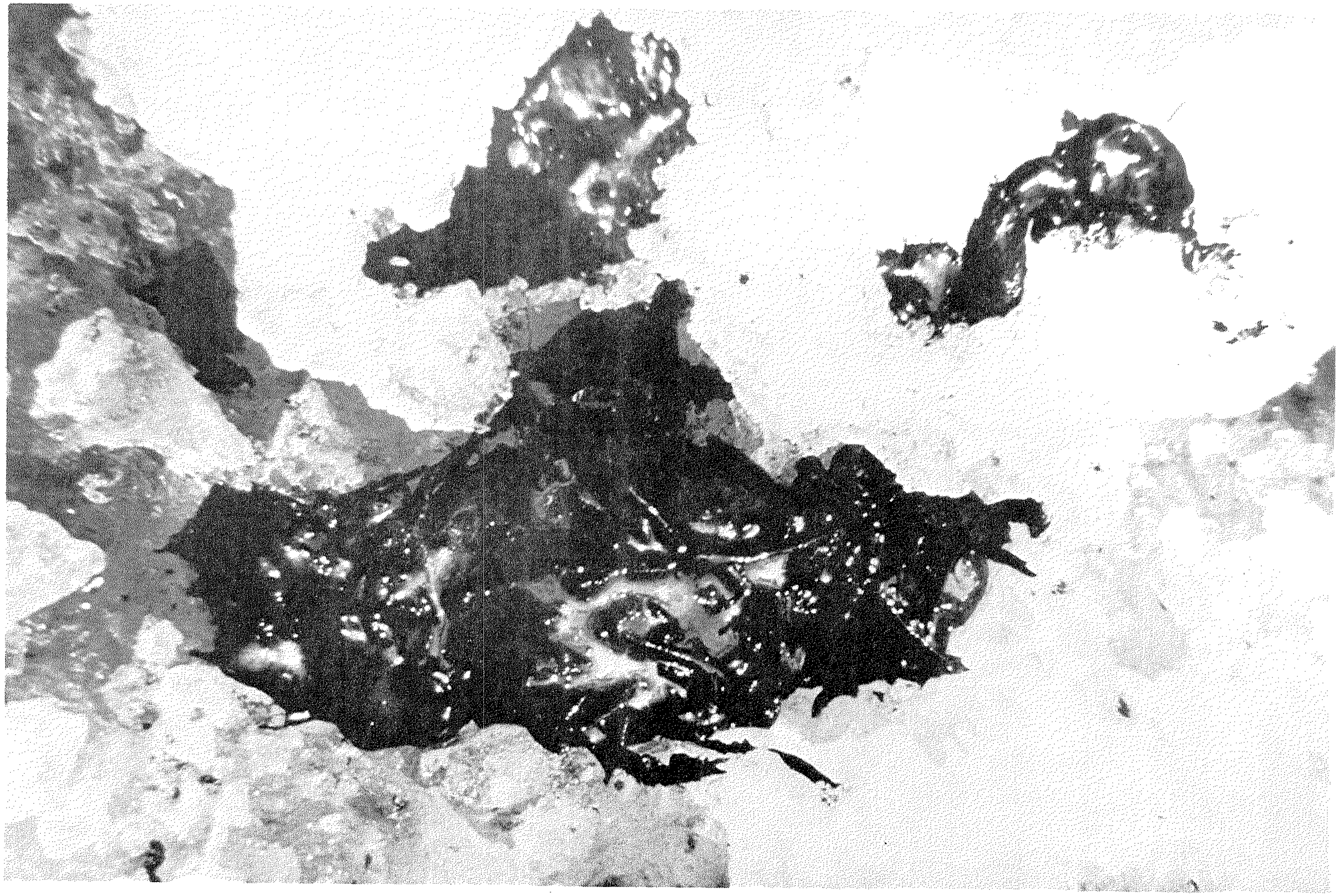


Figure 4. Oil on ice floe stranded on shore (scale 1 cm = 1.5 cm).

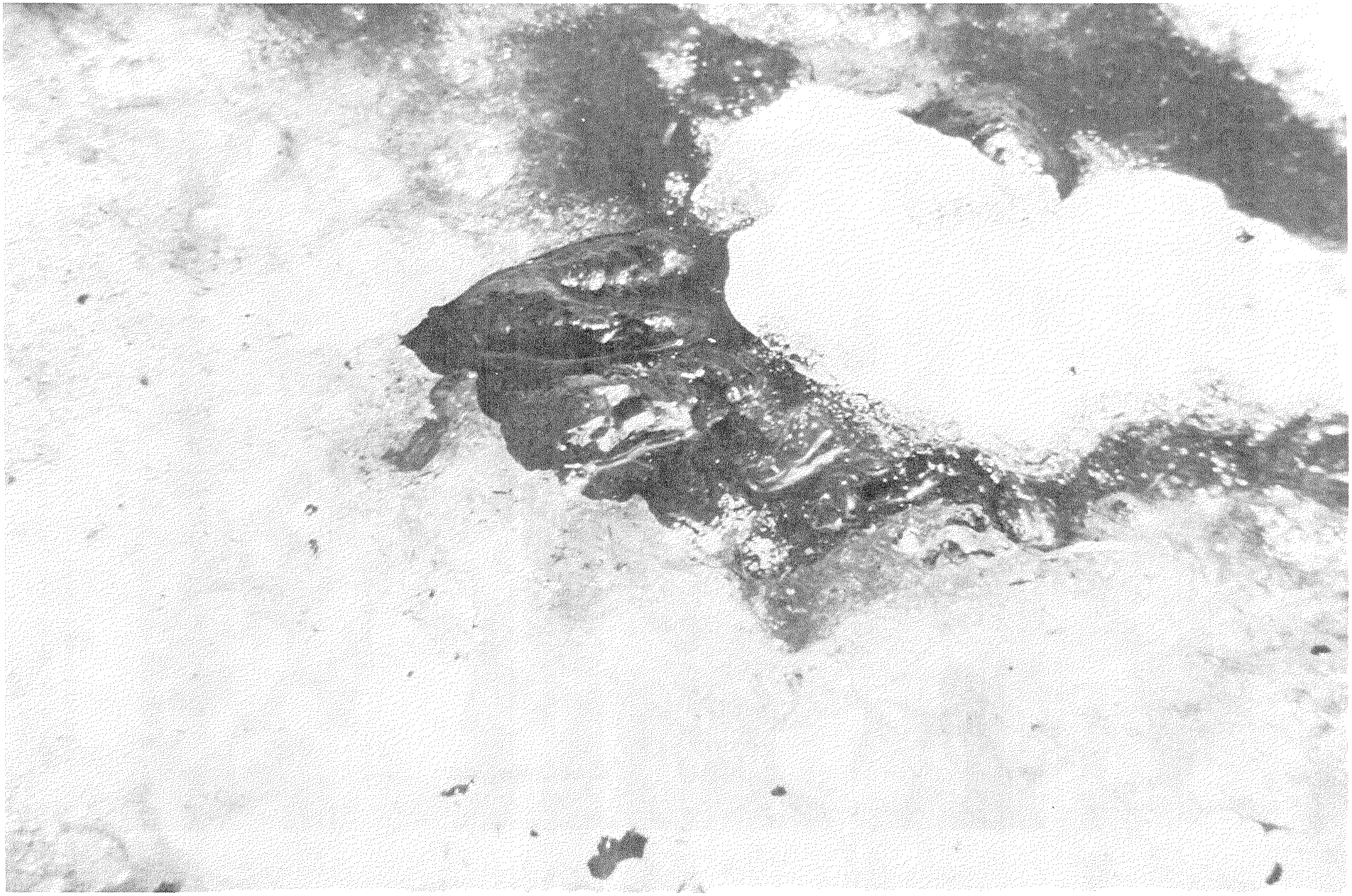


Figure 5. Oil entrained in ice floe (scale 1 cm = 1.5 cm).

Figure 6. Discontinuous band of oil (1-2 m wide) deposited on the back shore coating the bedrock, boulder, and cobble in a uniform layer.

Figure 7. Oil concentrated in a band at the berm of an exposed mixed beach.

Figure 8. Oil penetrating sand at the back shore beyond the berm of the mixed beach (scale 1 cm = 6 cm).

Figure 9. Oil cake stranded on the lower intertidal of a mixed beach (scale 1 cm = 7 cm).

Figure 10. Oil stranded on the back shore of a bedrock shoreline. Depth of oil in pool is approximately 7 cm.

Figure 11. Patch of oil high on the shore of a loose cobble beach. Depth of oil penetration approximately 20 cm.

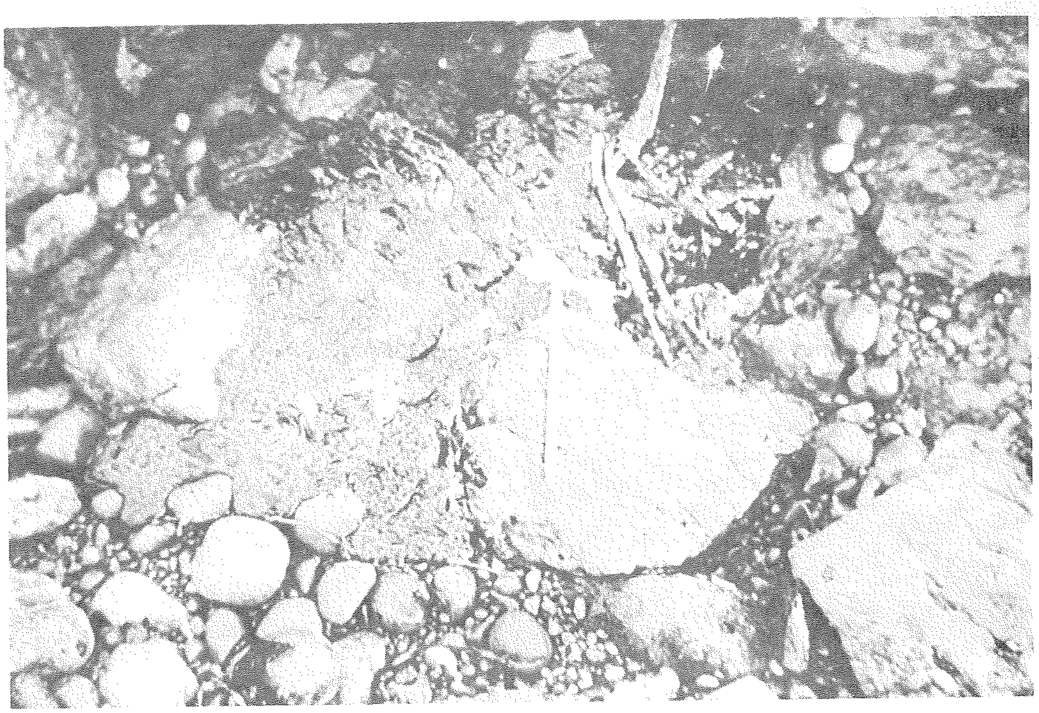


Figure 12. Viscous, tarry oil patch (approximately 1 cm thick) on back shore of exposed till deposit shoreline.

Figure 13. Sediments in intertidal zone stained with spots of oil (approximately 2 m - 2 cm diameter). Photo taken at the shore/water interface. Foreground is under water.

Figure 14. Dense deposit of fine oil stains (1-5 mm diameter) on shore of barachois behind an exposed barrier beach.

HYDROGEOLOGICAL CONSIDERATIONS FOR OIL WASTE DISPOSAL SITE SELECTION

Chang L. Lin
Nova Scotia Department of the Environment, Halifax, Nova Scotia

INTRODUCTION

During a major oil spill, large quantities of oil debris wastes have to be disposed of within a relatively short period of time. Incineration is often an effective and desirable method of disposal. In numerous circumstances where incineration is impossible and impractical, land disposal will be necessary.

During the emergency situation, there is usually insufficient time, manpower, or resources to properly locate and evaluate alternative sites and to secure necessary site use agreements. As a result, land disposal of oily wastes may encounter various environmental, operational, social, institutional, and legal problems if oily debris is disposed of at a hastily located or improperly situated site.

To minimize these problems, every oily disposal site must be properly evaluated, designed, operated, and monitored. Proper site selection can be assured only if it occurs through a rational planning process before a spill. Proper site selection is basic to safe oily waste disposal. This paper attempts to deal with the hydrogeological factors that must be considered in the initial site selection and planning for emergency oily waste disposal.

SITE SELECTION CRITERIA

From an emergency planning point of view, at least five basic factors must be considered in the site selection for oil spill debris disposal. These factors include (1) land use, (3) water quality, (3) location, (4) access, and (5) ownership. Table 1 is a summary of the criteria associated with these factors. Except for the water quality factor, the rationale and necessity for the other factors and criteria are obvious and require little elaboration. However, the stated criterion that the site should not be a source of water pollution is one of the major challenges of emergency oily waste disposal operation.

Table 1

Summary of oil spill debris disposal site selection criteria.

Factor	Criteria
Land use	Planned use of the site for debris disposal should be compatible with on-site and adjacent land use. Disposal at an approved sanitary landfill usually meets this criteria fully. Debris disposal within a residential area may not be compatible.
Water quality	The site should not be a source of water pollution. Disposal on porous soil overlying potable groundwater or in an area subject to flooding would not meet this criterion. Sites that do not overlie groundwater or, if they do, contain clayey soils, are likely to offer the best protection for groundwater.
Location	Sites should be situated as closely as practical to the point(s) where oil spill debris is (or would expectedly be) collected or stockpiled.
Access	Existing access roads into the site should be of all-weather construction or such roads should be constructed in an emergency situation. A site that cannot be readily accessed is of little use. Access may be temporarily facilitated by placement of a gravel road or military landing mats.
Ownership	Publicly owned lands may ensure better long term maintenance and acceptance of responsiblity compared to private property which can readily change ownership.

Oil is a potential water pollutant, and should definitely not be allowed to enter a drinking water supply and to contaminate potential ground and surface water supply sources. The theme of present day emergency oily waste disposal is 'Containment'. This involves the immmobilization of oily wastes, and the localization and minimization of contaminants. The potential water pollution problem associated with land disposal of oil spill debris may take one or a combination of the following forms (Fig. 1):

1. oil migration through soil
2. groundwater contamination
3. surface runoff of oily waste materials
4. washout of disposal areas
5. long term effect on vegetation

The surface water related pollution problems are in most cases obvious and can be minimized by proper control measures. For example, surface infiltration can be reduced by proper soil covering and compaction, and surface drainage problems can be controlled by proper landscaping, ditching, and ponding.

Because of the high annual precipitation in Nova Scotia, and the complexity of the subsurface contamination problem, there is little doubt that part of the infiltrating water will enter and move through the disposal site, resulting in the production of leachates. Some of these contaminants will eventually reach the water table and move along with the groundwater flow. To date, no universally applicable standards or criteria are available to eliminate this pollution problem and each site must be critically examined by qualified professionals. Discussed below are some of the major hydrogeological factors to be considered in the site selection for oil spill debris disposal in Nova Scotia.

HYDROGEOLOGICAL CONSIDERATIONS

Groundwater and Groundwater Flow Systems

Groundwater is the water present in the zone of saturation below ground surface and is part of the hydrological cycle. In the hydrological cycle the basic elements are precipitation, evapo-transpiration, runoff, and infiltration. Of these infiltration characteristics are the key elements of concern in groundwater hydrology, as it is this water which recharges and replenishes the groundwater resources. The infiltrating water moves downward through the unsaturated zone, enters the zone of saturation, and becomes groundwater.

The direction of groundwater flow must be known at any disposal site. In general, the direction of groundwater movement is perpendicular to the elevation contour lines which can be defined by three test wells. It is important to note that the actual groundwater flow field we are dealing with is a three-dimensional problem. For detailed analysis of contaminant transport, such as radioactive contaminants study, it may be necessary to install a series of piezometer nests to measure groundwater potential difference with depth and distance. Regardless of the minute details of the direction of actual groundwater movement, the groundwater flow is controlled by the fluid potential or hydraulic gradient, and will always be in the direction from high fluid potential to low fluid potential (Figure 2).

As groundwater flows through earth material, the water acts as an agent, constantly carrying, dissolving, and precipitating mineral matters as well as pollutants in solution or in suspended form in response to changes in biological, chemical, physical, and hydrogeological environment. Hence an understanding of the groundwater flow systems which descibe the constant movement of groundwater through earth materials from point of recharge from the ground surface to point of discharge to the ground surface is indispensable in assessment of any waste disposal sites, and certainly oily waste disposal sites are no exception.

The groundwater flow pattern in a given location is dictated by available infiltration, water table configuration, soil characteristics, subsurface geological conditions and hydraulic boundaries, and can be obtained by field instrumentation and analytical methods as well as numerical methods.

Water Table

The upper surface of the zone of saturation below ground surface is called the water table. In general, the water table is a subdued replica of landform. The water table varies with time and distance. The actual water table at any location reflects the balance of recharge/discharge of the groundwater system at that particular time.

Direct and extended contact of oily wastes with groundwater should be avoided. An ideal oily disposal site should be placed above the water table, and should have sufficient distance between the bottom of the disposal site and the highest water table position. This would also facilitate biodegradation of oil under aerobic conditions.

The annual precipitation in Nova Scotia is high, ranging from 110 to 150 cm. Moisture deficiency seldom occurs in soils in Nova Scotia. A large amount of precipitation is available for groundwater recharge, resulting in generally high water table conditions in Nova Scotia. Therefore, the general requirements that any oily waste disposal site be placed above the water table may not always be possible. It should also be noted that a backhoe trench may extend well below the water table and still maintain seemingly 'dry' working conditions presenting a false sense of security of the site. This is because seepage water evaporates as rapidly as it moves into the excavation.

Soil Characteristics

The oily waste disposal site must be underlain by low permeability soils for retardation and attenuation of contaminants. For contaminant control, we need earth material wih low permeability and low groundwater velocity. Permeability is a measure of the ability of earth material to transmit fluid. It is directly proportional to the size of particles. This hydraulic constant can be approximated by laboratory methods of field testing. Fine-grained material such as silt or clay has a permeability several orders of magnitude less than sand and gravel. Furthermore, the fine-grained material and clay-mineral content offer a larger surface area and thereby a greater capacity to attenuate contaminants by a mechanism such as sorption (Fig. 3). As water and its contaminants move through the fine material, several physical, chemical, and biological processes take place to remove dissolved solids from groundwater. Other processes act further to disperse and dilute the dissolved solids. At present, not all of these attenuation processes are completely understood and few can be quantified.

Velocity, the product of permeability and hydraulic gradient, is a measure of the movement of fluid. It is the critical factor in determining the configuration of a contaminant plume. This is because the biological and many of the chemical processes which act to attenuate groundwater contaminants are time-dependent. Rapid groundwater movement may allow contaminants to migrate proportionally greater distances before they are attenuated.

From both environmental and operational viewpoints, suitable overburden of sufficient thickness and areal extent must be available at any disposal site. It should be noted that although overburden with high percentage of fines is environmentally desirable these earth materials, once saturated, will significantly reduce their strength, and hence their workability and trafficability. Proper countermeasures must be provided to ensure continued operation during adverse weather conditions. In Nova Scotia the most suitable overburden is glacial till with sufficient rock fragments.

Geological Conditions

Subsurface geological conditions such as the types, distribution, sequence, and orientation of various geological formations determine the local details of the path of movement of groundwater. Furthermore, the lithology and composition of these bedrock units will influence the quality and quantity of natural groundwater. Hydraulically, it is the permeability contrasts and hydraulic boundaries that determine the groundwater pattern.

More than 60% of Nova Scotia is underlain by metamorphic and igneous bedrock. Here the primary openings are insignificant, and the secondary openings (fractures, joints, or faults) serve as the major conduits for groundwater flow (Lin, 1975).

Groundwater moves through intergranular space and/or fracture openings in bedrock and its effectiveness for leachate attenuation is determined by the relative importance of primary or secondary openings. In general, granular materials, especially those of fine-grained sedimentary rocks, provide greater opportunities for attenuating contaminants. In metamorphic and igneous rocks, where the primary intergranular opening is essentially negligible, the nature of groundwater flow is dictated by the size, frequency, and orientation of fracture openings. These openings are generally fresh and planar, and small in number. The movement of local groundwater contaminants could be fast, allowing little contact time with contaminants to achieve significant attentuation of contaminants. As a general requirement, therefore, no oily wastes should be disposed of directly above the bedrock with little or no protective cover of suitable overburden.

Topographic Relief/Locations

The topographic relief is the difference in elevation between the highest and lowest point in a region. As stated previously, the water table generally takes a subdued replica of landform. Naturally, the water table under a topographic high is higher than the water table in a topographic low - i.e. the groundwater at topographic high has a higher fluid potential than the groundwater at topographic low which has a lower fluid potential. The fluid potential is the driving force for groundwater movement. Groundwater always moves from the point of high fluid potential to the point of low fluid potential. Consequently, the magnitude and nature of topographic relief will determine the groundwater flow system to be of local or of regional extent. Therefore, without topographic relief to provide driving force and gradient, the groundwater will not move and development of a regional flow system is unlikely. The present landform of Nova Scotia is a plateau with a small regional topographic relief, marked by a series of elongated ridges and grooves left behind by Pleistocene glaciation. Consequently, development of regional groundwater flow systems is unlikely and the groundwater flow systems are mainly of a local nature, dictated by local topographic relief (Fig. 4). In the broadest sense, the topographic high is the recharge region whereas the topographic low, or valley or swampy area, is an area of groundwater discharge.

Therefore, with this understanding of groundwater flow and the various factors driving the flow and affecting its permeation it becomes clear that an oily waste disposal site should not be located in a major groundwater recharge area, where the path of groundwater flow and contaminants is likely long, and where a larger and wider portion of the aquifer is susceptible to contamination. Likewise, it should not be located too close to discharge areas, such as swamps, marshlands, lakes, or streams. Flood plains should also be avoided. With due consideration of all these criteria/factors mentioned above, the logical place to locate an oily waste disposal site is in a local topographic high where the water table is low, the groundwater flow system is of local nature, and the site is underlain by sufficient quantity of fine-grained earth material (Fig. 5).

CONCLUSION/SUMMARY

In emergency oily waste disposal site planning, we must recognize that there will never be a 'perfect' site meeting all possible requirements. The essence of a proper site selection process is in the delineation and preparation of environmentally acceptable sites at strategic locations before a spill. This includes also the identification and quantification of potential problems associated with the use of the site that must be incorporated in the planning, design, operation, and monitoring of the oily waste disposal operation. Once a suitable site has been located, consideration should be given to disposal methods. For example, the oily debris may be disposed of by land farming, landfilling, lagooning, or burial. There is no fixed rule as to which one of these methods must be used. Each disposal method should be tailored to specific site conditions, debris characteristics, type of cleanup operation and resources available.

Besides solving operational and administrative problems, the basic purpose of proper site selection for oily waste disposal is to ensure that the disposal site does not become a source of water pollution, especially of the groundwater resources. The recognized danger is that groundwater, the hidden resource, if left unattended, may become extensively polluted resulting in great loss of value. Unlike surface water, groundwater quality cannot be 'corrected' by pollution controls applied after the pollution has occurred. Instead, protection of groundwater resources depends entirely on pre-planning, on proper site selection before they are needed in a time of spill crisis.

ACKNOWLEDGEMENTS

The writer wishes to acknowledge that Table 1, Figures 1, 3, and 5 of this paper are taken from two procedure manuals, prepared by the U.S.

Environmental Protection Agency in August 1977. In preparation of this contribution the author acknowledges these publications and the others cited below.

LITERATURE CITED

HUBBERT, M.K. 1940. The theory of groundwater motion. J. Geol., 48: 785-944.

HUGHES, G.M. 1978. Groundwater contamination and its control. In *Civic Public Works*, August, pp. 38-39, and September, pp. 60-62.

LIN, C.L. 1975. Hydrogeology and groundwater flow systems of the Smith's Cove area, Nova Scotia. N.S. Department of the Environment, Water Planning and Management Division Report 75-1.

LIN, C.L. (in preparation). Regional groundwater flow systems and their implications in Nova Scotia.

ROWLAND, W.G., JR. AND M.L. MILLSTONE. 1977. Oil spills: a dilemma to be resolved. *J. Water Pollut. Control Fed.*, March 1977: 357-359.

U.S. ENVIRONMENTAL PROTECTION AGENCY, Cincinnati, Ohio. 1976. Gas and leachate from landfills, formation, collection and treatment. EPA-600/9-76-004, March 1976.

U.S. ENVIRONMENTAL PROTECTION AGENCY, Washington, D.C. 1976. A manual of laws, regulations, and institutions for control of groundwater pollution. Final Report, EPA-440/9-76-006, June 1976.

U.S. ENVIRONMENTAL PROTECTION AGENCY, Cincinnati, Ohio. 1977a. Oil spill: Decisions for debris disposal. Vol. I, Procedure Manual, EPA-600/2-77-153a, August 1977.

U.S. ENVIRONMENTAL PROTECTION AGENCY, Cincinnati, Ohio. 1977b. Oil spill: Decisions for debris disposal. Vol. II, Literature review and case study report. EPA-600/2-77-153b, August 1977.

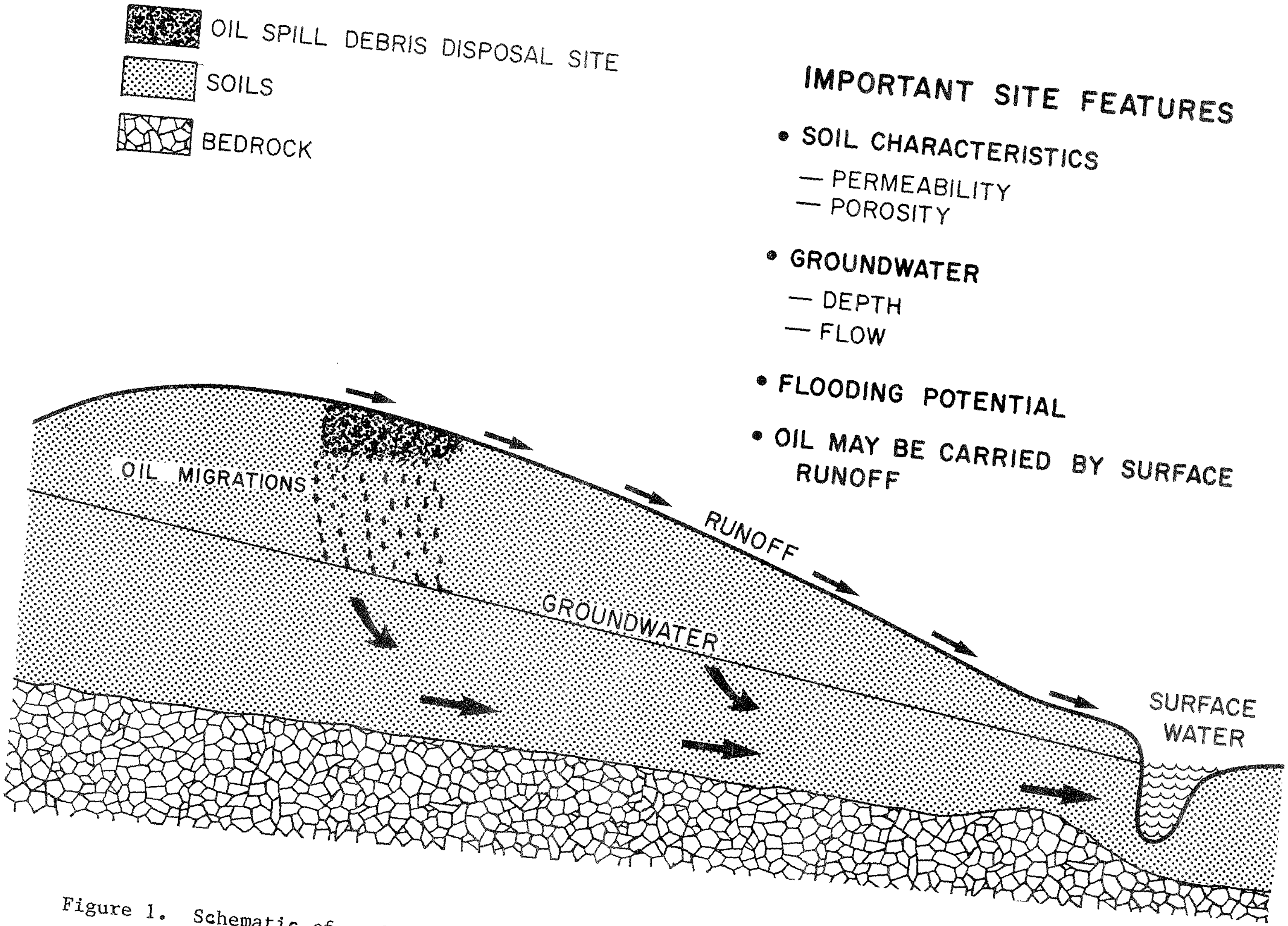


Figure 1. Schematic of geohydrological and soil conditions related to water contamination potential (modified after U.S. EPA, 1977a).

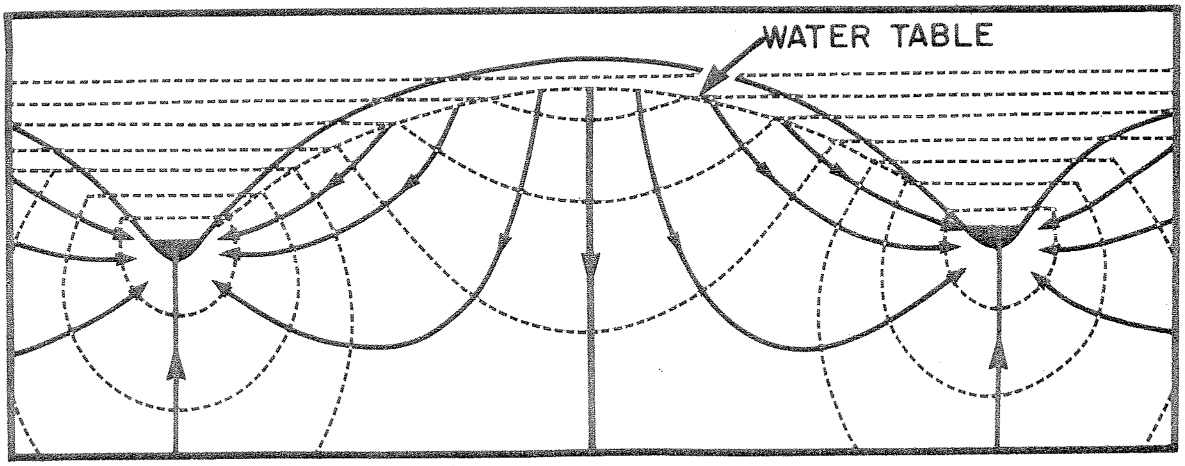


Figure 2. Idealized flow pattern in a uniformly permeable material dictated by fluid potential, moving from topographic high to topographic low (after Hubbert, 1940).

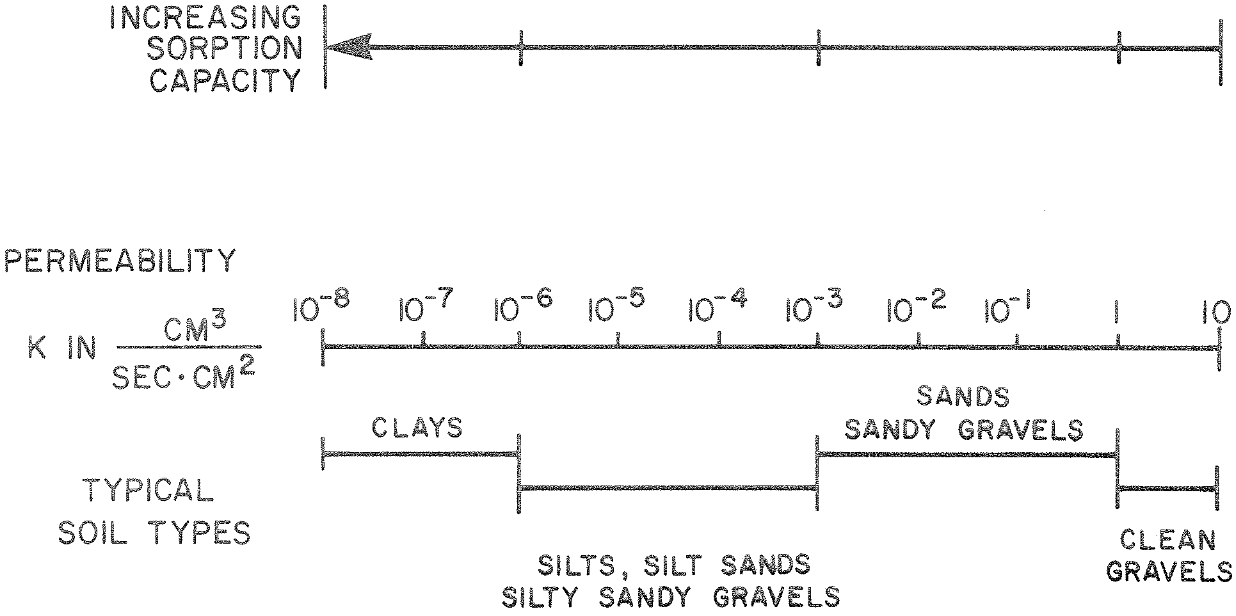


Figure 3. Soil permeabilities and sorptive properties of selected soils (after U.S. EPA, 1977a).

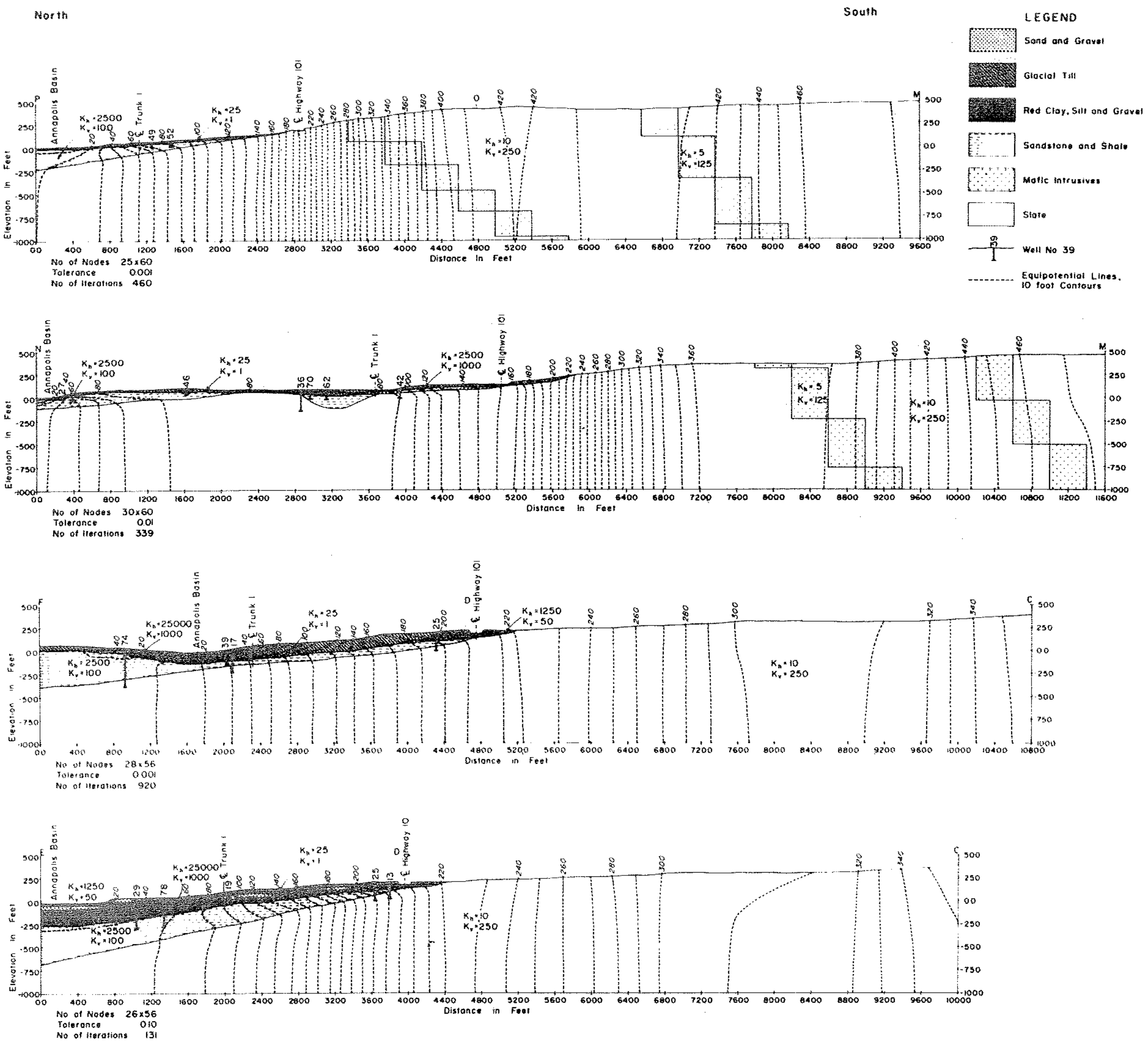


Figure 4. Regional groundwater flow patterns of the Smiths Cove area, Nova Scotia (after Lin, 1975).

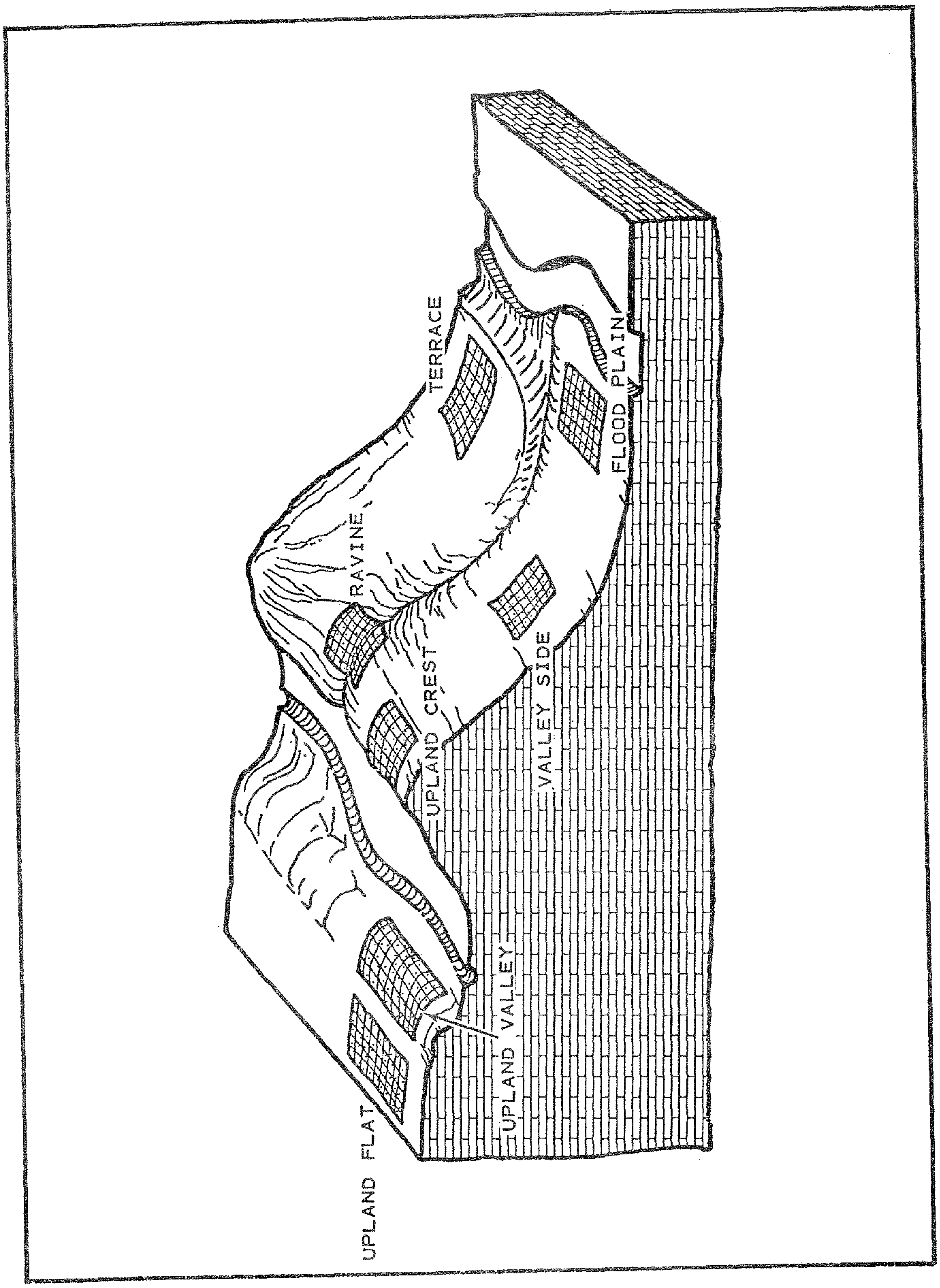


Figure 5. Relative location of various land forms (after U.S. EPA, 1977a).

DISTRIBUTION OF OIL, CHLOROPHYLL, AND LARVAL FISH ON THE SCOTIAN SHELF DURING APRIL AND MAY 1979 FOLLOWING THE KURDISTAN SPILL

R.N. O'Boyle
Marine Fish Division, Bedford Institute of Oceanography
Dartmouth, N.S., Canada

INTRODUCTION

On March 15, 1979, the MV *Kurdistan* broke in two in rough seas just off Cape Breton. Of the 30,000 tons of Bunker C oil that she was carrying, approximately 7000 tons were released into the ocean. Over the next month oil was reported from several parts of the Scotian Shelf, first from the Misaine and Banquereau Banks areas and subsequently from other parts of the Shelf.

As a direct result of this tanker accident, a number of studies were immediately initiated to determine the extent of oil pollution and potential slick movement out of the Cape Breton area (Vandermeulen and Buckley, 1980). Coincidentally, the Marine Fish Division of DFO carried out a number of sampling cruises through the affected area as part of its continuous Scotian Shelf Ichthyoplankton Program (SSIP), ongoing since April 1977. This long-term program is designed to examine temporal and spatial changes in the abundance and distribution of larval fish communities as well as changes in the Shelf hydrography, as these affect fish population stock-recruitment relationships.

The program includes several cruises each year over a multi-point grid covering the entire Shelf, and therefore provided a ready opportunity to incorporate an oil-sampling study. Cruises for April and May were modified to include surface oil sampling and to make observations on surface oil distribution.

This report summarizes the observations made during these two SSIP cruises, the first occurring only 15 days after the breakup of the *Kurdistan.* As well, distributions of some of the dominant forms of larval fish, along with that of surface chlorophyll and temperature, are discussed. Surface water temperature data are here included since they may relate to observed plankton bloom phenomena.

STANDARD CRUISE PROTOCOL

An SSIP cruise is carried out approximately once every two months. Each consists of sampling a 150-station grid over a 3- to 4-week period using a variety of plankton nets and oceanographic equipment.

At every station, surface water samples are taken routinely for determination of temperature, salinity, nutrients (PO_4, NO_3, SiO_3), chlorophyll, and particle structure (1-300 μ). At selected stations, these measurements are made throughout the water column with the use of Knutsen bottles. A BT and Secchi disc cast are made on all stations, or whenever possible. A number of plankton net tows are carried out as follows:

(1) Oblique Bongo: The standard MARMAP Bongo haul using 2x333 μ mesh nets. The ship's speed is varied between 2.0 and 2.5 knots to maintain a 45° wire angle. Wire is let out at 50 m/min and retrieved at 20 m/min. Maximum haul depth is 200 m. This tow provides an integrated sample of plankton from the water column.

(2) Surface Bongo: This is the same net as above, but is towed at the surface for 15 min at 2.5 knots.

(3) Isaacs-Kidd Trawl: A 6 ft mid-water trawl used to collect the macroplankton. The gear is towed obliquely at 5 knots.

(4) Surface Neuston: A 0.3x1.0 m frame fitted with a 1179 μ mesh. It is towed on the surface at 5 knots for 30 min. In one tow, it covers about 4061 m^2 of sea surface.

(5) Surface Box Neuston: A 0.5x0.5 m box frame fitted with a 243 μ mesh net. It is also towed on the surface at 5 knots, but only for one nautical mile. It samples about 741 m^2 of sea surface.

Although oil was collected in almost all nets, it was present in significant amounts only in the surface tows. Therefore, discussion will be limited to the latter only.

RESULTS

April 1979 Survey (L015)

The RV Lady Hammond left the Bedford Institute of Oceanography (BIO) at 1600 h on April 2 and did not complete the sampling grid until April 25. During this time, it sampled 124 of the 150 assigned stations. The cruise track is given in Figure 1. Sampling of the northern area took place between April 2 and April 12. Stations on the easternmost edge of Banquereau Bank could not be occupied due to rough weather.

Oil Observations

Figure 2 illustrates the April oil distribution as estimated from contamination of the surface neuston (1179 μ) tows. Detailed station-by-station oil reports are given in Appendix A. Oil pollution was observed generally over most of the cruise area, ranging from trace oil to heavy oiling (Figure 3). The heaviest concentrations were observed just off Cape Breton, at stations 32-01, 33-01, 34-01, 35-01, 37-06, 35-02, 34-02, 33-02, and 32-02. At station 32-01, the oil was so thick that the neuston net had to be cut from its frame. The oil in this area generally was a sticky, grease-like material which completely clogged nets and coated frames.

Moderate to low concentrations of oil were encountered both off Cape Breton and offshore from Halifax. In these areas, the oil was in the form of small particles, with no particles being greater than 10 cm in diameter. Small amounts of oil particles were found in surface tows as far south as Browns Bank. However, these observations are not as reliable as the others due to the possibility of cross-contamination between hauls. As this first survey was not designed to quantify oil distribution, no cleaning equipment was carried on board and consequently cross-contamination between tows most likely did occur.

Hydrography

Figure 4 summarizes the sea surface temperature regime for April 1979. Surface waters were coldest in the Canso-Misaine Bank area, with temperatures being generally below 0°C. The surface mixed layer depth in this area was at approximately 85 m.

The 2° isotherm ran from Halifax straight out through the Gully to just south of Banquereau Bank. Water in the 0 to 2°C region was mixed down to about 70 m.

Slightly warmer waters were encountered throughout most of the southern area of the Shelf. The highest temperatures were encountered just off the southern tip of Browns Bank. The surface layer in this whole area reached down to a mean of 56 m, except for just off Yarmouth where it was at 128 m.

Surface Chlorophyll

Figure 5 summarizes the surface chlorophyll (extracted) results obtained during April 1979. The highest levels (10-15 μg/L) were found on the Shelf break just south of Emerald Bank.

Larval Fish Distribution

Onboard sorting of the oblique Bongo tows was carried out during this cruise. The results for the predominant species - ammodytes (sand lance), American plaice, and redfish - are given in Figures 6 to 8.

Larval sand lance were found in substantial numbers over large areas of the Shelf. However, they were primarily concentrated along the coast and Middle Bank-Gully area. From their length-frequency distribution, these larvae were estimated to be about 20 to 30 days old. Larval American plaice were caught only on Western and Browns Bank. Very little data exists for plaice spawning. Nevinsky and Serebryakov (1973) observed plaice eggs and larvae on the Scotian Shelf primarily in May, indicating that the observations made here are most likely at the beginning of the spawning cycle.

Redfish spawn viviparous larvae from May to August (Leim and Scott, 1966). Figure 8 illustrates the concentrations of these larvae found durng the April cruise. As with American plaice, it appears as if spawning has only just started.

May 1979 Survey (L018)

The RV *Lady Hammond* left BIO at 10:00 on 15 May and did not complete the survey until 1 June. Only 78 of the 150 stations were sampled (Figure 9) due to an unscheduled oil sampling study being carried out 18-21 May on Banquereau Bank in cooperation with the Coast Guard. Sampling of the northern end of the Shelf occurred during 16-29 May.

Oil Observations

As in April, oil was observed in surface samples over extensive areas of the Shelf. It was particularly heavy in the Misaine Bank and Gully area. The farthest southwest that it was observed was in the LaHave Basin.

Generally, oil occurred in small, particulate form, 1 to 2 cm in diameter. Larger particles of up to 20 cm in diameter and 3 cm thick were found near Middle Bank. Often, large lumps of oil, one measuring 1 m across, were observed floating by.

Hydrography

The sea surface temperature structure is illustrated in Figure 11. The water had warmed up considerably since April, with temperatures ranging from 3 to 4°C off Cape Breton, the coldest area, to over 10°C just off the southern edge of the Shelf. The water column was fairly well stratified over most of the Shelf, with an overall surface mixed layer depth of 11 m.

Surface Chlorophyll Structure

The chlorophyll results are given in Figure 12. Very low values were observed throughout the Shelf. The highest concentration (2-5 µg/L) were off northern Cape Breton. Most of the Shelf exhibited values lower than 1 µg/L. This is a marked contrast to the situation in April when chlorophyll levels of 10 to 15 µg/L were observed.

Larval Fish Distribution

Only larval forms of cod (Fig. 13), American plaice (Fig. 14) and sand lance (Fig. 15) were caught in May.

Cod normally spawn on the Shelf during May-April (Leim-Scott, 1966). The cod caught here on Western-Sable Bank were about 30 days old, placing their spawning in late April. As no cod larvae had been caught during the April cruise it seems likely that spawning had occurred in the Sable Bank area during the late April or early May period.

American plaice larval catches were slightly higher in May than in April, supporting the hypothesis that spawning of this stock occurs primarily in May (Nevinsky and Serebryakov, 1973). All American plaice larvae were taken in the Western-Sable Bank area.

As in the April cruise, significant numbers of larval sand lance were found over large areas of the Scotian Shelf. The distribution was approximately the same as in April. However, in May sand lance occurred farther north than in April.

DISCUSSION

The Scotian Shelf Ichthyoplankton Program started in early 1977. It is too early to state what effects, if any, oil pollution will have on the various stocks on the Scotian Shelf since, before models of stock recruitment relationships can be constructed, at least ten years of data are needed. At this time we can only present the biological 'picture' on the Shelf at the time of the spill.

With respect to primary production, the cruise results indicate that there was probably a Shelf-wide bloom in March which slowly disappeared in a northerly direction. In April, the highest phytoplankton biomass was restricted to the northern area of the Shelf. By May the bloom was finished. From the changes in the mixed layer depth it appears that stratification as well occurs in a south-to-north direction and parallels the time-course of primary production. In April the southern Shelf waters were more stratified than those in northern areas, while in May most Shelf water was fairly well stratified.

A number of communities of fish were spawning on the Shelf just after the March 15 spill. Certainly sand lance, which are a major forage organism for groundfish such as cod and haddock on the Scotian Shelf, were spawning over large areas of the Shelf in at least March and April. This is earlier than previous reports have indicated (Leim and Scott, 1966).

Few larval sand lance (ammodytes) were caught in areas of heavy oil pollution during the April cruise period. However, without an historical time series it is impossible to state whether this was due to high larval mortality or to low spawning activity in these areas. The May results, however, tend to show that spawning of ammodytes larvae can occur in apparently oil-polluted waters (viz. Figures 10 and 15). One possible explanation of these observations may be that the water temperature in the Banquereau Bank area in April was simply too low for spawning to occur, and that indeed the reduced spawning in April had nothing to do with the coincidental oiling of the Shelf waters.

Only one stock of American plaice has been identified on the Scotian Shelf. The data presented here tend to show that this population was spawning in late April-early May. However, none seems to have occurred in areas north of the Gully where the heaviest oil concentrations were found. It therefore seems highly unlikely that oil pollution had any effect on this stock.

One stock of redfish has also been identified on the Shelf. Spawning of this population appears to have occurred in March over wide areas of the Shelf, excluding the north. Thus, the overall impact of oil pollution on this stock would also probably be minimal.

Two cod stocks are known to spawn on the Shelf - those of 4VsW and 4X. Evidence of the former occurring in the Western-Sable Bank area during April was found in the May survey results. Again, very few larval cod were encountered in the northern Scotian Shelf area. Thus it seems unlikely that oil pollution would seriously affect this particular stock.

All these comments are based on onboard-sorted material, and must await confirmation both from actual laboratory reports and from further cruise data.

SUMMARY

It is too early to state whether or not the oil spill will have any effects on recruitment success of Scotian Shelf fish stocks. It seems likely, however, due to an asynchrony in time and space, that no substantial egg and larval mortality due to oil pollution occurred.

REFERENCES

LEIM, A.H. and W.B. SCOTT. 1966. Fishes of the Atlantic coast of Canada. Bulletin, Fisheries Research Board of Canada, No. 155, Ottawa.

NEVINSKY, M.M. and V.P. SEREBRYAKOV. 1973. American plaice, *Hippoglossoides platessoides platessoides* Fabr., spawning in the Northwest Atlantic area. ICNAF Research Bulletin No. 10: 23-36.

VANDERMEULEN, J.H. and D.E. BUCKLEY, Editors. 1980. The *Kurdistan* Oil Spill, March 15/16, 1979. Activities and observations of the Bedford Institute of Oceanography scientific response team. Bedford Institute of Oceanography Report Series, BI-R-80-2.

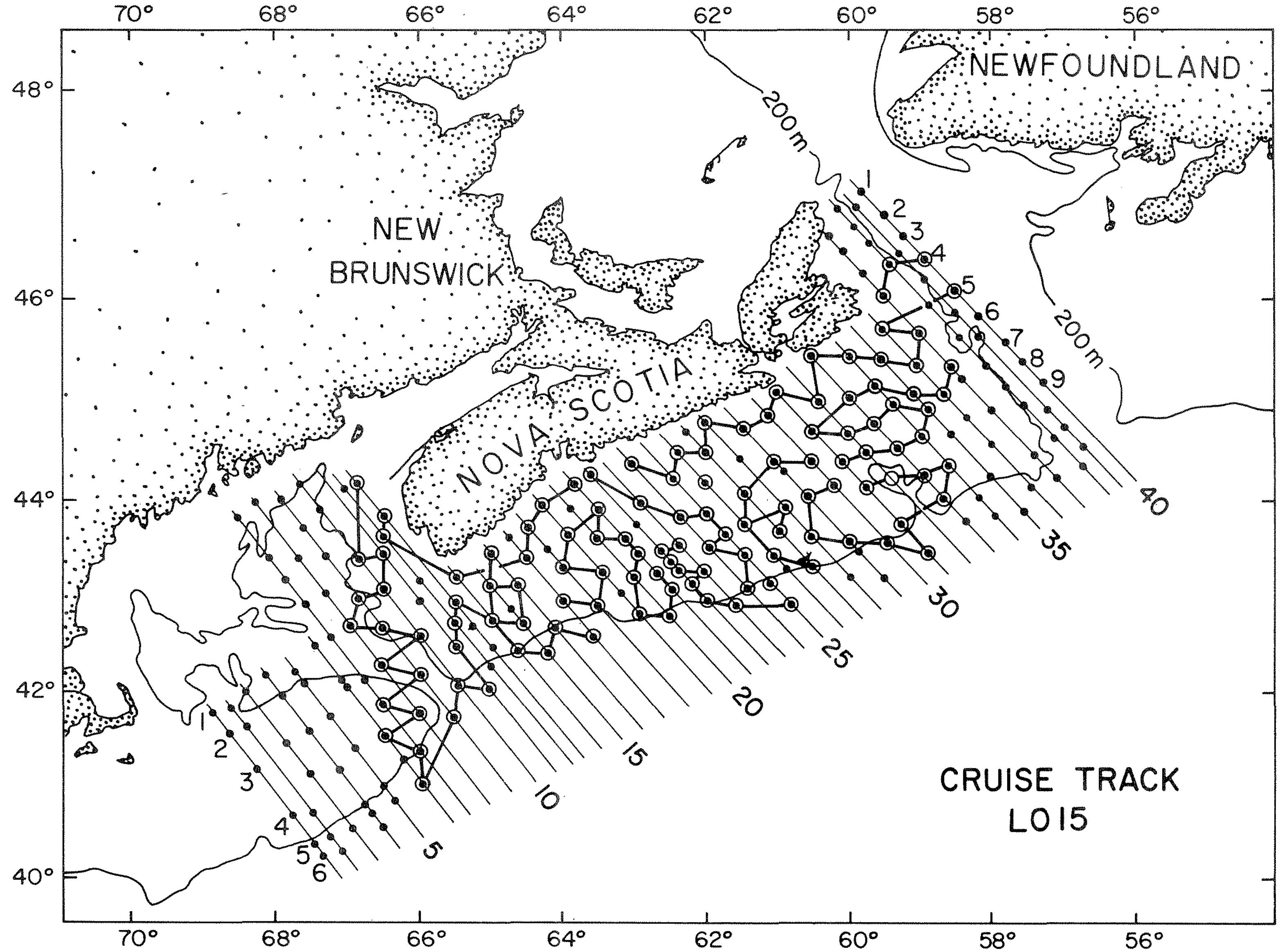


Figure 1. L015 cruise track and oil sightings.

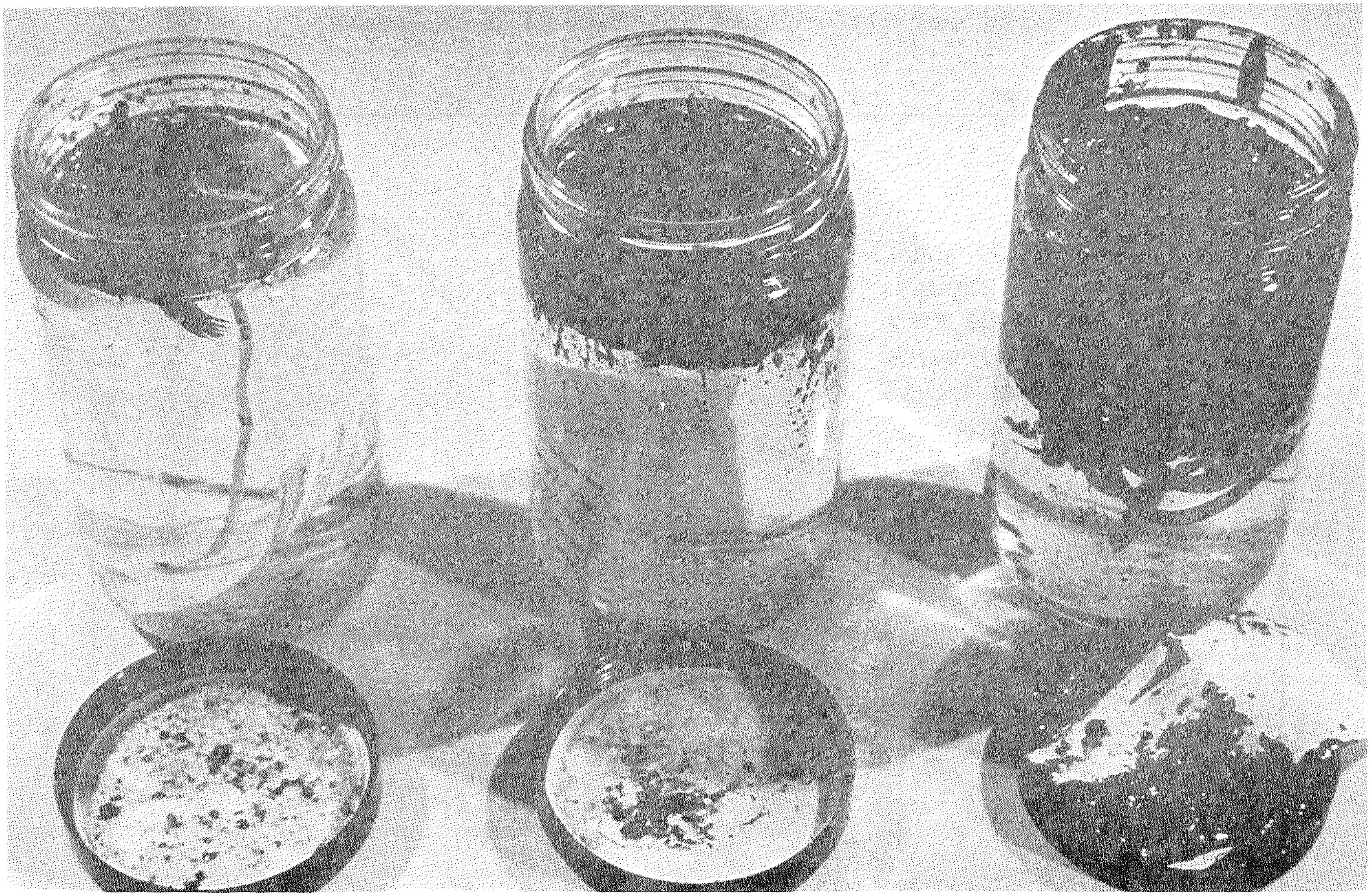


Figure 2. Typical tow samples from Lady Hammond Scotian Shelf Ichthyoplankton survey (SSIP) cruise April 1979, showing from left to right, trace, moderate-low and heavy oiling respectively (viz. Appendix A).

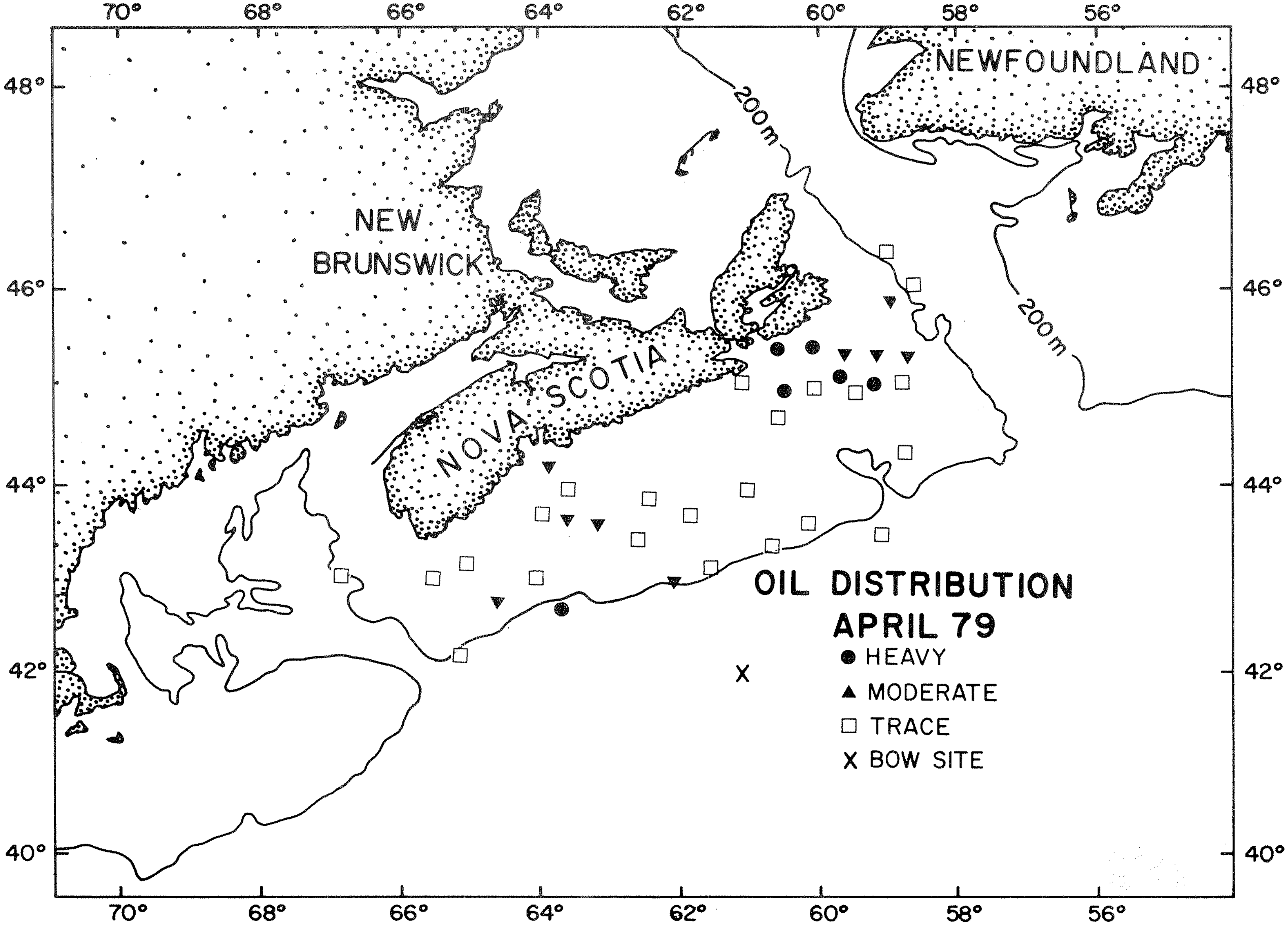


Figure 3. Distribution of oil taken from Neuston surface tows (April 1979).

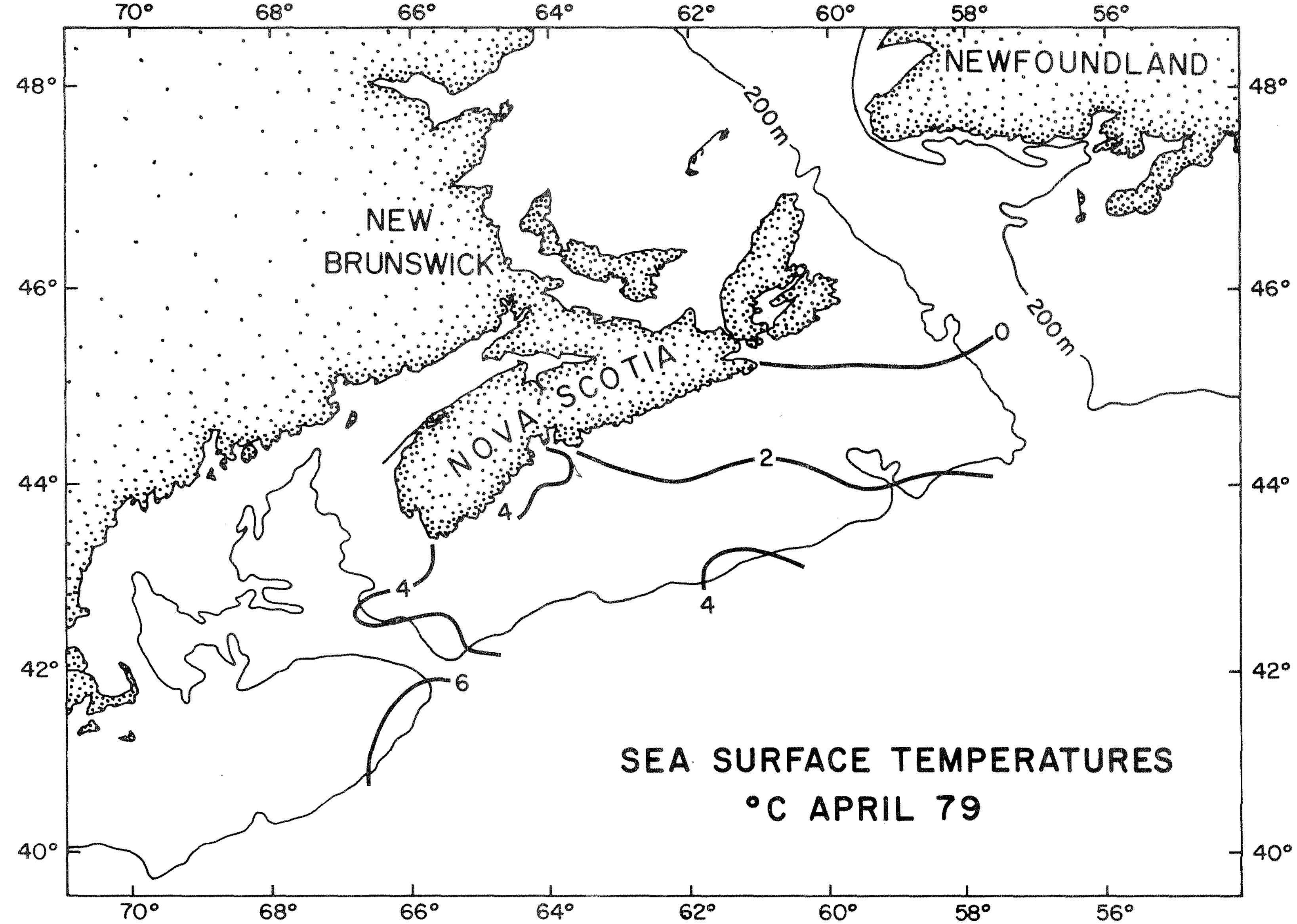


Figure 4. Sea surface temperature (°C, April 1979).

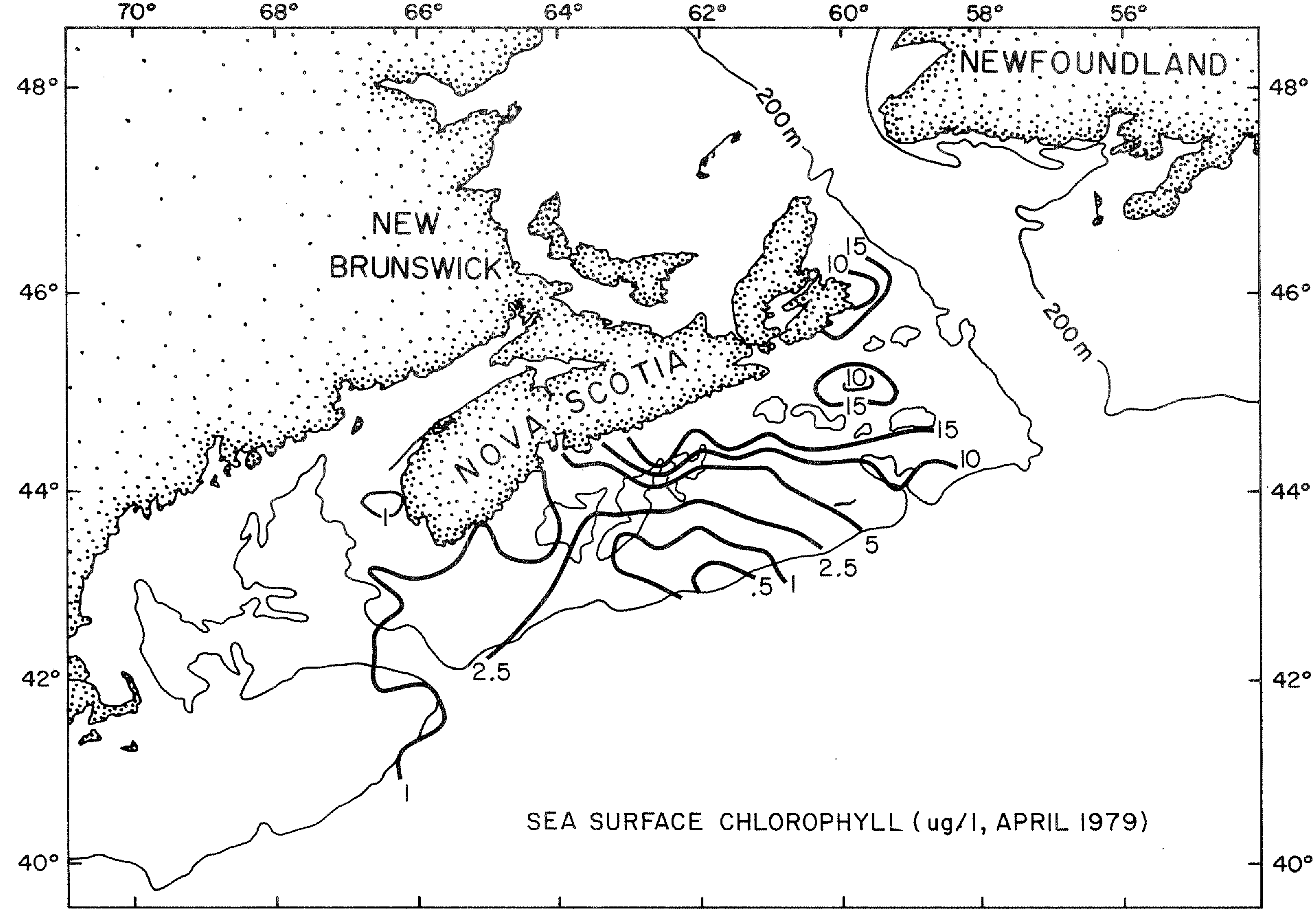


Figure 5. Sea surface chlorophyll (μg/L, April 1979).

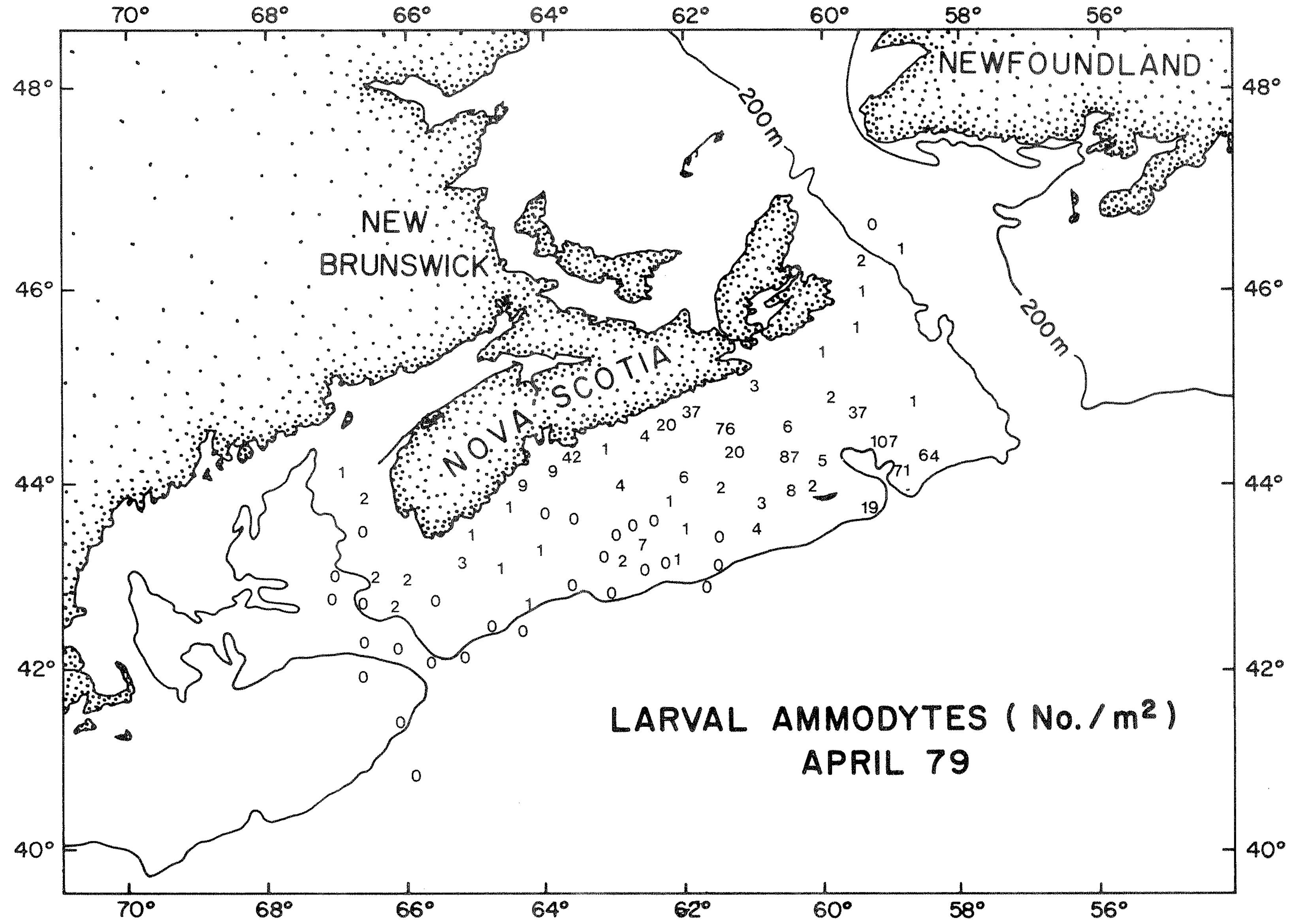


Figure 6. Larval ammodytes (number per m^2) in oblique Bongo tow data (April 1979).

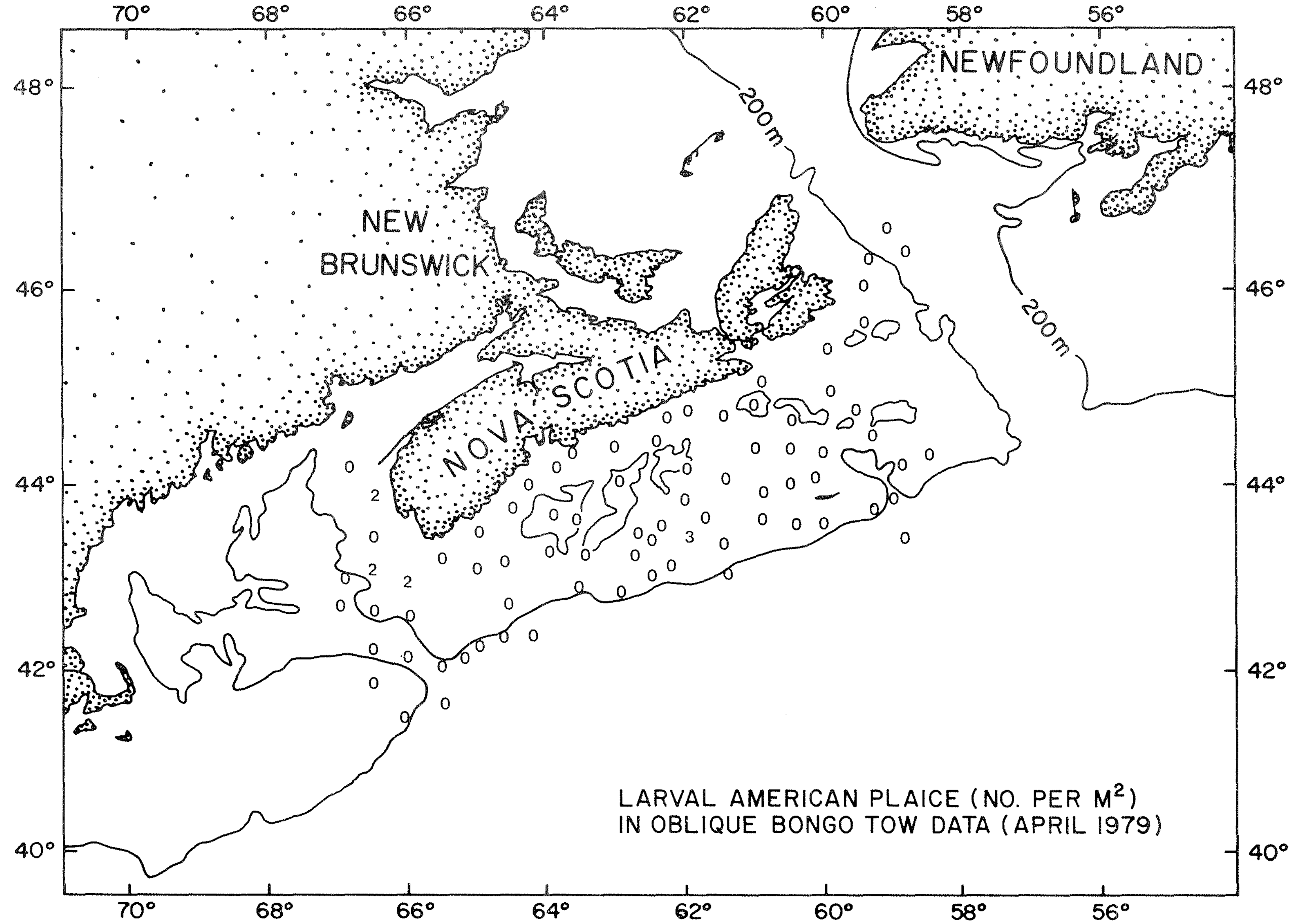


Figure 7. Larval American plaice (number per m^2) in oblique Bongo tow data (April 1979).

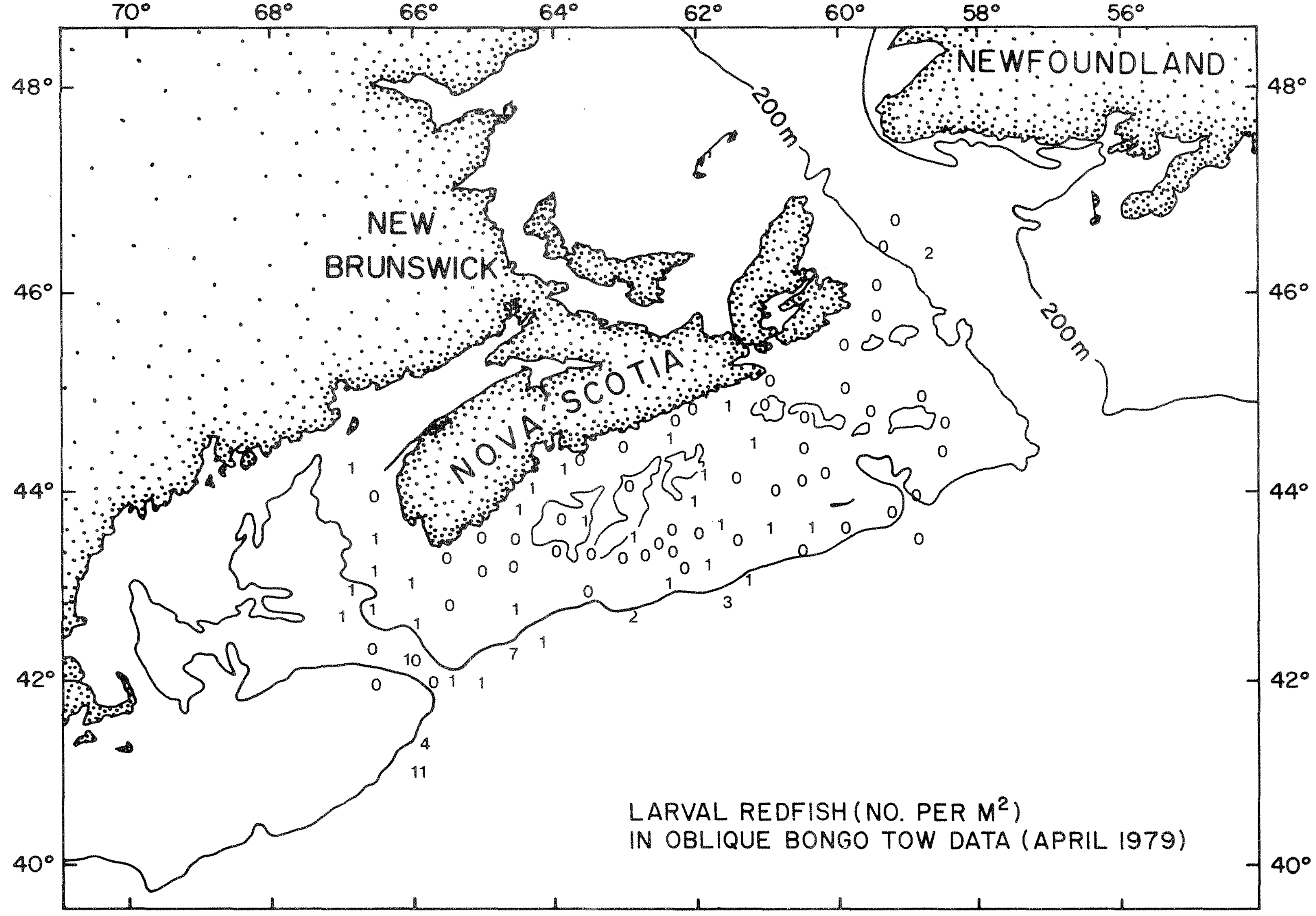


Figure 8. Larval redfish (number per m^2) in oblique Bongo tow data (April 1979).

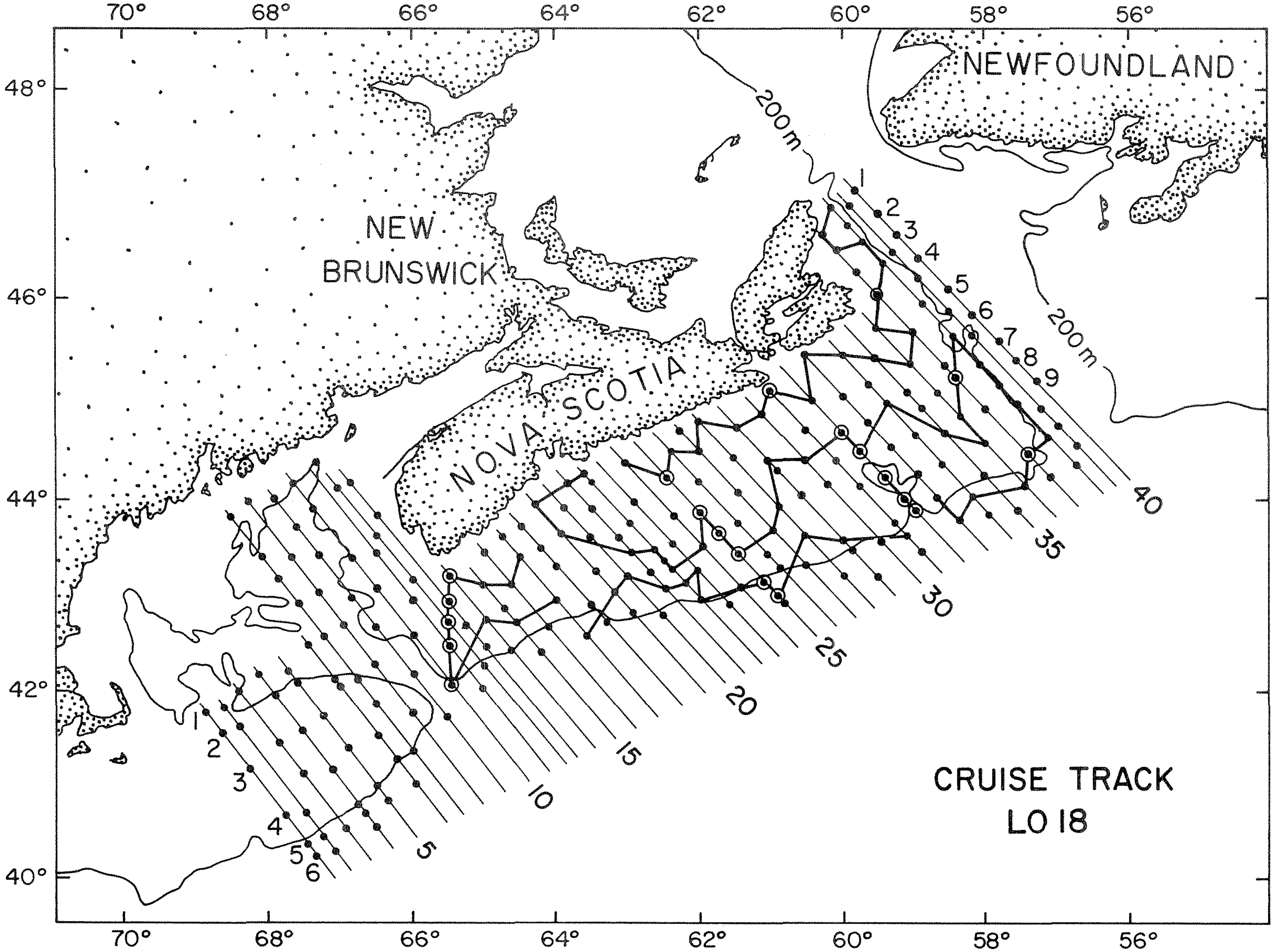


Figure 9. LO18 Cruise track May 1979.

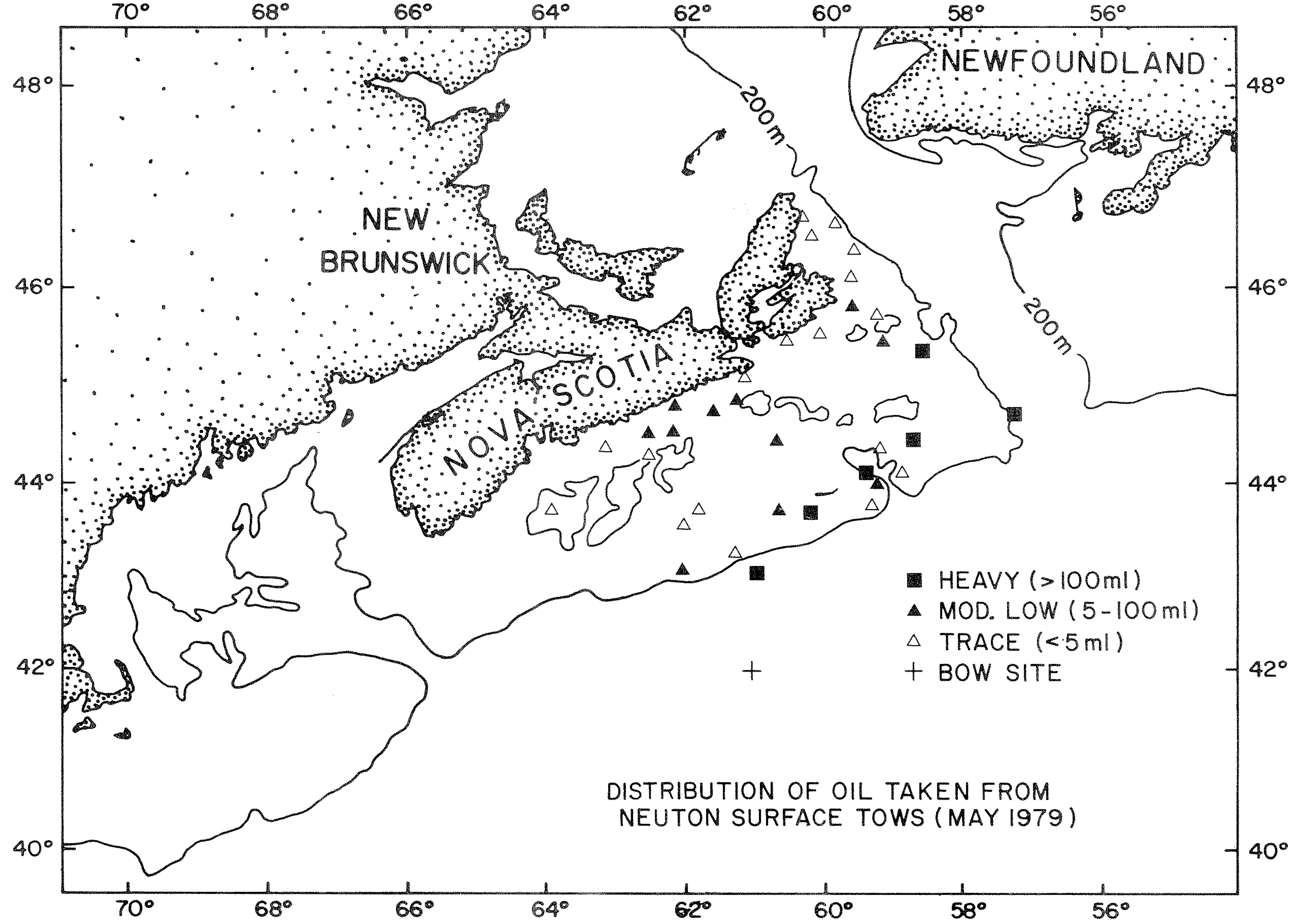


Figure 10. Distribution of oil taken from neuston surface tows (May 1979).

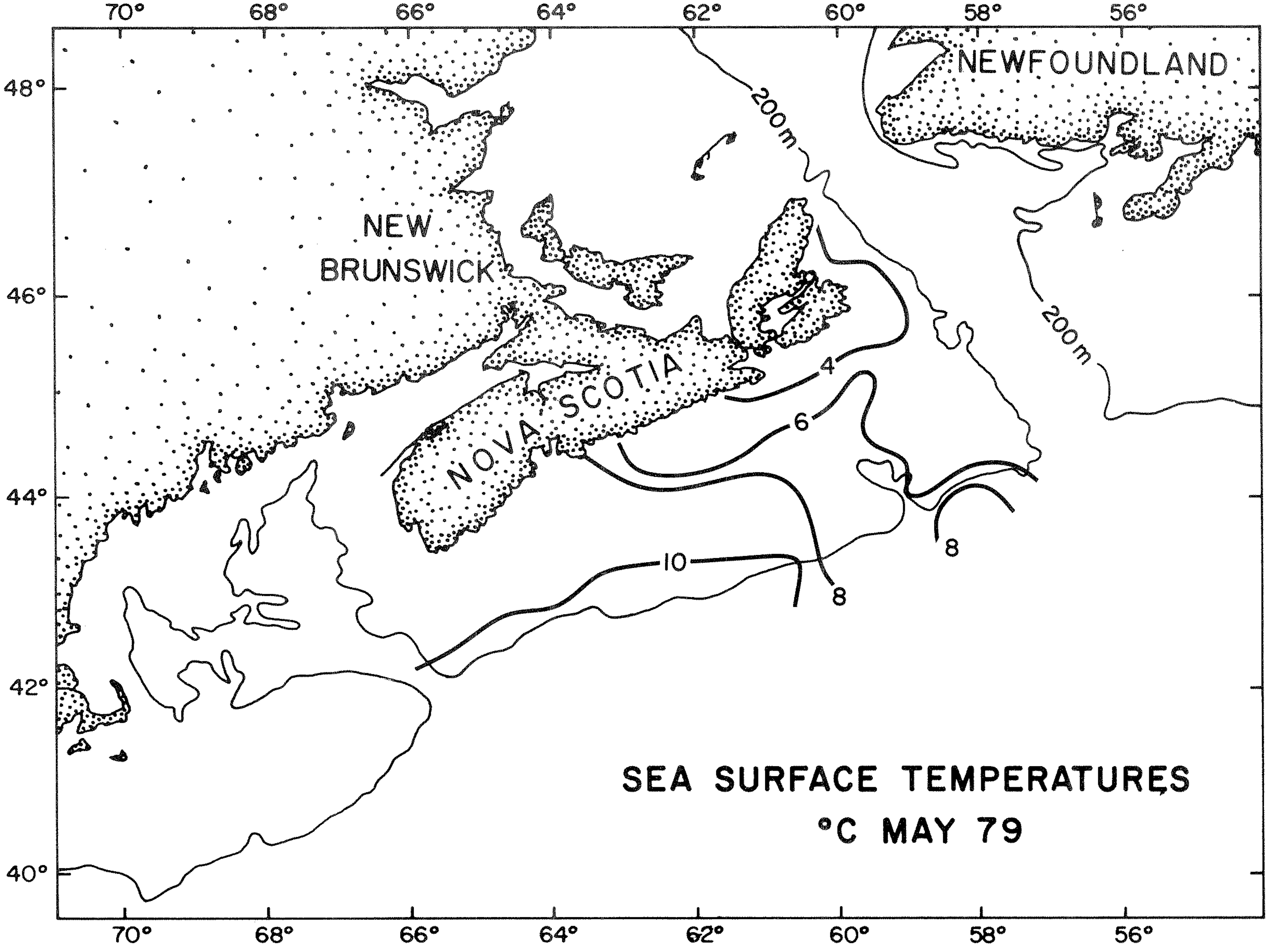


Figure 11. Sea surface temperature (°C, May 1979).

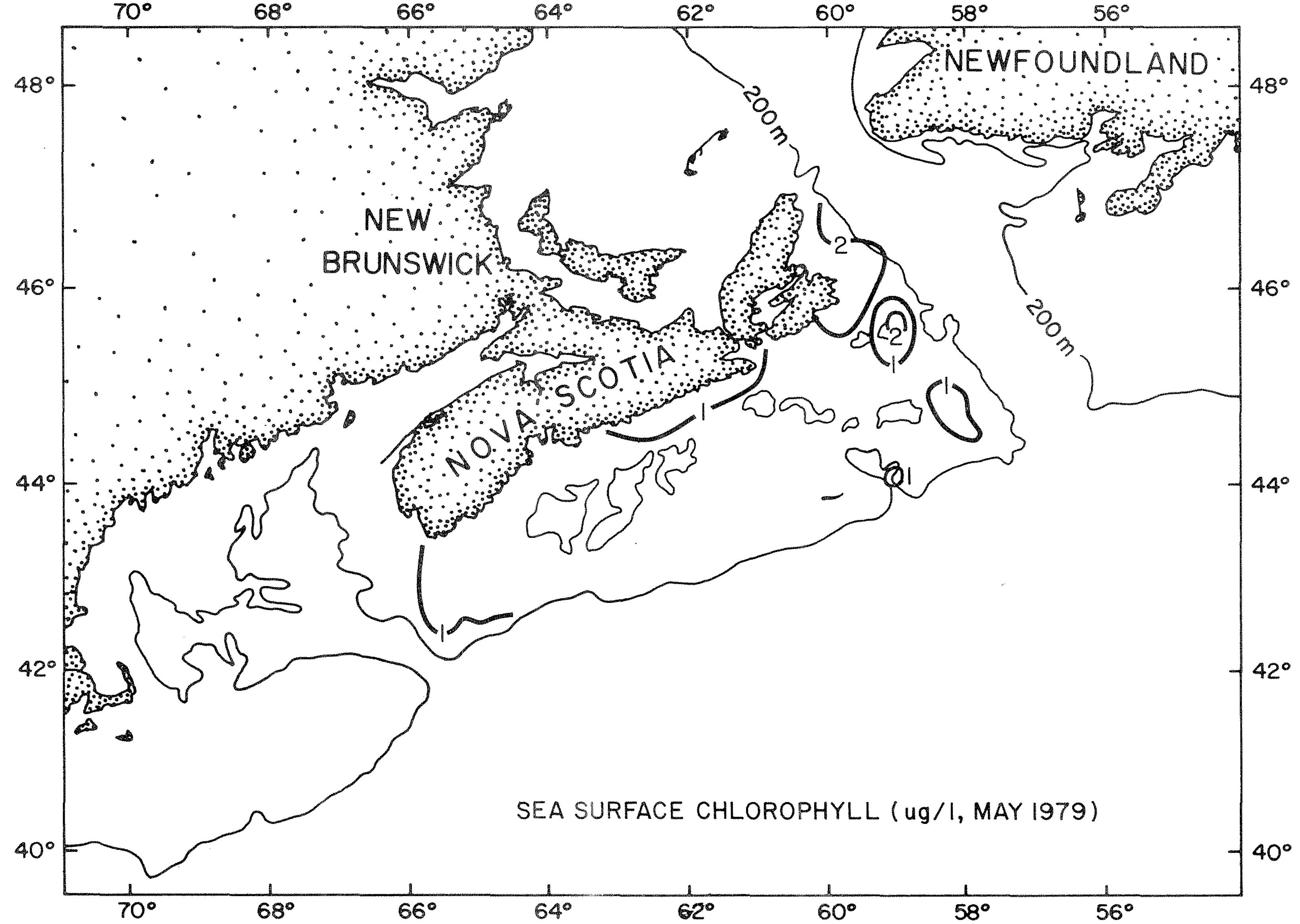


Figure 12. Sea surface chlorophyll (μg/L, May 1979).

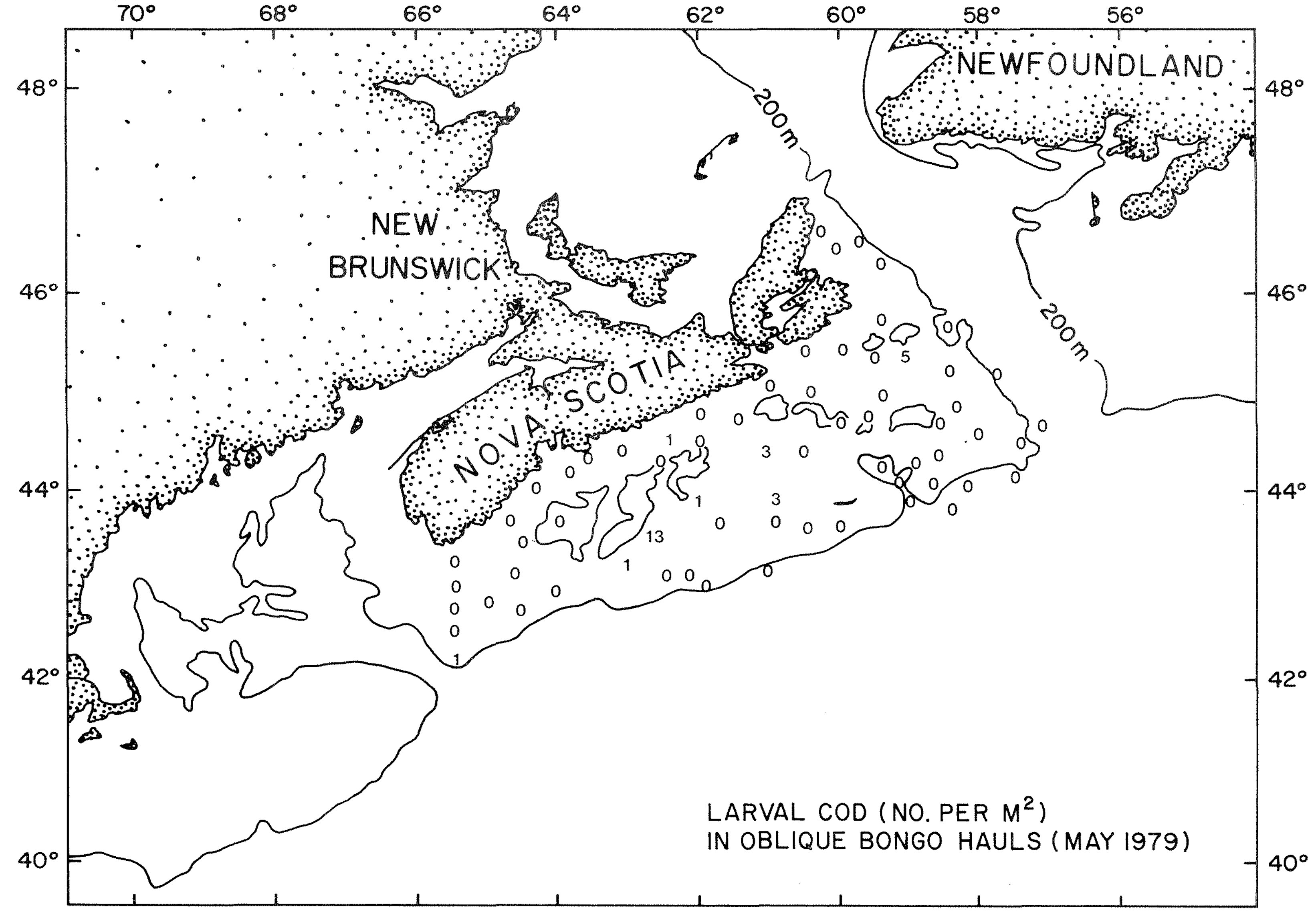


Figure 13. Larval cod (number per m^2) in oblique Bongo hauls (May 1979).

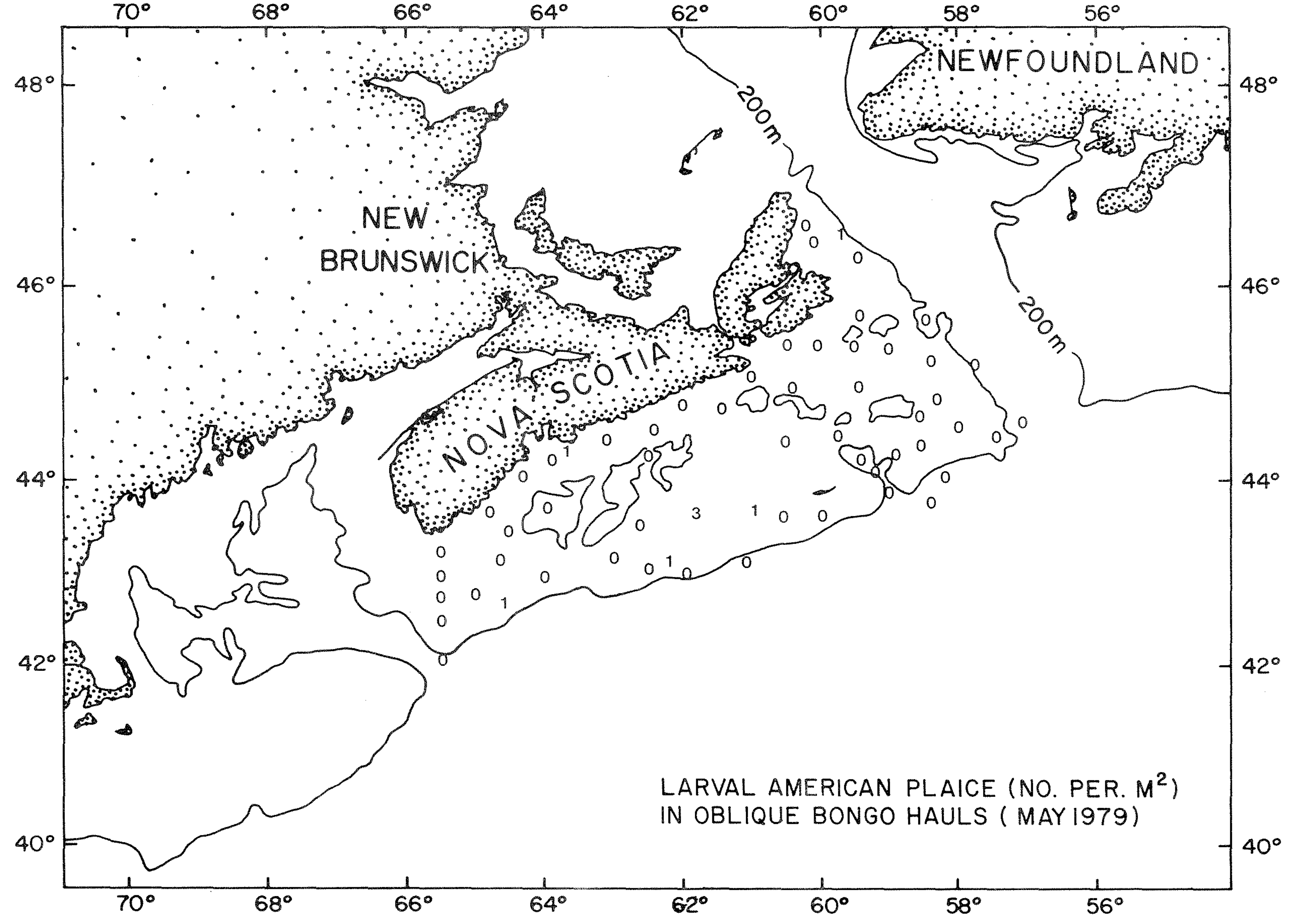


Figure 14. Larval American plaice (number per m^2) in oblique Bongo hauls (May 1979).

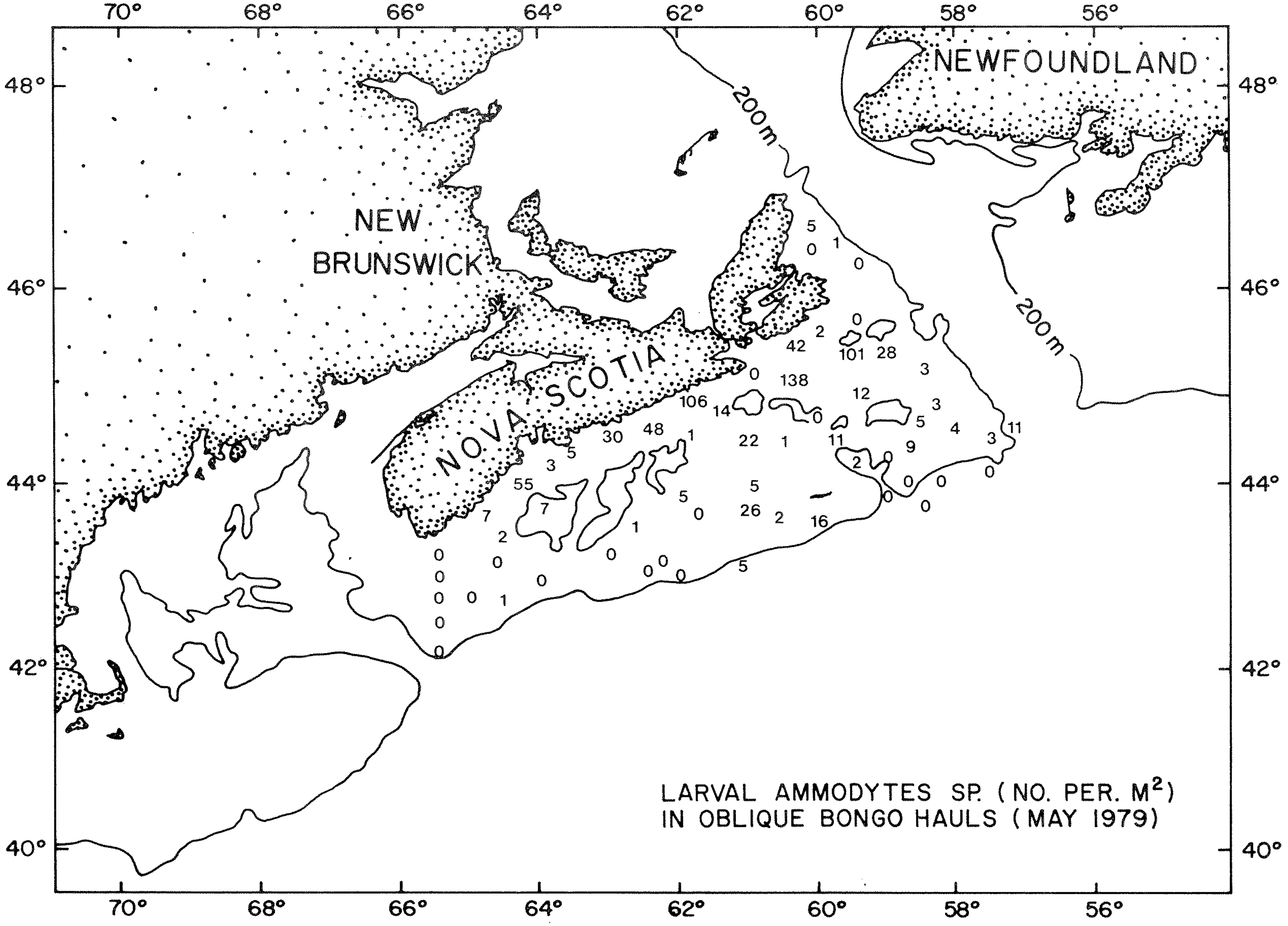


Figure 15. Larval Ammodytes sp. (number per m^2) in oblique Bongo hauls (May 1979).

Appendix A

LADY HAMMOND (L015) CRUISE INFORMATION AND OIL OBSERVATIONS

(Key to oil report: Heavy - Oil appeared as thick greaselike mass covering nets and frames; Moderate - Low Oil appeared as particulate suspensions floating in top 1/4 inch of one litre sample jar; trace - Oil appeared as individual particles floating on surface of sample held in one litre jar. (Viz. figure 2).

Station	Date (April/79)	Local Time	Latitude ° ' "	Longitude ° ' "	Oil Report
24-01	2	0040	44 28 07	63 04 66	-
25-01	3	0530	44 18 97	62 27 76	-
26-01	3	0735	44 32 85	62 24 99	-
27-02	3	1023	44 34 02	62 01 01	-
28-01	3	1330	44 51 05	61 59 61	-
28-02	3	1725	44 30 05	61 29 91	-
29-01	3	1950	44 47 98	61 28 02	-
30-01	3	2205	44 54 92	61 06 14	-
31-01	4	0100	45 09 37	61 00 37	Trace
32-01	4	0405	45 03 78	60 25 00	Heavy
33-01	4	0720	45 32 15	60 30 13	Heavy
34-01	4	1000	45 32 01	59 59 33	Heavy
35-01	4	1235	45 29 17	59 30 01	Heavy
36-02	4	1457	45 27 99	59 02 55	Moderate-low
37-05	4	1800	45 45 88	58 59 98	Moderate-low
36-01	4	2035	45 48 98	59 28 05	-
38-05	5	0110	46 02 88	58 52 47	Moderate-low
40-05	5	0355	46 13 31	58 31 13	Trace
40-04	5	0647	46 30 92	58 55 00	-
38-04	5	0920	46 16 93	59 24 21	-
37-04	5	1352	46 07 94	59 27 42	-
37-06	6	1257	45 25 37	58 36 68	Heavy
36-03	6	1527	45 10 58	58 38 51	Moderate-low
35-02	6	1755	45 08 83	59 03 38	Heavy
34-02	6	2010	45 13 94	59 33 66	Heavy
33-02	8	0047	45 06 08	59 57 65	Heavy
31-02	8	0525	44 47 98	60 28 91	Trace
32-02	8	0800	44 46 00	60 00 09	Heavy
33-03	8	1010	44 50 96	59 37 01	-
34-03	8	1209	45 03 80	59 22 04	Trace
35-03	8	1445	45 00 02	58 52 84	-
34-04	8	1645	44 45 32	58 56 91	-
33-04	8	1850	44 38 05	59 18 89	-
31-03	8	2230	44 27 97	60 03 26	

Appendix 1 continued

Station	Date (April/79)	Local Time	Latitude ° ' "	Longitude ° ' "	Oil Report
31-04	9	0203	44 14 20	59 46 21	-
32-04	9	0415	44 19 59	59 25 19	-
33-05	9	0645	44 21 08	58 56 82	-
34-05	9	0900	44 28 03	58 34 72	-
33-06	9	1105	44 07 89	58 40 46	-
32-06	9	1306	43 59 98	58 59 62	-
31-05	9	1540	43 52 33	59 15 44	-
31-07	9	1845	43 34 08	58 52 80	Trace
30-04	9	2130	43 38 78	59 26 53	-
29-05	10	0040	43 40 88	60 00 16	Trace
28-04	10	0337	43 44 73	60 30 79	-
49-04	10	0745	44 08 72	60 34 70	-
30-03	10	0940	44 13 98	60 12 25	-
30-02	10	1210	44 29 77	60 31 64	-
29-02	11	2245	44 29 14	61 01 99	-
27-03	12	0142	44 10 04	61 28 91	-
26-03	12	0428	43 51 20	61 29 21	-
28-03	12	0715	44 01 96	60 55 10	Moderate-low
27-04	12	0950	43 46 12	60 58 96	-
27-05	12	1235	43 26 10	60 30 42	Moderate-low
26-02	12	1945	44 15 82	62 01 83	-
22-01	16	1605	44 22 46	63 31 92	Trace
23-01	16	1855	44 04 13	62 56 14	Trace
24-02	16	2145	43 54 75	62 21 06	-
25-02	17	0010	43 56 95	62 01 41	-
25-03	17	0320	43 44 25	61 45 24	-
24-03	17	0505	43 35 07	61 55 70	-
25-04	17	0725	43 31 01	61 27 99	Moderate-low
24-04	17	1008	43 11 10	61 25 06	-
25-05	17	1227	43 14 01	61 06 17	-
25-06	17	1513	43 03 06	60 50 39	-
23-04	17	1915	43 03 03	61 35 78	-
22-08	17	2130	43 03 09	61 58 98	Moderate-low
22-07	17	2320	43 11 92	62 12 47	-
23-03	18	0120	43 21 91	62 02 09	-
22-06	18	0447	32 12 91	62 22 87	Moderate-low
22-05	18	0625	43 28 07	62 30 03	-
23-02	18	0840	43 37 79	62 23 10	-
22-04	18	1020	43 34 01	62 37 98	-
21-05	18	1252	43 20 12	62 40 88	-
21-06	18	1525	43 10 05	62 29 20	-

Appendix 1 continued

Station	Date (April/79)	Local Time	Latitude ° ' "	Longitude ° ' "	Oil Report
20-04	18	1729	42 52 23	62 29 10	-
19-05	18	1950	42 55 08	62 56 02	-
20-03	18	2020	43 17 02	63 01 01	-
21-04	19	0051	43 31 79	62 57 27	-
21-03	19	0315	43 39 15	63 06 21	Moderate-low
20-02	19	0535	3 42 23	62 30 24	Moderate-low
21-02	19	0820	43 60 00	63 31 09	-
19-02	19	1130	43 44 05	63 54 88	-
18-03	19	1354	43 23 51	64 00 01	Trace
19-03	19	1651	43 20 07	63 26 87	-
18-04	19	1900	43 00 14	63 29 95	-
17-03	19	2150	43 01 95	64 00 03	-
17-04	20	0025	42 42 15	63 34 99	-
16-03	20	0310	42 44 82	64 05 89	-
15-04	20	0520	42 30 15	64 11 85	-
14-03	20	0920	42 11 02	64 37 97	-
14-02	20	1315	42 50 91	64 58 94	Moderate-low
16-01	22	0128	43 32 13	64 59 11	-
15-01	22	0330	43 12 15	64 59 85	Moderate-low
16-02	22	0540	43 12 02	64 37 33	-
15-03	22	0805	42 47 99	64 33 91	Moderate-low
13-03	22	1233	43 02 12	65 30 10	-
12-05	22	1505	43 46 07	65 28 09	-
11-04	22	1713	42 33 19	65 29 81	-
11-05	22	2025	42 08 15	65 02 02	-
10-07	22	2305	42 09 90	65 29 04	-
09-07	23	0230	41 47 98	65 31 89	-
06-06	23	0640	41 08 09	65 59 97	-
07-09	23	0910	41 28 91	65 59 88	-
06-04	23	1205	41 37 00	66 30 00	Trace
08-07	23	1435	41 51 97	66 00 27	-
07-08	23	1705	41 56 03	66 29 78	Trace
09-06	23	2000	42 15 00	66 00 00	-
08-06	23	2220	42 20 00	66 30 01	-
10-06	24	0117	42 39 90	66 00 01	-
09-05	24	0340	42 43 89	66 29 84	-
08-05	24	0630	42 46 06	66 57 14	-
09-04	24	0830	43 01 91	66 49 03	-
10-05	24	1010	43 08 01	66 30 00	-
11-02	24	1300	43 30 80	66 29 80	Moderate-low

Appendix 1 continued

Station	Date (April/79)	Local Time	Latitude ° ' "	Longitude ° ' "	Oil Report
10-04	24	1526	43 27 93	66 50 94	-
13-01	24	2025	44 14 00	66 51 00	-
13-02	24	2300	43 55 00	66 29 00	-
11-03	25	0330	43 02 05	66 00 30	-
14-01	25	0635	43 15 92	65 28 96	Moderate-low
17-02	25	1030	43 29 00	64 31 00	-
18-01	25	1215	43 47 38	64 28 91	-
19-01	25	1441	44 02 83	64 17 03	-
21-01	25	1710	44 14 94	63 50 15	Moderate-low

PRELIMINARY OBSERVATIONS ON THE EFFECT OF BUNKER C FUEL OIL ON SEALS ON THE SCOTIAN SHELF

J. Parsons[1], J. Spry[1], and T. Austin[1]
MacLaren Marex Inc., Dartmouth, N.S., Canada

[1] Present address: Plansearch Inc., Dartmouth, N.S., Canada

INTRODUCTION

Although some information does exist concerning the effect of crude oil and Bunker C oil on seals, the studies to date have been of a limited nature. Smith and Geraci (1976) studied the effect of crude oil on wild, captive ringed seals (*Pusa hispida*) and concluded that crude oil did not cause mortality in their experiments. However, crude oil did cause transient eye, kidney, and possibly liver lesions in these animals. Similarly, Davis and Anderson (1976) concluded that Bunker C oiling of a small wild population of grey seals in the U.K. was not a direct cause of death in that case. However, that study was not intensive and was limited to a small sample of animals. Furthermore, no post-mortem results were given to positively verify the effects of oil. Thus neither study, although they are probably the best available to date, has provided definitive evidence of the effects of Bunker C oil on seal populations or on individuals. Nor has either study combined both field and laboratory procedures to yield population health data.

Recent reports of live stranding and subsequent death of a heavily oiled grey seal pup near Halifax, Nova Scotia, shortly after the *Kurdistan* spill, again raised the question of potential oiling effects on marine mammals during off-shore spills. Accordingly, this study was initiated to monitor mortality and extent of oiling of marine mammals after the wreck of the *Kurdistan* and to determine both the direct and indirect effects of Bunker C oil.

The survey and study effort was directed primarily at two commonly occurring species of seal, the harbour seal (*Phoca vitulina*) and the grey seal (*Halichocrus grypus*). The study region encompassed all areas which were hit by oil that had leaked from the *Kurdistan.* The study itself is divided into two parts: the Eastern Shore between Ingonish and Halifax, and Sable Island.

This paper reports on the preliminary field observations made during the first two months of the study (April and May, 1979), including an outline of various physiological and morphological measurements made. A more detailed report, including hydrocarbon and physiological data, will be published later.

MATERIALS AND METHODS

A system of reporting strandings of marine mammals to the MacLaren Marex office in Dartmouth, Nova Scotia, was established in cooperation with the Canadian Coast Guard (Low Point, Mulgrave, and Halifax), the Environmental Protection Service and the Fisheries and Marine Service. Meanwhile, a field crew was available in the area from Sydney to Halifax to immediately respond to stranding reports and to maintain contact with the oil spill cleanup crews working this area. This field crew was equipped with a 17-ft Zodiac in order to reach the more remote sections of the coast and islands.

When located the stranded animals were photographed and a broad suite of measurements were made, including morphometric and behavioral, and the extent of oiling. Also tissues were collected for histopathology and for later hydrocarbon analysis, and blood samples were taken for later analysis and hematological examination. In the case of dead animals a full post mortem was performed to determine cause of death.

OBSERVATIONS

At the date of writing the field portion of the study is nearly complete; a crew is still available to respond to strandings and one more sampling period on Sable Island (August 1979) is required to complete the growth and behavioural data, and to assess longer term effects on health.

Mainland

Initially, sampling was conducted in Cape Breton and the Eastern Shore region of Nova Scotia. Between April 30 and May 24, the field crew performed ten post-mortem examinations. The majority of the carcasses were too autolyzed for a proper gross and histopathological examination but, when feasible, tissues were collected for hydrocarbon analysis. Table 1 provides locations of reported and examined carcasses.

Only opportunistic observations were made along the mainland since most animals were in the water when located, and the degree of oiling could not be accurately determined. No live animals were captured and sampled during this period since they were too wary and there were no pups available as yet.

Sable Island

On May 21 reports of oiled seals were received from Sable Island. These were confirmed by Brian Beck of the Fisheries and Marine Service, Bedford Institute of Oceanography. By May 29 a field crew was paced on the island to begin intensive sampling of live and dead animals. The majority of animals, including newborn pups, showed some degree of soiling by oil (Figure 1).

The majority of animals that were captured were harbour seal pups; however, several adult harbour seals and a few first-year grey seal pups were also captured. A total of 52 blood samples was collected.

Post-mortem examinations of any carcasses found provided data on pup mortality, tissue hydrocarbon levels and cause of death. Comparisons will be made with earlier studies of pup mortality and growth rates for the Sable Island seal population.

The majority of seals observed were oiled to a varying extent, from light patches of oil to 100% oil covering. The heavily-oiled animals did not seem to be physically impaired by the oil. Generally, the eyes and edges of the eyelids remained free of oil and no eye lesions could be detected using Fluoroscene-dye (Ayerst) methods. Smith and Geraci (1976) indicated eye lesions of a transient nature were observed in ringed seals that were probably caused by the volatile components of crude oil. However, since Bunker C oil does not contain a large proportion of volatiles, especially not after weathering (Clark and Brown, 1977), that may account for this lack of eye lesions in these animals.

A large number of seal sightings reported into our study group that could not be examined. These are listed in Table 2. In all cases the seal sightings were confirmed by the reporting agency but could not be examined by our field crew, either because the carcasses had been removed, or had been washed out to sea again, or were too badly autolyzed.

Further Data Analysis

Analysis of all weight data obtained to date has been carried out at the MacLaren Marex office. The tissues collected for histopathology have been transferred to Dr. Finley of the Nova Scotia Agricultural Station and are being prepared in that laboratory. Dr. R. Thompson will be consulted on these results as soon as they are available. Those tissues which will be analyzed for hydrocarbons are being prepared for analysis at the MacLaren Marex Laboratory, Dartmouth, Nova Scotia. The hematological analysis undertaken by Dr. DeWitt (Pathology Laboratory, Truro) are detailed in Table 3. This analysis is complete as of July 27, 1979; however, final results will not be released until after the final field trip to Sable Island in August. The clinical biochemical analysis of serum is also detailed in Table 3. This has not commenced as yet due to delays in obtaining the necessary equipment. These tests will be performed in the MacLaren-Marex Laboratory.

The final analysis will be arranged after the mid-August field trip to Sable Island. This trip is necessary to complete the weight data for growth rate analysis. Further blood samples will be drawn to determine the longer term effects of oiling and the levels of hydrocarbons (if any) remaining in the blood. On completion of the last field trip, final reports of this study will be prepared for the sponsors and, if approved, will be prepared for formal journal publication.

SUMMARY

A study was initiated to monitor mortality and effect of oiling in marine mammals, including the harbour seal (Phoca vitulina) and the grey seal (Halichocrus grypus). Between April 30 and May 24 ten post-mortem examinations were performed in the field. The majority of animals examined on Sable Island, including newborn pups, showed some degree of oiling. Oiling varied from light to 100% covering.

A broad range of measurements were made, including morphometric measurements, observations on oiling, and sampling of body tissues and fluids for subsequent laboratory analyses for physiological stress and

hydrocarbon uptake. Analyses of these observations and samples are now under way, and will be reported on later.

BIBLIOGRAPHY

CLARK, R.C., JR. and D.W. BROWN. 1977. Petroleum: properties and analysis in biotic and abiotic systems. In Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Volume 1. Nature and Fate of Petroleum (Malins, D.C., Ed.). Acad. Press, pp. 1-89.

DAVIS, J.E. and S.A. ANDERSON. 1976. Effects of oil pollution on breeding grey seals. Mar. Poll. Bull. 7: 115-118.

FRANKEL, S., S. REITMAN and A. SONNENWIRTH (eds.) 1970. Gradwohl's Clinical and Laboratory Methods and Diagnosis, vol. 2. C.V. Moss Co., St. Louis, MO.

SMITH, T.G. and J.R. GERACI. 1975. Effect of contact and ingestion of crude oil on ringed seals, Beaufort Sea. Tech. Rep. #5, Beaufort Sea Project, Department of Environment, December 1975.

Figure 1. Oiled (upper) and unoiled (lower) harbour seal pups seen on Sable Island, June 1979. Note the clean ring, result of tearing, around the eyes of both animals.

Table 1

Locations of oiled and non-oiled seals stranded along the Eastern Shore and Cape Breton Island and investigated during this study.

Location		Description
Eastern Shore	Sambro	1 Oiled grey seal, dead
	Ecum Secum	1 Non-oiled harbour seal, live
	Tor Bay	1 Oiled harbour seal, dead
		11 Non-oiled harbour seals, live
	White Head	1 Non-oiled grey seal, live
	Canso	13-15 Non-oiled harbour seals, live
	Fox Island	1 Oiled harbour seal, dead
Cape Breton	Isle Madame	1 Non-oiled grey seal, dead
	Point Michaud	2 Oiled harbour seals, dead
		1 Oiled grey seal, dead
	Fourchu Bay	8 Non-oiled harbour seals, live
		3 Non-oiled grey seals, dead
	Gabarus Bay	8 Non-oiled harbour seals, live
	Scatarie Island	1 Oiled grey seal, dead
		1 Oiled harbour seal, dead
	Low Point	1 Oiled harbour seal, dead
	Ingonish	1 Oiled grey seal, dead

Table 2

Seal sightings, confirmed but not examined.

Date	Species	Number	Location	Reported by	Comments
April 19-22	Unidentified	3	St. Ann's Bay Sydney Harbour Mira Bay	Environmental Protection Service (EPS) and Canadian Wildlife Service (CWS)	Dead, all heavily oiled
April 22	*Halichocrus grypus*	1	Mira Gut	N.S. Lands and Forests	
April 26	Unidentified	3	Scatarie Island	Coast Guard	Removed during cleanup
May 2	Unidentified	2	Mira Bay	Coast Guard	
May 7	*Phoca vitulina*	2	South Shore		Oiled pups found in nets
May 11	Unidentified	1	Cape Auget		Dead, oiled
May 11	Unidentified	1	Richard's Pond	N.S. Lands and Forests	Dead, oiled
May 15	Unidentified	2	English Town		Adults, believed to be oiled
May 16	Unidentified	2	Louisburg		Dead, oiled
May 21	*P. vitulina* *H. grypus*	50	Bird Rock, Nfld.	Memorial University	All alive, approximately 50% were oiled
May 21	*P. vitulina*	1	River Bourgoise		Young, oiled, dead
May 21	Unidentified	several	Cape Breton		Oiled seals in fishermen's nets
May 28	Unidentified	1	Lower East Chezzetcook	EPS	

Table 2 continued

Date	Species	Number	Location	Reported by	Comments
May 30	Unidentified	1	Guysborough Harbour	EPS	
May 30	Unidentified	1	Purcell's Cove	EPS	
June 8	Unidentified, probably *P. vitulina*	1	Tignish, P.E.I.	PEI Dept. of Fisheries	Dead, oiled, caught in fisherman's net
June 22	Unidentified	1	Richard's Pond	N.S. Lands and Forests	Dead, oiled
June 22	Unidentified	1	Janvrin Island	N.S. Lands and Forests	Dead, oiled
June 25	*H. grypus*	1	St. Peter's	N.S. Lands and Forests	Cleaned and released
June 27	*H. grypus*	2	Scatarie Island	N.S. Lands and Forests	Dead, oiled

Table 3

Blood studies: hematological and chemical parameters
(after S. Frankel *et al.*, 1970)

Test	Purpose
HEMATOLOGY	
Hemoglobin (Hb)	- to determine the number of grams of hemoglobin per 100 mL of whole blood
Packed Cell Volume (PCV)	- to determine the percentage of cells in whole blood
Erythrocyte Count (RBC)	- to determine the number of red blood cells per cubic millimetre of whole blood
Leucocyte Count (WBC)	- to determine the number of white blood cells per cubic millimetre of whole blood
Differential Count (Diff)	- to determine the relative numbers of various types of leucocytes in the blood
CLINICAL CHEMISTRY	
Sodium (Na)	- to establish the ion balance of the blood
Potassium (K)	
Chloride (Cl)	
Total Bilirubin	- liver function tests
Conjugated Bilirubin	
Blood Urea Nitrogen (BUN)	- renal function test
Glucose (Gl)	- measures glucose level in blood
Uric Acid	- liver and kidney function test
Hydrocarbons	- measures the level of oil which has been incorporated into the tissues
ENZYMES	
Creatine Phosphokinase (CPK)	- indicates the acute stress levels and muscle tissue damage
Glutamic Oxalacetic Transaminase (SGOT)	- liver function tests
Glutamic Pyruvic Transaminase (SGPT)	
Gamma Glutamyl Transpeptidase (GGT)	

THE EFFECTS OF *KURDISTAN* OIL ON SEABIRDS

R.G.B. Brown[1] and B.C. Johnson[2]

1. Canadian Wildlife Service, Bedford Institute of Oceanography, Dartmouth, N.S., Canada B2Y 4A2
2. Canadian Wildlife Service, P.O. Box 1590, Sackville, N.B. E0A 3C0

INTRODUCTION

The oil tanker *Kurdistan* broke in two off northern Cape Breton on March 15, 1979, releasing *ca.* 7900 tons of Bunker C fuel oil, most of which did not begin to come ashore until mid-April. As usual with such incidents, seabirds were the animals most directly affected. The preliminary data presented here indicate that several thousand birds were killed - a mortality comparable with that caused by the *Arrow* and *Irving Whale* incidents off Atlantic Canada in February 1970 (Brown *et al.*, 1973).

OBSERVATIONS AND DISCUSSION

Table 1 summarizes the species composition of the kill during the *Kurdistan* dominated period. As in most spills the dominant birds were diving species. These spend much time on the water and so are most likely to come into contact with oil, and the fact that they sit low in the water ensures that this contact will affect a large part of their bodies. Alcids (murres, dovekies), diving-ducks (oldsquaw, eiders, scoters), and grebes suffered the heaviest losses. As one would expect, the percentages of the different species groups were very similar to those in the *Arrow* and *Irving Whale* kills, with alcids predominating offshore and diving-ducks and grebes inshore in all three cases (Table 2). In all, over 2600 birds are known to have been killed by oil off eastern Nova Scotia in the spring of 1979.

This total is an unknown but probably fairly small fraction of the actual kill. In theory one can assess the actual kill by counting the corpses along a sample of the oiled beaches, and then extrapolating this to cover all the shoreline affected by oil (Bourne, 1976; Brown *et al.*, 1973). In practice this has many unavoidable difficulties. The sampling is inevitably biased towards the more accessible sand or gravel beaches and against rocky shores. It is likely to miss dead birds which have been partly eaten by scavengers, or which became buried in sand; in cases where oiling is particularly thick it is often hard to see the birds at all. It is also likely to miss birds which came ashore alive and which then crawled away into cover. Re-surveying is also necessary for as long as the birds continue to come ashore, but the beach-cleaning operations prevented this in the case of the Kurdistan.

Moreover, oiled birds can be counted only when they come ashore, yet many of them never do. Hope-Jones et al. (1970) collected seabird corpses after an oil spill in the Irish Sea, banded them, and put them back in the water; the beaches in the area were well patrolled, yet only ca. 20% were recovered. Monat (1978) obtained a similar percentage when he repeated the experiment off Brittany. The corpses apparently begin to sink after about ten days. This is likely to have led to considerable underestimates of mortality following the Kurdistan spill, since it took a month for the oil to come ashore (Vandermeulen and Buckley, 1980).

Table 3 summarizes the results of counts along seven beaches between Alder Point and Mira Bay, Cape Breton Co. (H.P. Barkhouse and W.R. Barrow, Canadian Wildlife Service, unpublished) and at Sober Island, Fancy's Beach, Holland Harbour, and Port Bickerton, Halifax and Guysborough Co. (CWS unpublished) not long after the first oil and birds came ashore; at Martinique Beach, Halifax Co., after cleaning operations had begun there (D.N. Nettleship, CWS unpublished); and on Sable Island (R. Maclean, Atmospheric Environment Service, pers. comm.). The highest densities of dead birds were in Cape Breton Co., where they exceeded considerably the densities in Chedabucto Bay in 1970 after the Arrow spill; by contrast, the numbers of birds/km on Sable Island were only a sixth of those found there in March 1970. Numbers coming ashore in mainland Nova Scotia were relatively small. We do not at present have accurate estimates of the length of beach affected by oil, but extrapolation of the kill figures based on some conservative guesses suggests that the minimum mortality was at least 4810 birds. This is of the same order of magnitude as the mortalities following the Arrow and Irving Whale incidents. It takes no account of losses of corpses at sea. If one accepts an 80% loss (based on Hope-Jones et al. 1970 experiments), the actual mortality is likely to have been at least 25,000 birds. (If one takes an average of 17.7 birds/km, from Table 3, and extrapolates this over the whole 650 km coastline of Cape Breton, Richmond, Guysborough, and Halifax Counties, we then have a minimum mortality of 11,500 birds, and an actual mortality probably in excess of 50,000 birds.)

Too little is known of the population sizes of most of the species involved to make an estimate of the fraction of their numbers that might be represented or affected by this figure. However, Thick-billed Murre numbers are known to be declining at several colonies in the eastern Canadian Arctic and West Greenland (D.N. Nettleship, pers. comm.; Evans and Waterston, 1976), apparently from a combination of excessive hunting and drownings in salmon nets off West Greenland. Further attrition due to oil spills is bound to compound this decrease.

The primary effects of oil on birds are to destroy their insulation and waterproofing by interfering with the fine structure of the feathers. Secondary effects are likely to follow ingestion of the oil as the birds try to preen it off the feathers. These secondary effects have only recently been recognized, and their precise nature is disputed (see the reviews by Bourne, 1976; Brown, in press; Holmes and Cronshaw, 1977). Some experiments indicate that birds dosed with small quantities of oil suffer a decrease in salt excretion, nutrient transfer, and ovulation rates; other experiments suggest that ingestion of oil merely makes the birds less able to cope with future environmental stresses. However, it is likely that long term, sublethal effects will occur. These will be apparent not just in the species most prominent in the beach counts, but also in birds such as Herring Gulls and Crows which have been scavenging these oil-soaked corpses. Oil on the feathers may also be transferred to the outside of the eggs, and this may significantly reduce the hatching rate. This may well show up in the ongoing studies of eider numbers and breeding biology by the Nova Scotia Department of Lands and Forests' Wildlife Division in their Eastern Shore Wildlife Management Area.

We will conclude with one further general observation. First, Table 3 shows that there is not necessarily a relationship between the size of an oil spill and the numbers of birds it will kill. The ca. 30 tons released by the Irving Whale seem to have done as much damage as the major oil spills following the wrecks of the Kurdistan and Arrow. Second, ten very severely oiled dovekies, collected on Sable Island on March 24, 1979, were carrying oil whose chemical characteristics showed that it was *not* from the *Kurdistan* (E. Levy, pers. comm.). The moral to be drawn in both cases is that mortality caused by small, largely unreported oil spills must be taken just as seriously as that from the major, well publicized incidents.

SUMMARY

Over 2600 birds are known to have been killed by oil off eastern Nova Scotia in the spring of 1979. Most of these were victims of *Kurdistan* oiling. Most susceptible were the diving species, with heaviest losses among the alcids, diving-ducks, and grebes. Percentages of kills were similar to those in the *Arrow* and *Irving Whale* tanker accidents.

Extrapolation, to include those beaches not monitored and not accounted for, raises the kill-figure to *ca.* 4810 birds. Accounting for an 80% loss of dead birds at sea, raises the actual mortality due to the *Kurdistan* to an estimated 25,000 birds.

ACKNOWLEDGEMENTS

For help in the field and elsewhere we thank P.J. Austin-Smith, H.P. Barkhouse, W.R. Barrow, E. Greene, R. Hounsell, O.W. Keeping, E. Levy, A.R. Lock, R. Maclean, D.N. Nettleship, A.D. Smith, R.W. Trites, E. Verspoor, and members of the Nova Scotia Bird Society; we are also grateful for the cooperation of the Environmental Protection Service and the Nova Scotia Department of Lands and Forests' Wildlife Division.

LITERATURE CITED

BOURNE, W.R.P. 1976. Seabirds and pollution. In *Marine Pollution,* edited by R. Johnston. Academic Press, London, pp. 403-501.

BROWN, R.G.B. In press. Birds, Oil and the Canadian Environment. In *The Fate and Effects of Oil Pollution in the Canadian Marine Environment,* edited by J. Sprague, J.H. Vandermeulen, and P.G. Wells. Environmental Protection Service, Ottawa.

BROWN, R.G.B., D.I. GILLESPIE, A.R. LOCK, P.A. PEARCE and G.H. WATSON. 1973. Bird mortality from oil slicks off eastern Canada, February-April 1970. *Can. Field-Nat.* 87: 225-234.

EVANS, P. and G. WATERSTON. 1976. The decline of the Thick-billed Murre in Greenland. Polar Record 18: 283-293.

HOLMES, W.N. and J. CRONSHAW. 1977. Biological effects of petroleum on marine birds. In *Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms,* vol. II, *Biological Effects*. Edited by D.C. Malins. Academic Press, New York, San Francisco, London. pp. 359-398.

HOPE-JONES, P., G. HOWELLS, E.I.S. REES and J. WILSON. 1970. Effect of 'Hamilton Trader' oil on birds in the Irish Sea in May 1970. *Brit. Birds* 63: 97-110.

MONAT, J.Y. 1978. Effet du pétrole de l'AMOCO CADIZ sur les oiseaux de mer. Bilan provisoires. In ACOMO CADIZ. Premières observations des consequences à court terme de la pollution par hydrocarbures sur l'environnement marin, edited by G. Conan, L. d'Ozouville, and M. Marchand. Publ. CNEXO Série 'Actes de Colloques' No. 6: 135-142.

VANDERMEULEN, J.H. and D.E. BUCKLEY, Editors. 1980. The *Kurdistan* Oil Spill, March 15/15, 1979. Activities and observations of the Bedford Institute of Oceanography scientific response team. Bedford Institute of Oceanography Report Series, BI-R-80-2.

Table 1

Known kills of oiled birds in Nova Scotia (1) based on information passed on to the Canadian Wildlife Service between March 15 and June 22, 1979. Live but probably moribund birds are included in the totals.

Species	Eastern Cape Breton	Eastern Shore	Sable Island (2)
Loon sp.	1	6	0
Red-necked Grebe	0	73	0
Horned Grebe	0	15	0
Northern Fulmar	42	8	0
Storm-Petrel sp.	1	0	0
Gannet	5	3	0
Cormorant sp.	2	1	0
Great Blue Heron	3	0	0
Canada Goose	1	0	0
Black Duck	0	8	0
Oldsquaw	1	37	0
Common Eider	1?	94	2?
Scoter sp.	0	29	0
Red-breasted Merganser	0	4	0
Unidentified duck	5	0	0
Black-legged Kittiwake	2	0	0
Unidentified gulls (3)	29	19(4)	0
Murre spp. (5)	599	85	56
Razorbill	5	0	0
Dovekie	416	14	290 (6)
Black Guillemot	7	20	0
Unidentified alcids	15	0	0
Unidentified seabirds	581 (7)	191	25

(1) A dead, oiled Kittiwake was found on March 21 at Cape Sable, Shelburne Co.; the distances involved make it unlikely, though not impossible, that this bird was oiled by the *Kurdistan.*

(2) In the last week in May lightly spotted seabirds on the Banks east and west of Sable Island included 2 Fulmars, 1 Greater Shearwater, and 2 Herring Gulls, along with a Great Blackback with a fairly large oil patch on its belly.

(3) Probably Herring and/or Great Blackbacked Gulls.

(4) *Ca.* 12 out of 75 Herring/Great Blackbacked Gulls in Three Fathom Harbour, Eastern Shore, in late May were said to be lightly spotted with oil.

(5) Both Common and Thick-billed Murres were identified.

(6) Ten of these birds, collected on March 24, were covered with oil which did *not* come from *Kurdistan* (E. Levy, pers. comm.).

(7) In a subsample of 501 of thess unidentified birds, *ca.* 75% were said to be murres.

Table 2

The species-groups most affected by the *Kurdistan* incident, and also by the *Arrow* and *Irving Whale* spills in February-April 1970 (from Brown *et al.,* 1973). * indicates species-groups which feed under water.

Species-Group	*Kurdistan*			*Arrow*		*Irving Whale*	
	E. Cape Breton	Eastern Shore	Sable Island	Chedabucto Bay	Sable Island	Burin	St. Shotts
Loons*	1	6	0	5 (1.2%)	5	4 (3.6%)	1
Grebes*	0	88 (14.5%)	0	59 (14.8%)	0	2 (1.8%)	0
Fulmar	42 (2.4%)	8 (1.3%)	0	0	72 (10.6%)	0	0
Gannet*	5	3	0	0	12 (1.8%)	0	0
Cormorants*	2	1	0	0	0	0	0
Diving-ducks*	2	164 (27.0%)	2	229 (57.4%)	10 (1.5%)	23 (20.9%)	568 (98.8%)
Other or unidentified waterfowl	6	8 (1.3%)	0	10 (1.5%)	0	0	0
Gulls	31 (1.8%)	19 (3.1%)	0	3	1	0	0
Alcids*	1417 (84.2%)	119 (19.6%)	336 (93.1%)	86 (21.5%)	566 (83.4%)	76 (69.1%)	6 (1.0%)
Other or unidentified birds	210 (12.5%)	191 (31.4%)	25 (6.9%)	7 (1.7%)	12 (1.8%)	5 (4.5%)	0
TOTAL	1683	608	361	399	678	110	584

Table 3

Quantitative comparisons between the actual and estimated minimum kills of seabirds in the *Kurdistan*, *Arrow*, and and *Irving Whale* spills (Brown *et al.*, 1973).

Incident	Shoreline	Total Birds Found	Area Checked (km)	Birds/km	Area Oiled (km)	Extrapolated Minimum Kill		Oil Spilled (tons)
Kurdistan	Cape Breton Co. (1)	1305	27.3	47.7	*ca.* 80	3800	4810	7900
	Sheet Harbour to Canso (1)	26	6.1	4.3	*ca.* 130	570		
	Martinique Beach (1)	30	5.0	6.0	6	30		
	Sable Island (1)	336	26.4	12.7	32 (2)	410		
Arrow	Chedabucto Bay	350	18.7	18.7	*ca.* 130	2400	6400	1900 (3)
	Sable Island (March)	217	2.9	74.9	64 (2)	4800		8500 (3)
Irving Whale	SE Newfoundland	625	13.2	47.3	?	5000+(4) (6500+ ?)		13 - 30

Notes:

(1) The beach counts in Cape Breton Co. and between Sheet Harbour and Canso were made between April 27 and 20, 1979, that on Sable Island on May 9, and that at Martinique Beach, Halifx Co., on May 25.

(2) Both shores of Sable Island were affected by oil in 1970, but apparently only the north shore was oiled in 1979.

(3) The Chedabucto Bay and Sable Island *Arrow* spill figures are, respectively, the estimates of amount remaining in the Bay and amount estimated to have drifted out to sea (from Barber, 1970:54).

(4) The *Irving Whale* estimates were not made on the basis of beach counts alone.

APPENDIX 1

SCIENTIFIC NAMES OF SPECIES MENTIONED IN THE TEXT

Loon sp.	*Gavia* sp.
Red-necked Grebe	*Podiceps grisegena*
Horned Grebe	*Podiceps auritus*
Northern Fulmar	*Fulmarus glacialis*
Storm-Petrel sp.	*Oceanodroma leucorhoa* or *Oceanites oceanicus*
Northern Gannet	*Sula bassana*
Cormorant sp.	*Phalacrocorax* sp.
Great Blue heron	*Ardea herodias*
Canada Goose	*Branta canadensis*
Black Duck	*Anas rubripes*
Oldsquaw	*Clangula hyemalis*
Common Eider	*Somateria mollissima*
Scoter sp.	*Melanitta* sp.
Red-breasted Merganser	*Mergus serrator*
Black-legged Kittiwake	*Rissa tridactyla*
Herring Gull	*Larus argentatus*
Great Black-backed Gull	*Larus marinus*
Common Murre	*Uria aalge*
Thick-billed Murre	*Uria lomvia*
Razorbill	*Alca torda*
Dovekie	*Alle alle*
Black Guillemot	*Cephus grylle*
Common Crow	*Corvus brachyrhynchos*

TASTE PANEL ASSESSMENTS AND HYDROCARBON CONCENTRATIONS IN LOBSTERS, CLAMS AND MUSSELS FOLLOWING THE WRECK OF THE KURDISTAN

D.J. Scarratt

Fisheries and Environmental Sciences
Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick EOG 2XO

INTRODUCTION

When Bunker C oil from the tanker Kurdistan, wrecked in Cabot Strait in March 1979, first began to come ashore on Cape Breton Island, immediate concern was expresssed for the lobster fishery which, depending on the particular fishery district, opens between late April and May. It was known from earlier work following the Arrow spill (Wilder, 1970) that lobsters would take up Bunker oil from oiled waters or sediments or possibly from oiled food or prey. In certain circumstances this could result in tainting (off-flavors) of the meat, which in turn would have serious repercussions on the marketability of lobsters from these oiled areas. In anticipation of such a possibility following the Kurdistan spill and following reports of oiling of inshore waters of Nova Scotia two lines of enquiry were suggested: one - to repeat some of the earlier experimental work to determine, using taste panels, whether the Kurdistan Bunker C would cause tainting in laboratory lobsters. And secondly - whether tainting could indeed be discerned in wild lobsters taken from known oiled waters.

The following results are necessarily preliminary since trained taste panels were not available. As well, we were dealing with environmental samples with high intrinsic variabilities.

METHODS AND RESULTS

To a considerable degree, organoleptic (taste and odor) methods evolved over the course of the emergency. It will therefore be more appropriate to describe methods and results in order.

At first taste panelists were selected at random from among volunteers; later a prepared screening was used to select judges. For screening tests cooked, uncontaminated lobster flesh was mixed 50:50 with water in a blender and Kurdistan Bunker C oil added at concentrations of 0.002, 0.005

and 0.01%. Taste panelists were selected from those who could detect oil at the 0.002% concentration. All subsequent panels used judges selected by this criterion.

For taste tests oil-exposed lobsters and non-oiled control lobsters were boiled separately in 3% brine for 8 min, measured from the time the water resumed boiling after the lobsters were introduced. Lobsters were hand shelled, and the hepatopancreas collected in a beaker. Tail meat was quartered and each part placed in a plastic cup which was then capped. The hepatopancreas was also redistributed to plastic cups (about 4 g/cup) which were capped. The caps were coded, and suspect and control samples were paired. A taste panel was offered samples of tail meat and hepatopancreas of both exposed and controlled lobsters. Each panelist was then asked to judge two or more pairs for odor and/or flavor, and to note any differences. Any assessment of an oily off-flavor in a suspect sample was regarded as a positive judgment.

For hydrocarbon analyses the various tissues were extracted, and duplicate analyses performed using the method of Zitko (1975). Results were expressed as pyrene equivalents.

Experimental Tainting Tests

1. Lobsters on oiled sediment

Sixty lobsters were selected at random from unoiled stocks held at the Halifax Laboratory and divided among six tanks (three experimental and three control) 90x90x45 cm deep equipped with overflow standpipe to give about 27.5 cm water depth. Three quantities of Kurdistan oil were weighed out - 200, 100 and 20 g - and mixed with 5-kg lots of clean grade 2 sand (earlier experiments had shown that oil mixed with water separated out rapidly and stuck to the tank sides and was not available to lobsters). An equal quantity of unoiled sand was spread on the floors of the three control tanks. Each of the tanks was filled with water at about 3°C, and the lobsters introduced. A meal of fresh-frozen herring chunks was given and the water turned off. Each tank was aerated with compressed air delivered through an aquarium airstone. After 4 hr the water flow was restarted at a rate sufficient to maintain the temperature between 3 and 5°C. After 3 d the food was removed and five lobsters taken from each tank for taste panel assessment. Two days later the remaining lobsters were removed. There were no mortalities.

Tail meat and hepatopancreas were prepared as outlined above for taste testing, and were then offered to a panel of 14 judges for odor and flavor assessment. Results are shown in Table 1.

The number of positive judgments required at $p < 0.05$ is 12; thus, although as many as 7 judges of 14 correctly identified the oiled sample after 5 d exposure, the results cannot be considered statistically significant, although there is an apparent trend of increasing number of positive results as the oil exposure increased. It will be seen later that many of the control lobsters, having been kept in captivity for several months, had high concentrations of fluorescent hydrocarbons in their tissues and that therefore discrimination of exposed samples might have been more difficult.

In a subsequent test (Treatment A) four lots of 14 lobsters each were exposed in tanks as before. Two of the tanks contained 200 and 100 g oil in 5 kg sand, respectively; two tanks contained sand only. Water temperature was 15°C. This allowed accelerated uptake and was designed to simulate longer exposure at lower temperatures. The lobsters were fed chunks of fresh-frozen herring. Half the lobsters were removed after 2 d exposure, and the remainder after 4 d. The taste panel comprised nine judges. Results are shown in Table 2. Parallel hydrocarbon analysis results are shown in table 4.

Again, the results were not significant generally, although in one case the number of correct identifications (7 out of a possible 9) was significant at $p < 0.05$. It should be noted that, as in the previous test, the number of correct identifications tended to increase with the increase in oil-exposure time.

2. Lobsters fed oiled feed

In a similar test (Treatment B) 20 lobsters selected at random from laboratory stocks were fed an artificial diet containing 2% Kurdistan Bunker C. Lobsters were held at 15°C, 10 in each of two tanks and fed *ad libatum* three meals over a 24 hr period. One tank was used for control lobsters and the other was used for the feeding of oiled food. Two days

Table 1

Positive identification of meat and hepatopancreas of lobsters exposed to 'Kurdistan' oil in sand. A total of 14 judgments were made in each category. Tank temperature 3 to 5°C.

Exposure - hr		Dosage Low	 Medium	 High
67	meat	0	1	5
	hepatopancreas	0	2	5
115	meat	2	4	7
	hepatopancreas	1	2	2

Table 2

Treatment 'A' - Successful identification of Kurdistan oil-exposed meat and hepatopancreas of lobsters by taste and odor. Two exposure times, 2 days and 4 days, to Kurdistan oil in sand at 15°C.

		Number of correct identifications (out of nine)	
	Dose	A1 2 d	A2 4 d
Tail meat odor	low	2	4
Tail meat odor	high	4	7*
Tail meat flavor	low	4	6
Tail meat flavor	high	6	6
Hepatopancreas odor	low	3	4
Hepatopancreas odor	high	3	3
Hepatopancreas flavor	low	3	6
Hepatopancreas flavor	high	4	5

*Significant at $p < 0.05$.

Table 3

Treatment B: Successful identification of odor and flavor of lobster tail meat and hepatopancreas of lobsters fed 2% Kurdistan oil. Tank temperature 15°C (out of 18).

	Number of correct identifications	
	Odor	Flavor
Tail meat	9	8
Hepatopancreas	6	9

Table 4

Polycyclic aromatic hydrocarbons in experimental lobsters in ng/g pyrene equivalents, wet weight. () number in sample.

	Treatment A - Oil in sand			
	1 ppt		0.5 ppt	
	Tail	Hepatop.	Tail	Hepatop.
A1 - 2 d	342	1747	103	1989
Control	38	907	60	1195
A2 - 4 d	194(6)	3048(7)	137(6)	2624(3)
Control	18(6)	416	40	930

	Treatment B - 2% oil in food	
	Tail	Hepato.
Treatment B (10/5/79)	545(5)	6747(5)
Treatment B (11/5/79)	159(2)	5852(4)
Control	54(4)	1517(4)

after the last feeding half the lobsters were taken for organoleptic and chemical analysis. The remaining lobsters were analyzed about four hours later. No mortalities occurred over the test period. Results of taste panel analysis (Table 3) were not significant at $P < 0.05$, even when all results (32/72) are summed. Significance at the 95% confidence level would require 34/72 positive observations.

Hydrocarbon concentrations in lobsters artificially contaminated by exposure or by feeding in the laboratory are shown in Table 4.

Tainting and Petroleum Hydrocarbons in Wild Lobster Stocks

In view of the fact that the eastern Nova Scotia lobster seasons open progressively beginning April 20, it was decided to sample lobsters either just before, or shortly after, the season opened and analyze both organoleptically and spectrofluorimetrically.

1. Guysborough County lobsters

The first area sampled in late April was Guysborough County, west of Canso, followed 1 w later in early May by sampling in Chedabucto Bay. Both these areas had suffered moderate oiling during April. Control samples were taken from Halifax Laboratory aquarium stock, and from commercial catches at Port Hood on the Gulf of St. Lawrence side of Cape Breton Island, respectively. All samples of 'wild' lobsters were taken by commercial fishermen using standard traps and bait. (In some instances special provisions were made toallow collecting of lobsters before the official season.) All lobsters were transported to Halifax for analysis. Taste panel results from testing this wild stock are shown in Table 5. Test results were not significant. At $p = 0.05$, 15 and 30 positive judgments respectively would be required to give statistically significant results in the two analyses. This may be in part due to the fact Halifax Lab stock, used as controls, had a higher body burden of fluorescent hydrocarbons than either Port Hood controls or lobsters from the suspect Guysborough county areas, although hepatopancreas levels at Canso appear slightly elevated (Table 6).

Table 5

Taste panel assessments of wild lobsters.

	No. of judges	No. of judgments	Positive judgments	Conclusion
Canso area - meat	7	20	0	Not significant
- hepatopancreas	7	20	1	Not significant
Chedabucto Bay - meat	16	46	8	Not significant
- hepatopancreas	16	46	9	Not significant

Table 6

Fluorescent hydrocarbons in lobsters ng/g wet weight. () number of lobsters if more than 1

Sample	Stomach	Tail meat	Hepatopancreas
Halifax Lab. (control)	130	49	1630
Port Hood (control)	trace	16(6)	110(6)
Canso area		18	640
Canso area		19	500
Chedabucto Bay	N.D.	7(6)	180(6)

Table 7

Taste panel analysis of wild lobsters from Scatarie Island, (sample C1).

	No. of positive judgments/Total no. of judgments	
	Odor	Flavor
Tail meat	9/14*	8/14**
Hepatopancreas	8/14**	8/14**

* $p < 0.05$
** $p < 0.01$

2. Scatarie Island lobsters (early May)

The area of coast believed to have been the most heavily oiled was in the general area of Scatarie Island. Six samples were taken from shallow water in this area during the second week of May, before the lobster season opened. It was reasoned that Kurdistan oil, being heavy, might be readily admixed with shallow bottom sediments, particularly in areas where strong onshore winds had been experienced, and thus create the type of conditions shown to cause lobster contamination in the laboratory (Treatment A). These lobsters were similarly prepared and subjected to organoleptic and spectrofluorimetric analysis.

Initial taste panel results on one sample, C1, from Scatarie Island gave the results shown in Table 7 using a simple triangular test with one suspect and two control samples (Kramer and Twigg, 1966). Individual tests comprising 14 judgments require at least nine positive judgments for $p < 0.05$. Eight positive judgments have $p < 0.1$. The total of all tests, 33/56, is significant at $p < 0.01$.

3. Degree of off-flavors

In earlier assays (Treatments A and B above) panelists had commented that different oiled samples contained off-flavor to varying degrees. In order to accommodate a subjective estimate of the degree to which each sample contained off-flavors, each panelist was asked to rate both oil taste and aroma on a scale of 0-4, none to extreme. Results are summarized in Table 8. With few exceptions, the judges found oil contamination of wild lobsters from Scatarie Island to be slight and not objectionable. It is interesting to note that this slight contamination appeared to be manifested either as a stronger odor of the tail meat, or as a stronger flavor in the tomalley (hepatopancreas).

All six subsamples of sample C (including C1) were subsequently assessed for tainting by 14 judges in a series of six triangular comparison tests. For each test, each panelist received one reference sample of tail meat andand one of hepatopancreas from the same lobster. The reference, labelled R, was either from the suspect area (C2, C3, C4) or from unpolluted waters (Port Hood). Two coded samples of meat and tomalley, one each from control and suspect lobsters, accompanied the reference. One of

Table 8

Range of judgments of 'off-flavors' from Scatarie Island lobsters, sample C1. 0 = none, 4 = extreme.

	Tail meat		Hepatopancreas			
Judge	Odor	Flavor	Odor	Flavor	r	$\bar{x}$
1	0	0	1	2	3	.75
2	2	1	2	1	6	1.5
3	1	2	0	0	3	.75
4	2	1	1	1	5	1.25
5	0	0	0	0	0	0
6	1	0	0	1	2	0.5
7	0	1	0	0	1	0.25
8	2	1	1	0	4	1.00
9	0	0	2	3	5	1.25
10	1	1	2	2	6	1.50
11	2	2	0	0	4	1.00
12	1	0	1	1	3	0.75
13	2	1	0	3	6	1.50
14	0	0	2	0	2	0.50
r	14	10	11	14		
$\bar{x}$	1.00	0.71	0.78	1.00		

Table 9

Subjective assessment of tainting in six samples of wild lobsters. B = borderline, S = suspect.

	Tail meat		Hepatopancreas		
Sample	Odor	Flavor	Odor	Flavor	Conclusion
C1 (Near Scatarie)	B	-	-	B	Borderline
C2 (Glace Bay)	-	-	-	-	OK
C3 (Scatarie Island)	S	-	-	B	Borderline
C4 (St. Annes Bay)	-	-	-	-	OK
C5 (Fourchu Hd.)	-	-	-	-	OK
C6 (Port Morien)	S	-	-	S	Suspect

Table 10

Pyrene equivalents, ng/g wet weight, in wild lobsters. () number in sample

	Suspect		Control	
	Tail	Hepatopancreas	Tail	Hepatopancreas
C1 (Scatarie Island)	112(7)	3129(9)	25(7)	572(7)
C2 (Glace Bay)	168(8)	1911(12)	12(4)	378(4)
C3 (Scatarie Island)	77(7)	2398(7)	18(4)	411(5)
C4 (St. Anne's Bay)	31(5)	823(7)	15(3)	333(4)
C5 (Fourchu Hd.)	12(5)	251(5)	17(4)	416(8)
C6 (Port Morien)	8(3)	826(6)	15(7)	288(5)

Table 11

Pyrene equivalents (ng/g) in lobsters. () number in sample. (All controls are from Port Hood, except F which was from Pictou.)

	Suspect		Control	
Sample	Tail	Hepato.	Tail	Hepato.
D1A Scatarie Island, Tin Cove	13(5)	561(6)	10(9)	281(9)
D1B Scatarie Island, Gulf Cape	30(7)	479(7)	9(9)	234(9)
D2 Port Morien	46(7)	494(6)		
D3A Sactarie (N. side)	16(8)	739(8)	17(8)	329(8)
D3B Donkin Glace Bay	36(7)	1012(7)		
E1A Baleine (Lorraine)	15(7)	410(10)		
E1B Scatarie (S. side)	20(6)	545(9)	19(12)	391(18)
E2A Scatarie (Hay I)	21(7)	787(13)	9(14)	297(24)
E3A Glace Bay	14(9)	699(10)	10(7)	408(18)
E3B Cow Bay Morien	17(10)	1388(13)		
F1A Larrys River	17(8)	245(12)	3(17)	142(23)
F2B Larrys River	25(7)	552(12)		
G1A Louisbourg	16(5)	610(14)	23(7)	376(17)
G1B Gabarus	24(5)	350(8)		
G2A Petit de Grat	92(9)	5655(14)		
G2B Forchu	11(8)	1435(14)		
G3A Port Nova	25	2412(13)		
G3B Scatarie Island (Hay I)	15	241(14)		
n	18	18	8	8
$\bar{x}$	25.17	1034.11	12.5	308
s	18.87	1269.14	6.54	89

the coded pairs was always from the reference lobster. Panelists were asked to rate the coded meat and tomalley samples in relation to the reference on the basis of oily taste and odor (Larmond, 1977).

Numerical scores were assigned to panel responses with a value of 5 being used for 'equal to R', 4-1 for less oily, and 6-9 for more oily according to degree. The Friedman two-way analysis of variance (Siegal, 1956) was applied to the data and decisions made on that basis. Three categories were used for reporting where the probabilities of tainting are expressed thus:

$p < 0.05$ = contaminated

$0.05 < p < 0.10$ = borderline

$p > 0.10$ = suspect

When the six samples had been assessed, it was shown that lobsters from Scatarie Island (sample C1, C3) and from Port Morien (C6) were borderline and suspect, respectively (Table 9). Note again the manner in which tainting is manifested as enhanced odor in the tail meat, and flavor in the tomalley.

Several of these samples when analyzed spectrofluorimetrically (Table 10) showed higher concentrations of hydrocarbons than did Port Hood controls. Spectral analysis showed them to be compatible with a Bunker C source. However, a comparison of tainting and hydrocarbon contamination does reveal some inconsistencies, and suggests that the compounds causing off-flavors are not necessarily those which cause fluorescence.

4. Cape Breton samples (late May, June)

The high concentrations of fluorescent hydrocarbons in lobsters from the Scatarie Island area, together with the evidence of low level tainting of lobsters in that area (Table 9), encouraged further work around Scatarie Island. Accordingly, in late May, six more samples were taken, three from around Scatarie Island and one each from Donkin and Port Morien (sample D). These were followed in early June by more samples from the Scatarie area (sample E). A final series of samples (sample G) from Louisbourg, Gabarus, Petit de Grat, Fourchu, Port Nova and Acatarie was taken in late June. All these samples were assessed for tainting by a panel of 14

Table 12

Pyrene equivalents (ng/g wet weight) in mussels (Mytilus edulis). () number in sample.

Location		Size (mm)	ng/g
Half Island Cove	oiled	25-30	2989(20)
Half Island Cove	oiled	35-40	2321(10)
Larrys River	control	25-30	77(10)
Larrys River	control	35-40	34(10)
L'Archeveque	subtidal	35-45	516(6)
L'Archeveque	intertidal	25-30	705(20)
L'Archeveque	intertidal	35-45	590(6)
L'Archeveque	subtidal	20-40	456(20)
Petit de Grat	subtidal	45-60	516(6)
Petit de Grat	subtidal	25-30	1093(20)
Havre Boucher	subtidal control	45-60	6(6)
Havre Boucher	subtidal control	25-30	50(20)
Dominion Bridge	(raw)	45-70	1139(9)
Dominion Bridge	(cooked)	45-70	1311(9)
Maddens Cove	(raw)	55-70	301(9)
Maddens Cove	(raw)	55-70	224(9)
Maddens Cove	(cooked)	55-70	394(9)
Lennox Passage, Haddock Harbour		35-55	192(9)

Table 13

Pyrene equivalents (ng/g wet weight) in clams (Mytilus edulis). () number in sample.

Location		Size (mm)	ng/g
Fourchu	cooked	35-40	1049(19)
Forchu	raw	35-40	510(10)
Janvrin Harbor	cooked	55-70	411(6)
Janvrin Harbor	raw	55-70	157(6)
Dominion Beach	cooked	55-70	678(9)
Dominion Beach	raw	55-70	250(9)
Fullers Bridge	cooked	30-55	2501(9)
Fullers Bridge	raw	30-55	958(9)
Morien Sand Bar (S. side)	cooked	45-55	575(10)
Morien Sand Bar (S. side)	raw	45-55	327(10)

judges using an uncontaminated reference sample and two or three coded samples for comparison. In some tests, two contaminated samples were tested against the reference. The following samples gave evidence of minor tainting:

Sample	Lobster Meat		Lobster Tomalley		Conclusion
	Odor	Flavor	Odor	Flavor	
D1A Tin Cove	S	S	-	-	Suspect
E3A Glace Bay	-	-	-	B	Borderline
G2A Petit de Grat	-	-	B	-	Borderline
G2B Fourchu	-	-	B	-	Borderline

These same samples were also analysed spectrofluorimetrically and showed marginally higher hydrocarbon levels than did Port Hood controls (Table 11). A final sample series (G) was taken in late June to verify whether oil concentrations in the lobsters might increase as the season progressed. All controls were from Port Hood and were collected during the same week as the respective suspect samples. Results from the G series are also shown in Table 11.

Formal taste panels were discontinued after this time and only occasional informal 'spot checks' by Fisheries Officers were performed. Fisheries Officers also routinely examined commercial lobsters suspected of physical oiling by floating oil patches contaminating lobster cars or holding pounds. Two such samples from Larry's River (sample F with controls from Pictou) were assessed by taste panel and analyzed spectrofluorimetrically. Taste panel results were not significant statistically. One additional lobster was analyzed and gave a reading of 368 ng/g pyrene equivalent in the hepatopancreas, which is not indicative of oiling.

Observations on Shellfish - Mussels and Clams

No species other than lobsters were assessed by taste panels; however, several stocks of wild clams and cultivated mussels were analyzed for fluorescent hydrocarbons (Tables 12, 13).

None of the clam samples could unequivocally be considered to be from either control or uncontaminated areas. Thus Janvrin Lagoon, near

Janvrin Harbour, for example, remains contaminated by oil from the tanker Arrow wrecked in 1970 (Gilfillan and Vandermeulen, 1978). It is interesting to note that effective concentration of oil is increased roughly two-fold by cooking.

DISCUSSION AND CONCLUSIONS

From the foregoing it is clear that in the laboratory lobsters will take up Kurdistan Bunker C when exposed to oiled sediments under experimental conditions, with the degree of uptake depending on the dose and exposure time. The exposure will give rise to elevated concentrations of fluorescent hydrocarbons in tail meat and hepatopancreas and to detectable tainting. Similarly lobsters fed oil-contaminanted food show elevated levels of hydrocarbons in their tissues, but taste panel tests were insufficiently sensitive to show significant levels of tainting. Generally, Kurdistan oil appears to behave similarly to Arrow Bunker C when ingested by lobsters and it seems reasonable to assume then that Kurdistan contaminated lobsters will similarly self-cleanse over a period of weeks (Wilder, 1970).

The assessment of field samples showed that high concentrations of hydrocarbons may occur in lobsters captured in areas known to have been contaminated by oil, although there was not necessarily any parallel tainting. From the chemical analyses there is good reason to believe that Kurdistan Bunker C was implicated, although it also became clear that the compounds causing 'off-flavors' are not necessarily the same as those measured fluorimetrically.

It is interesting to note that tainting is not necessarily objectionable. For example, in some areas, specifically those close to Scatarie Island which experienced heavy oiling, there were examples of lobsters which had oily off-flavors although the majority of taste panelists did not consider these flavors objectionable. There are also differences between the aroma and the flavor of tainting due to oil. Tasters fairly consistently considered the aroma to be more pronounced in the tail meat, and the flavor to be more pronounced in the hepatopancreas.

Contamination of lobsters for short periods by floating oil did not appear to cause detectable off-flavors nor cause significant elevation of tissue hydrocarbon concentration.

Lobsters from contaminated areas, for the most part, had tissue hydrocarbon concentrations 2-3 times that of control animals. In one extreme case (hepatopancreas) a fifteenfold elevation was measured. In contrast clams and mussels, both suspension feeders, had pyrene-equivalent hydrocarbon concentrations 10-40 times those from unoiled areas.

Apart from the confiscation of lobsters visibly contaminated with oil droplets, no formal intervention was made into the fishery, which was allowed to proceed as normal except that advisory notices were posted on certain clam flats. There were no authenticated complaints of tainted or contaminated products from consumers.

ACKNOWLEDGEMENTS

A number of persons were involved in the design and execution of experiments and the subsequent analyses. They were: James E. Stewart, B. Arie, L. Marks, H.C. Freeman, J.R. Dingle, J. Castell, A. Woyewoda and S. Varga. Their reports comprise a series of memoranda which form the basis of this paper. A larger number of persons served as members of taste panels, and others assisted with the capture, transport, care and maintenance of samples. Their cooperation and assistance was greatly appreciated.

The oil used in tainting experiments and as a chemical reference was furnished by Mr. G. Donaldson from a sample collected by the CGS *Rally* at position 45°24'N, 60°20.7'W. It was described as 'heavy' Bunker C. The assistance of Canadian Coast Guard in the collection and transport of samples is gratefully acknowledged.

REFERENCES

GILFILLAN, E.S. and J.H. VANDERMEULEN. 1978. Alterations in growth and physiology of soft-shell clams, *Mya arenaria*, chronically oiled with Bunker C from Chedabucto Bay, Nova Scotia 1970-1976. J. Fish. Res. Board Can. 35: 630-636.

KRAMER, A. and B.A. TWIGG. 1966. Fundamentals of quality control for the food industry. Avi. Publ. Co., Inc. Westport, Conn., p. 120-154.

LARMOND, E. 1977. Laboratory methods for sensory evaluation of food. Can. Dept. Agric. Publ. 1637, 32 p.

SCARRATT, D.J. and V. ZITKO. 1972. Bunker C oil in sediments and benthic animal from shallow depths in Chedabucto Bay, N.S. J. Fish. Res. Board Can. 29: 1347-1350.

SIEGEL, S. 1956. Non-parametric Statistics for the Behavioral Sciences. McGraw-Hill, Toronto, 166 p.

WILDER, D.G. 1970. The tainting of lobster meat by Bunker C oil alone or in combination with the dispersant Corexit. Fish. Res. Board Can. MS Rept. 1087, 25 p.

ZITKO, V. 1975. Aromatic hydrocarbons in aquatic fauna. Bull. Environ. Contam. Toxicol. 14: 621-631.