MESA Special Report

The Bouchard #65 Oil Spill, January 1977

April 1978

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

On 28 January 1977, the barge *Bouchard* #65 ran aground in Buzzards Bay, Massachusetts, spilling 81,146 gallons of no. 2 heating oil into the ice-covered bay. Swift currents carried the oil under the ice and through crack systems where it collected in rafted ice, rubble fields, and pressure ridges. The oil was contained at the surface in this manner until ice breakup began 8 days after the spill. At this time, oil was released from the ice in the form of thin sheens and oily floes and transported 27 miles by the currents through the Cape Cod Canal and into Cape Cod Bay.

A preponderance of naturally occurring hydrocarbons was demonstrated in the sediments, as well as weathered petroleum hydrocarbons. Weathered #2 oil found in the sediment could not be identified as the *Bouchard* cargo.

Serious and immediate biological impact was not evident, perhaps as a result of containment of oil by ice. Only long-term studies will reveal possible long-term impacts.

Clean up operations recovered 18.3% of the oil, 84% of which was recovered by direct suction. A burn was attempted on a 4000 gallon pool of the oil and it is estimated that 50% of that pool was burned off.

Recommendations include improved aerial surveillance techniques, suggestions for changes in sampling schemes, testing of new instruments for water column sampling, suggestions for improved clean up techniques, and a section on contingency planning for oil spill research.

PREFACE

In recent years, much time and effort has been expended by researchers in an effort to document the physical, chemical and biological interactions of spilled oil with the environment. Offshore oil development in Alaska, Canada, and other cold regions, and the subsequent threat of major spills in these areas has made research on oil in ice-covered waters one of the most pressing, while at the same time most difficult, areas of study. Few research institutions have been able to afford either the time or the money involved in this aspect of Arctic research.

The rare instance of heavy icing conditions combining with an oil spill in the lower 48 states occurred with the grounding of the *F.E. Bouchard* #65 in Buzzards Bay, Massachusetts in January, 1977. This spill provided scientists with a unique opportunity to pursue a variety of research goals.

This report is a synthesis of the work and results of those researchers through the spring of 1977. It attempts not only to document their work, but also to provide a series of recommendations for future oil spill research and cleanup operations.

ACKNOWLEDGEMENTS

This report reflects the efforts of the National Oceanic and Atmospheric Administration (NOAA), and 21 other organizations and institutions who participated in the investigation and documentation of the oil spill in the ice covered waters of Buzzards Bay. The effort was partially supported by the Bureau of Land Management through interagency agreement with NOAA. The participating organizations and institutions, exclusive of NOAA components, in alphabetical order, were:

ARCTEC, Inc.
Cannon Engineering
Coastal Services, Inc.
Department of Natural Resources, Town of Bourne, Massachusetts
Energy Resources Company
Environmental Devices Corporation
Environmental Protection Agency
Geophysical Survey Systems, Inc.
Jetline Services, Inc.
Marine Biological Laboratory, Woods Hole, Mass.
Massachusetts Division of Marine Fisheries
Massachusetts Division of Water Pollution Control
Pacific Marine Environmental Laboratories
Science Applications, Inc.
Shellfish Wardens, Falmouth, Mass.
U.S. Coast Guard
U.S. Fish and Wildlife Service
U.S. Navy Atlantic Audiovisual
University of Rhode Island
University of South Carolina
University of Washington
Woods Hole Oceanographic Institution

Appendix I lists the participants representing these organizations and details NOAA components involved.

GLOSSARY

The ice terminology used throughout this report is that adopted by the World Meteorological Organization (WMO). For the convenience of those who may be unfamiliar with this terminology, the definition of the terms used in this report are directly quoted from *WMO Sea-Ice Nomenclature, Terminology, Codes and Illustrated Glossary, 1970*.

Brash ice: Accumulations of floating ice made up of fragments not more than 2 m across; the wreckage of other forms of ice.

Concentration: The ratio in tenths (oktas) of the sea surface actually covered by ice to the total area of sea surface, both ice-covered and ice-free, at a specific location or over a defined area.

Crack: Any fracture which has not parted.

Deformed ice: A general term for ice which has been squeezed together and in places forced upwards (and downwards). Subdivisions are rafted ice, ridged ice, and hummocked ice.

Fast ice: Sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Fast ice may be formed *in situ* from sea water or by freezing of pack ice of any age to the shore, and it may extend a few meters or several hundred kilometers from the coast.

Floe: Any relatively flat piece of sea ice 20 m or more across. Floes are subdivided according to horizontal extent as follows:

Big:	500-2000 m across
Medium:	100- 500 m across
Small:	20- 100 m across

Fracture: Any break or rupture through very close pack ice, compact ice, consolidated pack-ice, fast ice, or a single floe resulting from deformation processes. Fractures may contain brash ice and/or be covered with grease ice and/or young ice. Length may vary from a few meters to many kilometers.

Grease ice: A stage of freezing when the ice crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matte appearance.

Hummock: A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a bummock.

Ice cover: The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic local; this local may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea.

Ice keel: A downward-projecting ridge on the underside of the ice canopy; the counterpart of a ridge. Ice keels may extend as much as 50 m below sea-level.

Lead: Any fracture or passage-way through sea ice which is navigable by surface vessels.

Open water: A large area of freely navigable water in which sea ice is present in concentrations less than 1/10.

Rafted ice: Type of deformed ice formed by one piece of ice overriding another.

Ridge: A line or wall of broken ice forced up by pressure. May be fresh or weathered.

Rubble Field*: An area of sea ice that has essentially all been deformed. Unlike hummock field, this term does not imply any specific form of the upper or lower surface of the deformed ice.

Tide Crack: Crack at the line of junction between an immovable ice foot or ice wall and fast ice, the latter subject to rise and fall of the tide.

*Added term; not contained in WMO original.

1. INTRODUCTION

1.1 BACKGROUND

Buzzards Bay leads to the western entrance of the Cape Cod Canal and is an important shipping lane for New England's small tanker, barge, and freighter traffic. The bay is shallow, has numerous rock ledges and a narrow channel. In severe winters it is ice-choked.

The Buzzards Bay area has a long history of shipping mishaps, including several oil spills spanning more than ten years of recent history. This history, however, has not been well documented. The major spills of recent years have been tabulated in Table 1.1. These spills provide evidence that the petroleum residues found in sediments in Buzzards Bay are the result of a long succession of oil spills. The first spill which was scientifically noted occurred in the late 1940's when a barge grounded off West Horse Neck Beach in winter, and lost an undetermined amount of No. 2 fuel oil. The effects of this oiling were conspicuous, according to Cameron E. Gifford, (pers. comm.), who observed a windrow of oil-soaked surf clams (*Spisula*) 1.8 to 2.4 m wide and 4.8 km long along the beach.

During the winter of 1963, another barge grounded near Cleveland Ledge and spilled additional No. 2 fuel oil, (George Hampson, Woods Hole Oceanographic Institution, pers. comm.). This oil washed ashore around Nyes Neck. Although no biological study was made, gulls were observed feeding in the area of the spill, apparently on dead marine organisms.

The most serious spill occurred on 16 September 1969, when the barge *Florida* ruptured her hull and spilled 175,000 gallons of No. 2 fuel oil off North Falmouth. Strong northwest winds drove the slick into Wild Harbor, the Wild River, and its salt marsh system, while thoroughly mixing the oil with the water. Oil was reported to have penetrated sediments in water depths of 7 to 10 meters (Hampson and Sanders, 1969). Within days the oil-soaked beaches were littered with dead or dying fish, worms, crabs, lobsters, other crustacea, and mollusks. Biotic effects were observable in the sub- and

inter-tidal zones for the next six months as additional mortalities occurred (Sanders, Grassle and Hampson, 1972). Long-term effects have been demonstrated over at least seven years in populations of *Fundulus* (Stegeman and Sabo, 1976) and for other organisms (Michael *et al.*, 1975 and Burns, 1975). Oil remains in the sediments in this area in the summer of 1977 and part of the area is closed to shellfishing at the time of this report.

Additional spills in Buzzards Bay include the 9 October 1974, *Bouchard* spill of an indeterminate amount of No. 2 fuel oil at Anchorage site "C" near the western entrance of the Cape Cod Canal. The wind moved the slick northeasterly between Wings Neck and Scraggy Neck. On 11 October oil was reported in Hospital and Winsor Coves, and on the beaches in the Red Brook Harbor area. By 12 October dead marine organisms were observed around Bassetts Island and in Winsor Cove, where there was oil on the water surface and in bottom sediments (Hampson, 1974). The most serious effects involved the total loss of bivalves including surf clams, razor clams, quahogs, and bay scallops. The loss was especially serious because both Hospital and Winsor Coves are classified by the State as the best shell fishing areas in Bourne (Carr, 1974). The damage from this spill was severe enough that the shellfishing areas of Winsor Cove and around the southern end of Bassetts Island were closed at the time this report was prepared. A constant source of low level petroleum hydrocarbon input into the bay system can be attributed to recreational boating and marinas, highway runoff, spoil areas, and the urban/industrial complex at New Bedford.

Name of Spill	Location	Date	Kind of Oil and Amount	Area Inundated by Oil	Observations of Immediate Effects	Research to Determine Effects	Literature
Horseneck spill	Horseneck Beach - west side of Buzzards Bay	Late 1940's winter	#2 Fuel oil undetermined amount	3-mile strip of Horseneck Beach Westport	Windrow of dead surf clams (*Spisula*)* 6' to 8' wide and 2 to 3 miles long	None	None
Dynaflow spill	off Cleveland's Ledge	1963 winter	#2 fuel oil undetermined amount	Around Nye's Neck Falmouth	Heavy densities of gulls feeding in oiled area - suggested dead marine organisms	None	None
Florida Barge West Falmouth spill	off West Falmouth	1969 Sept. 16	#2 fuel oil 175,000 gals.	West Falmouth Wild Harbor Wild Harbor River Silver Beach	Within days beach littered with dead or dying fish, worms, crabs, lobsters and other crustaceans	Continual Sanders Hampson Grassle Souza Blumer Stegeman Michael	See literature cited
Bouchard 1974	Anchorage site "C" Buzzards Bay	1974 Oct. 9	#2 fuel oil undetermined amount	Bassetts Island Redbrook Harbor Area Winsors Cove Hospital Cove Falmouth	Total loss of bivalves	Farrington Carr Ashkenas	Nothing published to date. Some data expected to be published in Fall of 1977

Table 1.1. Recent oil spills in Buzzards Bay prior to *Bouchard* spill, 1977.

1.2 ENVIRONMENTAL SETTING

Buzzards Bay, located on the southern Massachusetts coast (Figures 1.1 and 1.2) is a shallow non-estuarine bay, approximately 46 km long and 19 km wide, with an average depth of 11 m (Gilbert *et al.*, 1973). Connecting Buzzards Bay with Cape Cod Bay to the north is the man-made Cape Cod Canal. This canal provides safe, inshore passage for shipping traffic between northern and southern New England, avoiding the dangerous shoal waters of the outer Cape Cod region.

The bay is a very productive region in terms of marketable fish and shellfish. The shellfish beds of the eastern bay are among the most valuable, and provide a substantial income for area residents. Resort clientele and summer home owners utilize the productive waters of the bay for recreational fishing and boating, providing support for a thriving local tourist industry.

Buzzards Bay has an extremely complex hydrography due to the influence of the canal and Cape Cod Bay currents. The tidal wave flowing into Buzzards Bay is slowed by its relatively long course over the continental shelf. The tidal wave in Cape Cod Bay, on the other hand, travels through deeper water and thus has a higher velocity. This difference in bottom configuration between the two bays creates a discrepancy in tidal phase and in mean tidal range (2.8 m in Cape Cod Bay versus 1.2 m in Buzzards Bay). The stronger Cape Cod Bay tidal current helps to create a distorted tidal wave in Buzzards Bay for which the duration of the ebb is shorter than the duration of the flood (Anraku, 1961).

Sediments in northern Buzzards Bay are generally patchy sands and gravels silty clays in the areas protected from high current velocities. Variable tidal velocities and bottom relief are responsible for this patchiness (Gilbert *et al.*, 1973).

The winter of 1977 was unusually severe for the northeastern United States. Icing conditions were reported for many parts of the New England coast from December through February, in areas normally having little or no ice cover during the winter months. While no reports are available to indicate when Buzzards Bay began to freeze, heavy icing was reported at the Army Corps of Engineers Wing Neck Station on 14 January.

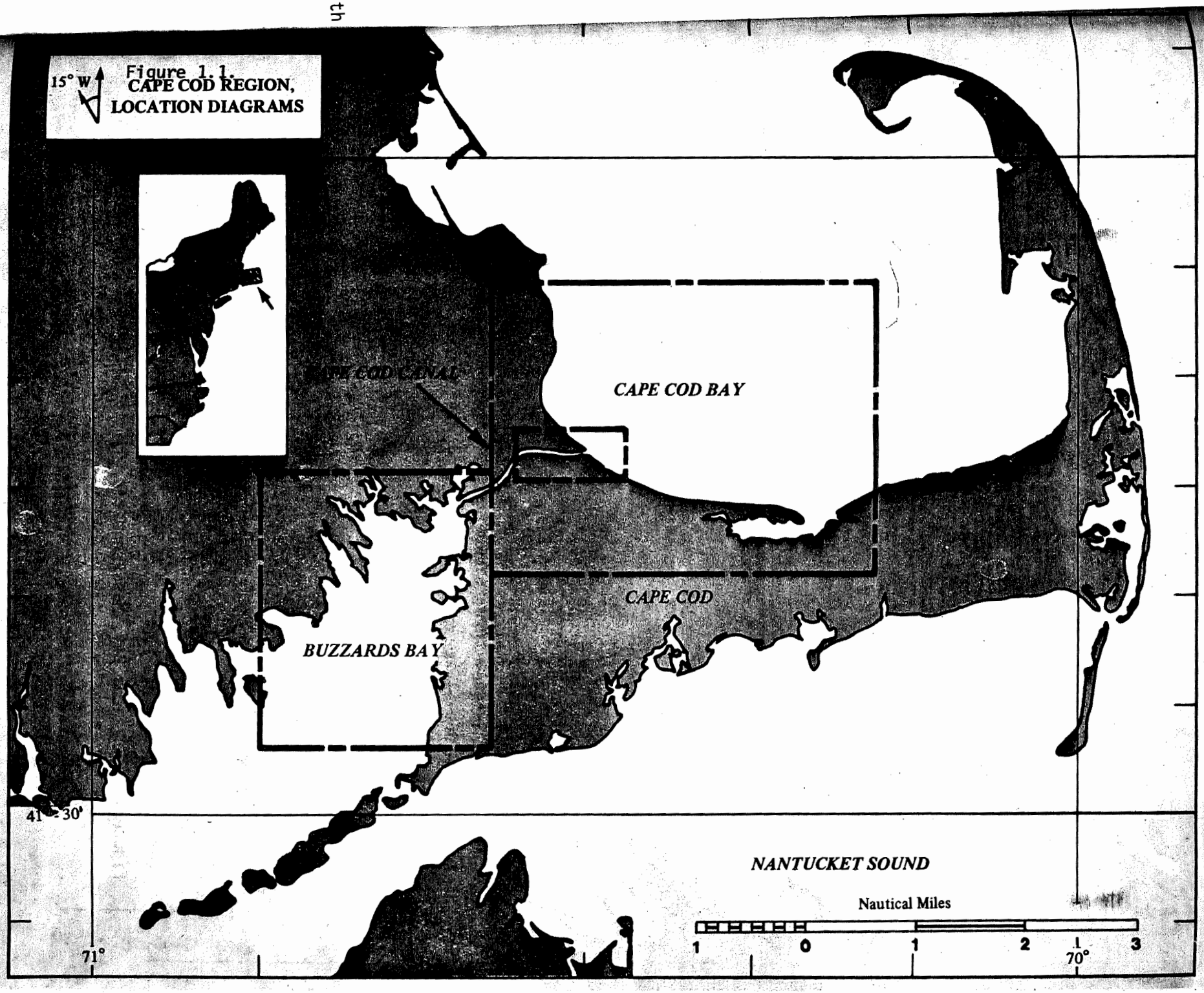

Figure 1.1.
CAPE COD REGION,
LOCATION DIAGRAMS

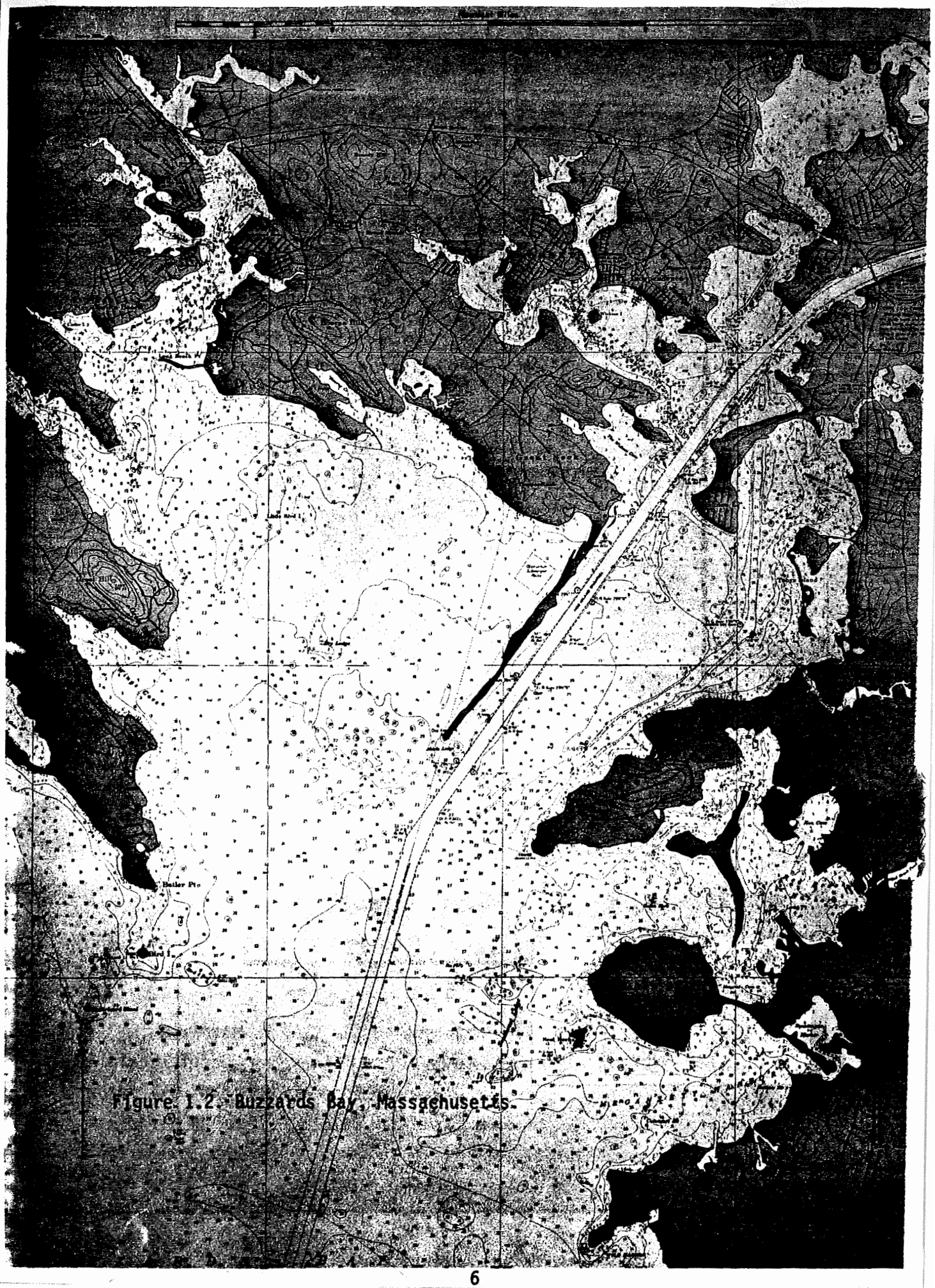

Figure 1.2. Buzzards Bay, Massachusetts.

Weather was clear and cold for most of February with the exceptions of a 12 cm snowfall on 5 February, and 6 days of overcast and rainy weather. Daily temperatures averaged -5.6^{o}C from 28 January to 11 February. A five day warming period kept temperatures almost continually above freezing from 11-15 February, accelerating ice melt. The prevailing northwest winds at the site often gusted to 20 knots. This presented an added hazard to researchers as wind chill factors dropped into the -20-30°C range. Daily mean and range of air temperatures and windspeeds for the study period are presented in Appendix II, Figures 1 and 2. Hourly weather conditions may be found in Appendix II, Table 1.

At the time of the spill (28 January), ice thickness averaged 33 cm with a maximum thickness of 120 cm. Several periods of rain and above freezing temperatures in early January (refer to Appendix II, Table 4) had reduced the salinity of the ice in Buzzards Bay to 2-4 $^{o}/_{oo}$ (Figure 1.3) and promoted a nonporous ice structure. The ice in Buzzards Bay existed in two major forms. Shorefast ice, characterized by a smooth surface with some tidal cracks running through it, was present in the more protected coves. This type of ice was found in Wings Cove, Phinneys Harbor, Megansett Harbor, and the area between Wings Neck and Scraggy Neck (Figure 1.4). In areas not protected by shorelines, broken ice formations were evident. Formed primarily by wind stresses and strong tidal currents, these features consisted of small floes (20-100 m) interspersed with brash ice, some of which was forced up into pressure ridges and rubble fields. Movement of this active ice area was evidenced by the opening and closing of leads as tidal currents changed direction and water velocities fluctuated.

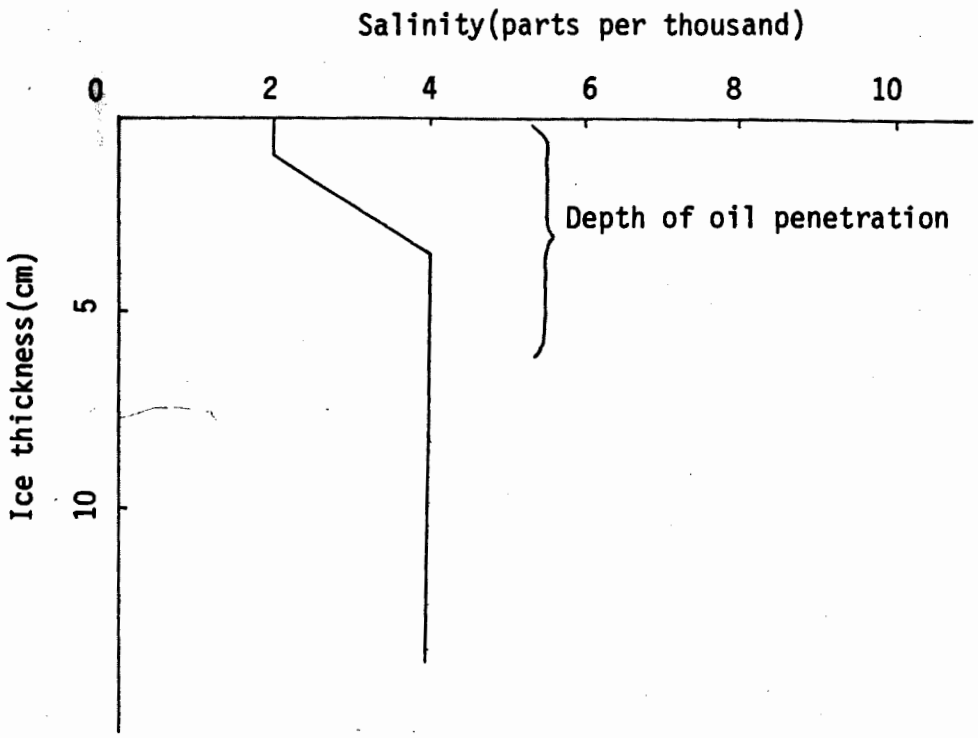

Figure 1.3. Salinity profile of ice core from Buzzards Bay, Massachusetts, 4 February, 1977.

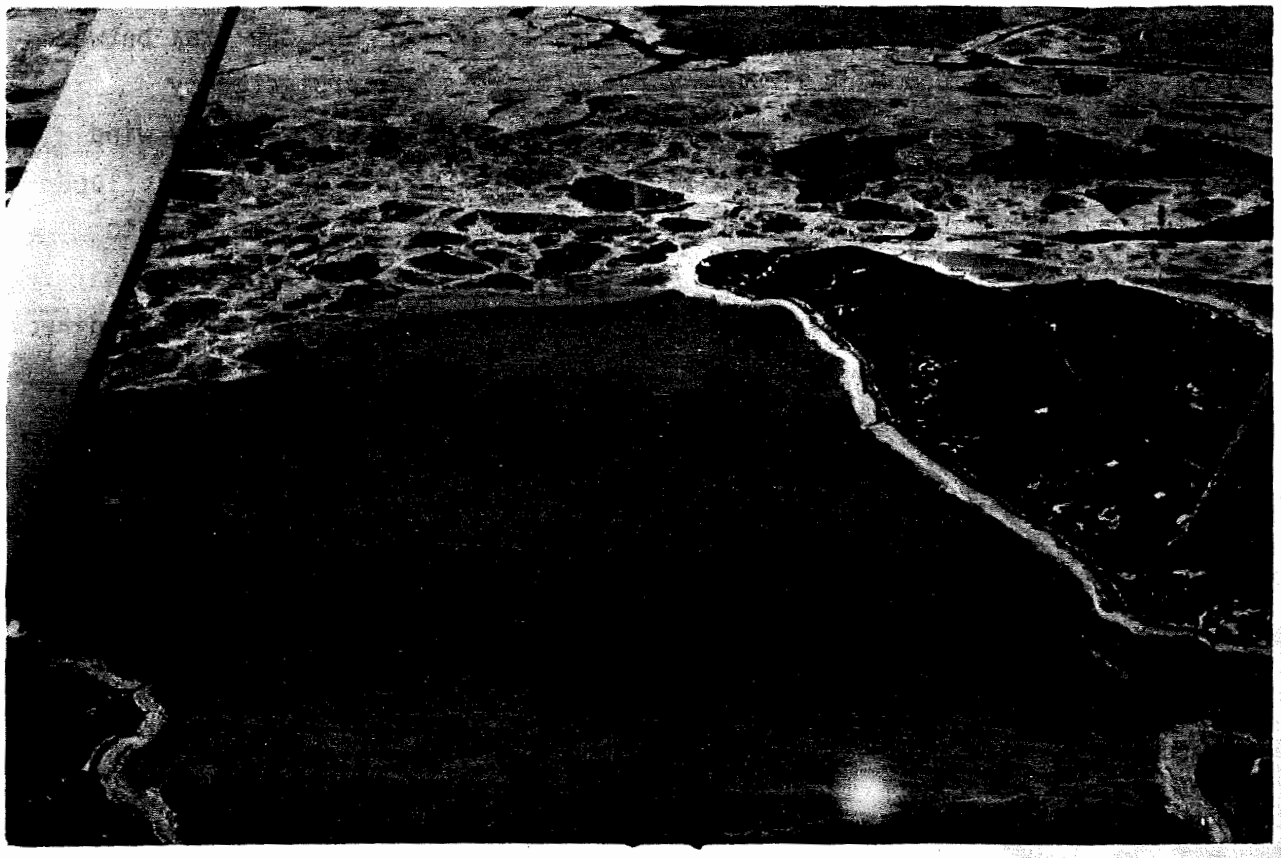

Figure 1.4. Shorefast ice zone, Wings Neck region. Note tidal cracks in ice in lower half of photograph.

1.3 CHRONOLOGY OF THE SPILL INCIDENT

On 28 January 1977, the barge *(Frederick E.) Bouchard* #65, enroute to Portland, Maine with 3.2 million gallons of #2 heating oil aboard, ran aground on Cleveland Ledge in Buzzards Bay, Massachusetts.

At 1300 hours on that day, the B #65 had entered ice in the bay and was slowly making headway north to the Cape Cod Canal. Her tug left her and went ahead to break ice at approximately 1700 hours, leaving the barge free to drift. Strong, gusting winds (20-30 knots) (Appendix II, Table 1) and wind-driven ice apparently pushed the barge aground at 1810 hours on Cleveland Ledge, 0.6 km west of Cleveland East Ledge (Figure 1.5). Four of the barge's tanks were holed, including no. 1 port, and nos. 1, 3, and 6 starboard.

At 2030 hours the barge was floated off the ledge and towed to a site 0.3 km west of Wings Neck Point where it was intentionally grounded on hard, sandy bottom in an attempt to slow the leakage. Another barge, the *F.E. Bouchard* #85, reached the stranded vessel at 0100 hours on 29 January, and commenced offloading operations (Figure 1.6), but shifting winds, tides and currents made this operation very difficult. Ice breaking assistance was provided by the Coast Guard cutters, *Bittersweet* and *Towline*.

At 1430 hours the barge was towed from Wings Neck to the Massachusetts Maritime Academy docks at the west entrance to the Cape Cod Canal to complete offloading. Leakage from the barge had stopped by this time, as enough oil had been spilled and offloaded to allow water levels in the holed tanks to rise above the ruptures.

On 30 January, the barge was towed to Boston where offloading was finally completed. Final measurements by the Bouchard Transportation Company indicate that a total of 81,146 gallons of #2 heating oil was spilled.

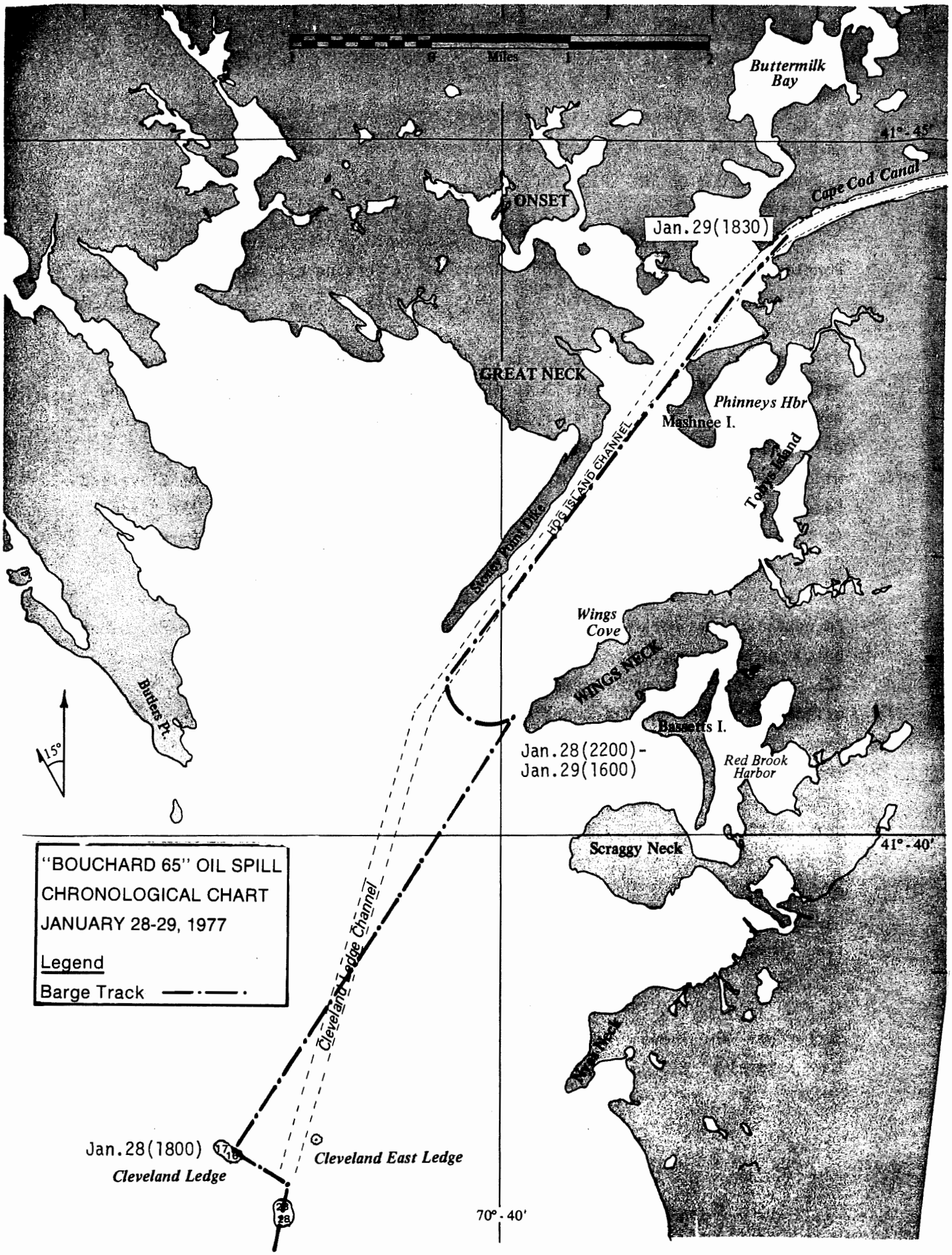
Miles
Buttermilk Bay
41°-45'
Cape Cod Canal
ONSET
Jan.29(1830)
GREAT NECK
Phinneys Hbr
Mashnee I.
Tobys Island
HOG ISLAND CHANNEL
Stony Point Dike
Wings Cove
WINGS NECK
Bassetts I.
Red Brook Harbor
Butters Pt.
15°
Jan.28(2200)-
Jan.29(1600)
Scraggy Neck
41°-40'
"BOUCHARD 65" OIL SPILL
CHRONOLOGICAL CHART
JANUARY 28-29, 1977
Legend
Barge Track
Cleveland Ledge Channel
Jan.28(1800)
Cleveland Ledge
Cleveland East Ledge
70°-40'

Figure 1.6. Stricken *F.E. Bouchard* #65 (foreground) and *Bouchard* #85 d
offloading operation, 29 January.

2. TECHNICAL APPROACH

Research on the spill and its immediate effects included aerial reconnaissance, ground level ice surveys, and a detailed sampling program including water, sediment and biota surveys.

Aerial Reconnaissance:

Overflights of the spill began on the morning of 29 January while the *Bouchard* #65 was still grounded at Wings Neck Point. Aerial surveys continued through 21 February at which time little active ice remained in Buzzards Bay, and patches of oiled ice were barely distinguishable.

Aerial photography using hand-held 35 mm cameras and lenses with focal lengths ranging from 35 to 135 mm provided a record of the movement of oil and oiled ice. Daily sketches of the spill's progress made on standard base maps (NOS) complemented the photographic record. Although two high altitude overflights (2400 m) were made during the study period using vertically mounted Hasselblad cameras, hand-held cameras were found to be more economical and far more versatile, producing high quality, near vertical photographs.

Aerial surveillance involved three types of photography: (1) high altitude (1200-2400 m) oblique photos to record general ice configuration within the northern half of Buzzards Bay; (2) mid-altitude (450 m to 900 m) aerial mosaics and/or single photos to document stability of oil once trapped within the ice (Figure 2.1); and, (3) low altitude shots (15-150 m) to locate specific oil concentrations within mosaic patterns for comparison with ground survey efforts.

Two numbered plywood plaques, 1.5 m^2, were anchored to oiled floes in an attempt to document floe movement from aircraft at the time of ice breakup (Figure 2.2). Logistic difficulties prevented the placement of more than two plaques.

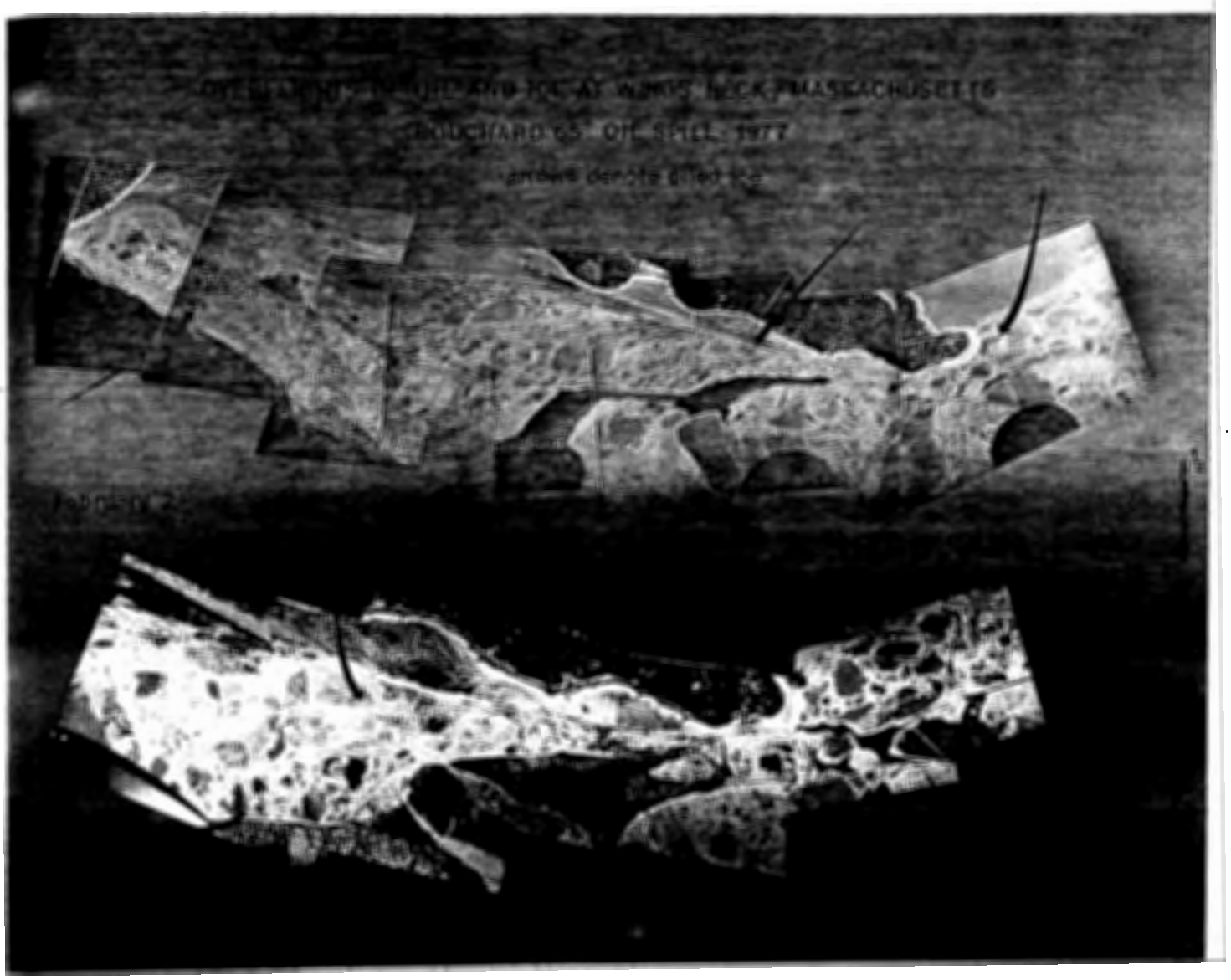

Figure 2.1.

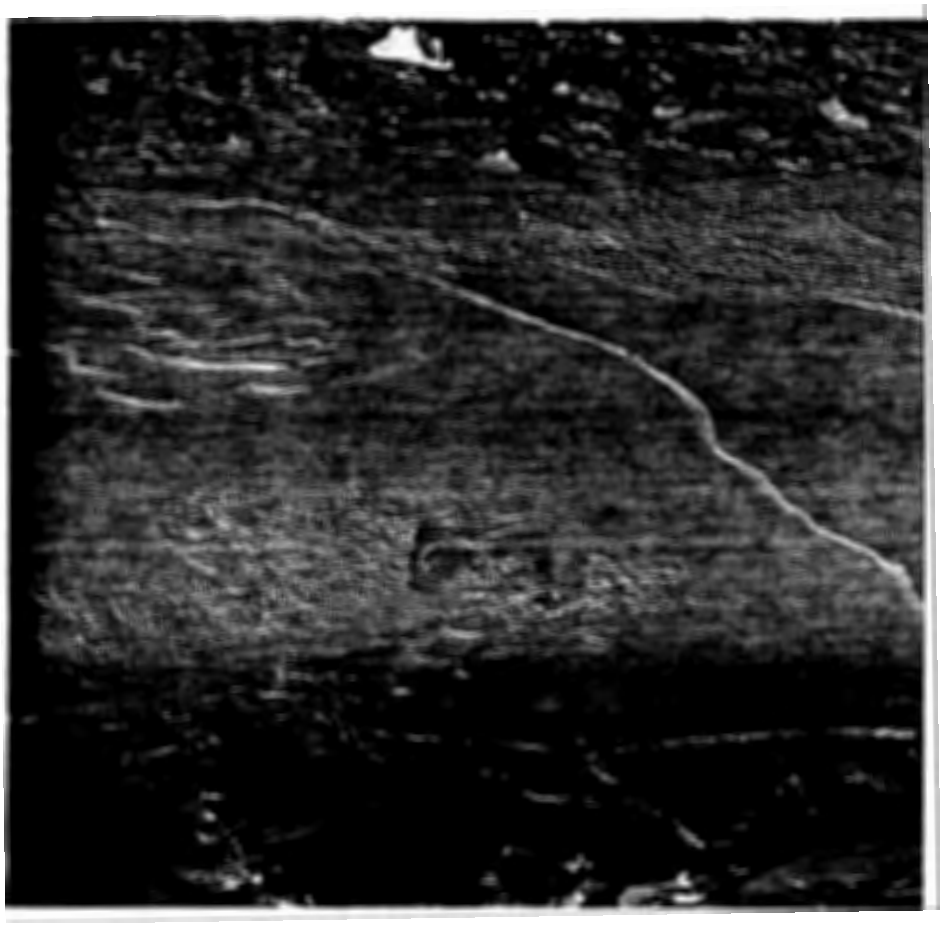

Figure 2.2. One of two plywood placques anchored in ice to measure floe movement, 8 February.

Bird surveys were conducted during overflights to count and identify waterfowl potentially affected by the spill.

Ground Surveys:

Ground surveys were carried out by teams moving across the ice. For ground level exploration far from shore or in areas of shifting ice, Coast Guard and private helicopters were required to safely place workers on the ice.

These surveys included measurements of ice thickness, oil pool depth, and penetration of ice by oil as determined by cross-sectioning raised blocks. Sipre ice corers (7.6 cm diam) (Figure 2.3) and Russian-type corers (12.7 cm diam) (Figure 2.4) were also used to examine ice blocks and floes. Special attention was paid to the underside of ice blocks in order to determine whether there was significant absorption of oil as it passed beneath the ice. Samples taken from the oiled portions of these cross sections and cores, were later melted to determine the percent composition of oil by volume.

Attempts were made to establish which kinds of ice configurations were most likely to form barriers and collection points for oil. As work progressed, it appeared that much of the oil was clearly visible on the surface, incorporated within brash ice and pools. Holes were drilled through the ice to determine whether there were any hidden lenses of oil under floes. A subsurface interface radar system (Figure 2.5) was also employed for this purpose by Geophysical Survey Systems, Inc. (GSS). No lenses of oil were located by either of these methods. See Appendix VI for details of the GSS findings.

Ground level work also included intensive study of the ice, relating salinity, temperature, porosity, texture, and brine channel development to the incorporation of oil within ice structures.

Figure 2.3. Sipre ice corer in use, 10 February.

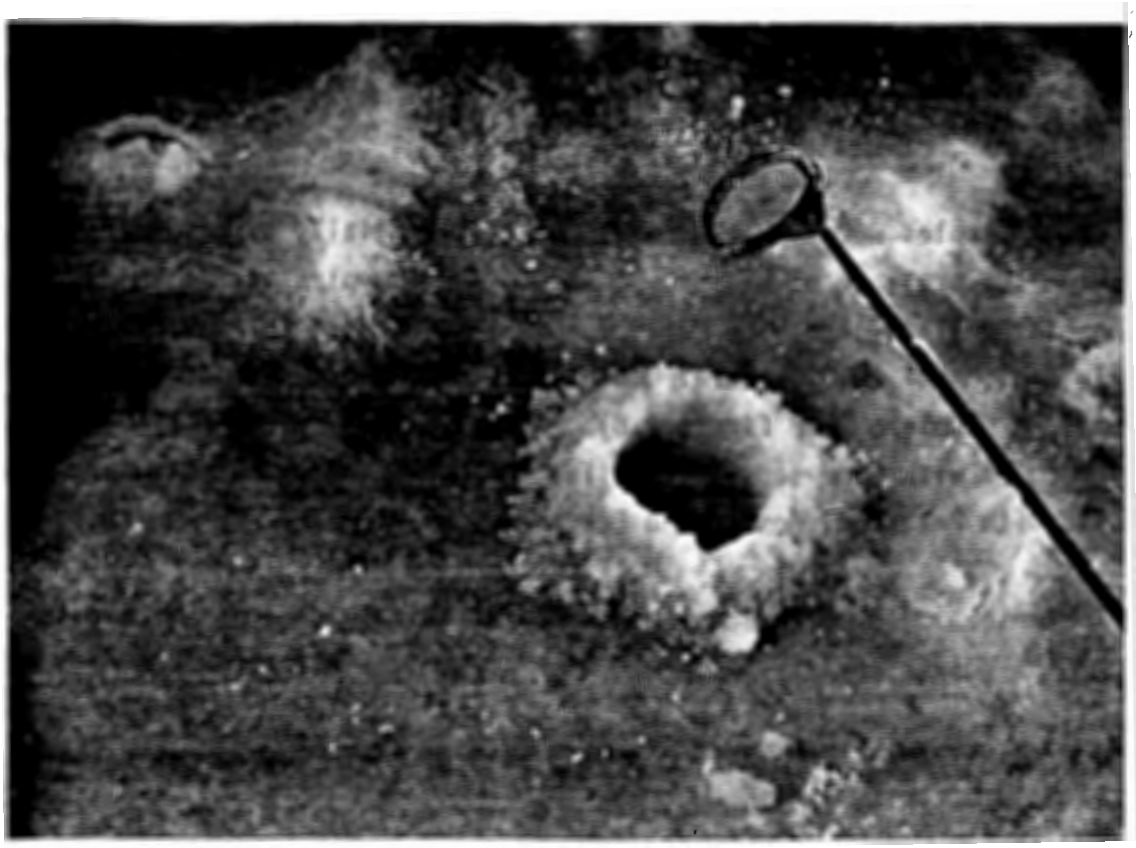

Figure 2.4. Russian type ice corer.

Figure 2.5. Subsurface interface radar system in use, 4 February.

Sampling Programs:

Water samples were taken throughout the potentially affected area to determine the presence of hydrocarbons. Surface samples were gathered with hexane-rinsed glass jars, and water column samples were retrieved with Niskin, Sterile Bag (Model 1030, General Oceanics, Miami, Florida), and type 885 Vacuum Tube samplers (see Figure 2.6). Sampling holes were drilled through the ice cover with hand saws and unoiled chainsaws. Sediment samples were gathered with Petersen, Boston and Eckman grabs.

Contamination of each sampling apparatus which was required to pass through the oil/water interface and water column was a major concern as analysis results were often required in parts per billion. For this reason, results established through the use of Niskin samplers may be questionable. These include all ENDECO samples to 7 February and the University of Rhode Island sample (Master Sample List, Appendix III). Sterile bag samplers were considered more effective but were difficult to load and operate in the extremely cold working conditions and may leach contaminants from the plastic bags to the sample. The vacuum tube sampler provided rapid and apparently sterile operation, but requires further testing to verify the sterility of the method.

Only master station 10 in the entrance to Phinneys Harbor (for location see Appendix III, Figure 1) was sampled repeatedly on a regular basis in order to monitor the changes in hydrocarbon levels at a given station. Water current velocity was recorded hourly at that station from 2-4 February in an attempt to correlate tidal flow with the encroachment of oil beneath shorefast ice (Appendix IV, Tables 1a, 1b, and 1c).

Shellfish surveys undertaken by the Massachusetts Division of Marine Fisheries included collection of samples for analysis of hydrocarbons in tissues, and diving transects to establish any obvious disruption of shellfish beds by hydrocarbons or ice scouring. Results of this work are discussed in Section 3.3.

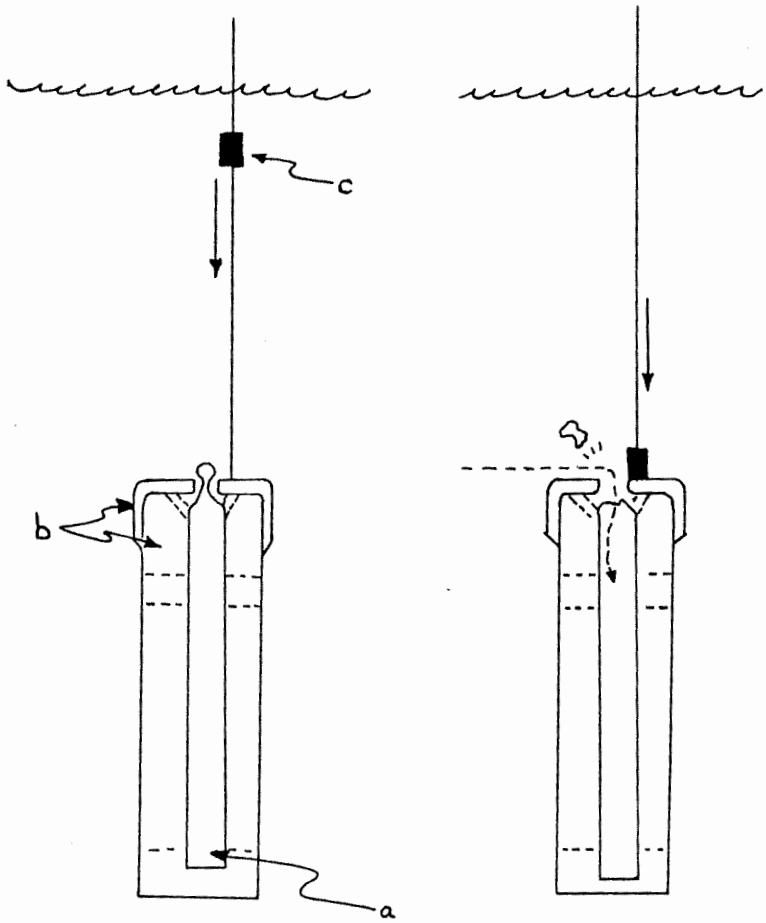

Figure 2.6. Schematic of type 885 vacuum tube sampler.

(a) evacuated glass cylinder.
(b) steel casing and removable cap.
(c) messenger.

In addition, air samples were taken by University of Rhode Island researchers on 15 February, using an air column sampler developed by their laboratory (Figure 2.7). A detailed description of sampling activities at each of the 104 stations is provided in Appendix III.

Throughout the sampling period attempts were made to document the chain of custody for each sample. Tags were provided for recording the date, location and method of sampling as well as the signature of the responsible field technician. Each transfer was documented by signature in order to insure that the origin of the analyzed sample could be documented.

Analysis:

Hydrocarbon concentration analyses of water and sediment samples involved the use of a fluorescence spectrophotometer with an excitation wavelength of 295 nm and emission wavelength between 315 and 350 nm. The results of these analyses are provided in Appendix III. Because fluorescence spectrophotometry cannot distinguish between the recent spill and oil from older spills, a separate sampling of sediments was carried out by the Ecosystems Center of the Marine Biological Laboratory of Woods Hole in an effort to determine the origin of the oil. A sediment size analysis, screening for numbers and identification of benthic organisms, analysis of volume of plant pigements and sediment respiration rates, was carried out by the Marine Biological Laboratory. Results of this analysis are discussed in Section 3.3. Gas chromatography and mass spectrometry were used to analyze these sediments for hydrocarbons (ERCO analysis). These sediment samples were sieved through a 1 mm screen, extracted and the extracts fractionated to give two fractions -- f_1 - the alphatic fracti and f_2 - the aromatic fraction. In addition, a sample of the *Bouchard* oil was added to a clean sediment from Rhode Island Sound and treated in the same manne as the other samples to provide reference chromatograms. Internal standards o 20 μg each of nonadecyl benzene and cholestane were added to all of the sample The amount of hydrocarbon material in the f_1 and f_2 fractions of each sample were gravimetrically determined and are listed in Table 3.4 in micrograms per gram dry weight of the sediment.

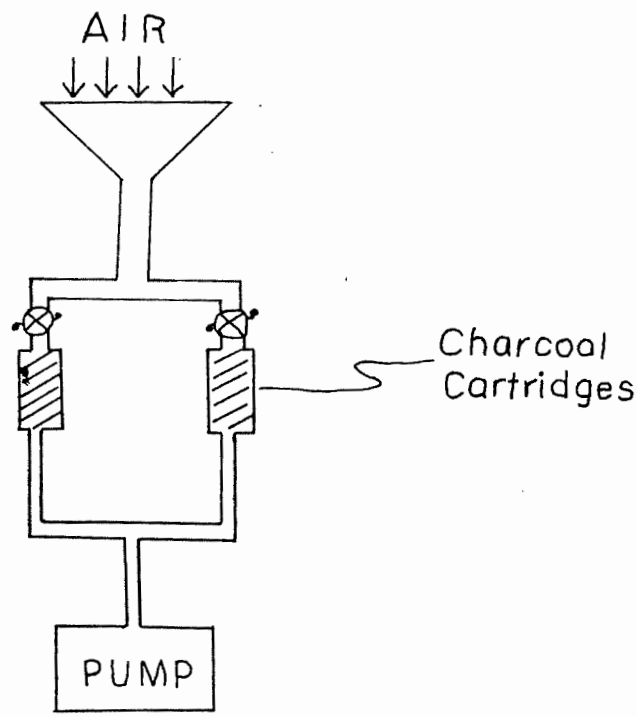

Figure 2.7. Schematic of apparatus for sampling air above an oil slick. (From University of Rhode Island).

In addition to the samples charted in Appendix III, samples of snow, ice and water, showing obvious oiling were collected on 10 February in an attempt to investigate weathering of the *Bouchard* cargo and the possibility of changes in toxicity as a result of the oxidation (see Section 3.1.2 for details).

3. RESULTS AND DISCUSSION

3.1 CHEMICAL PROCESSES

3.1.1 Characteristics of the B #65 Cargo

Samples of B #65 heating oil were sent to E.W. Saybolt and Co., Inc. of Wilmington, California for determination of the chemical characteristics of the oil. Their findings are as follows:

Viscosity @ 15°F	10.60 cSt (centistokes)
Viscosity @ 30°F	7.65 cSt
Viscosity @ 50°F	5.42 cSt
Gravity, API @ 60°F	35.00
Pour Point, ^{o}F	+5.00
Flash, PMCC, ^{o}F	160.00

3.1.2 Weathering of *Bouchard* #65 Cargo

Oil impregnated samples of ice, snow, and water were gathered by ARCTEC Inc. on 10 February and analyzed at NOAA/NMFS/National Analytical Facility for saturated and aromatic hydrocarbons. The oil from the cargo was used as the reference. Results of the analysis and a description of the samples are provided in Table 3.1.

Approximately 85% of the reference cargo oil consisted of saturated hydrocarbons, ranging from n-C_9H_{20} through n-$C_{23}H_{48}$. The remaining 15% consisted mostly of aromatic hydrocarbons, ranging from one through three substituted aromatic rings (Figure 3.1). This contrasts with the 1969 *Florida* spill in Buzzards Bay in which the No. 2 fuel oil spilled contained two to three times as much of the more toxic aromatic hydrocarbon portion.

Above n-$C_{15}H_{32}$ the gas chromatographic profiles of the saturated hydrocarbons from the field samples were identical to that of the *Bouchard* cargo. When evaporation of the more volatile components is taken into consideration, it appears that samples were contaminated by oil from the *Bouchard* cargo. Evaporation of the alkanes was confined to those more volatile than n $C_{16}H_{32}$.

The major features of the gas chromatogram of the saturated hydrocarbons were fourteen n-alkanes and two branched n-alkanes. These alkanes approximate the distribution of components of the cargo oil as a whole. Because of this, losses of these alkanes observed in the environmental samples were useful to estimate the degree of evaporative weathering of the whole oil.

Accordingly, relative losses of these sixteen alkanes in the samples, expressed as a percent of those found in the cargo, are reported in Table 3.1. The percent loss of alkanes indicates that little evaporative weathering (10% or less) of the spilled oil occurred in seven out of eleven samples. The least weathering (4%) was observed in two oiled samples from under the ice. It appears that the four samples showing the greatest losses (20-30%) were from more exposed environments.

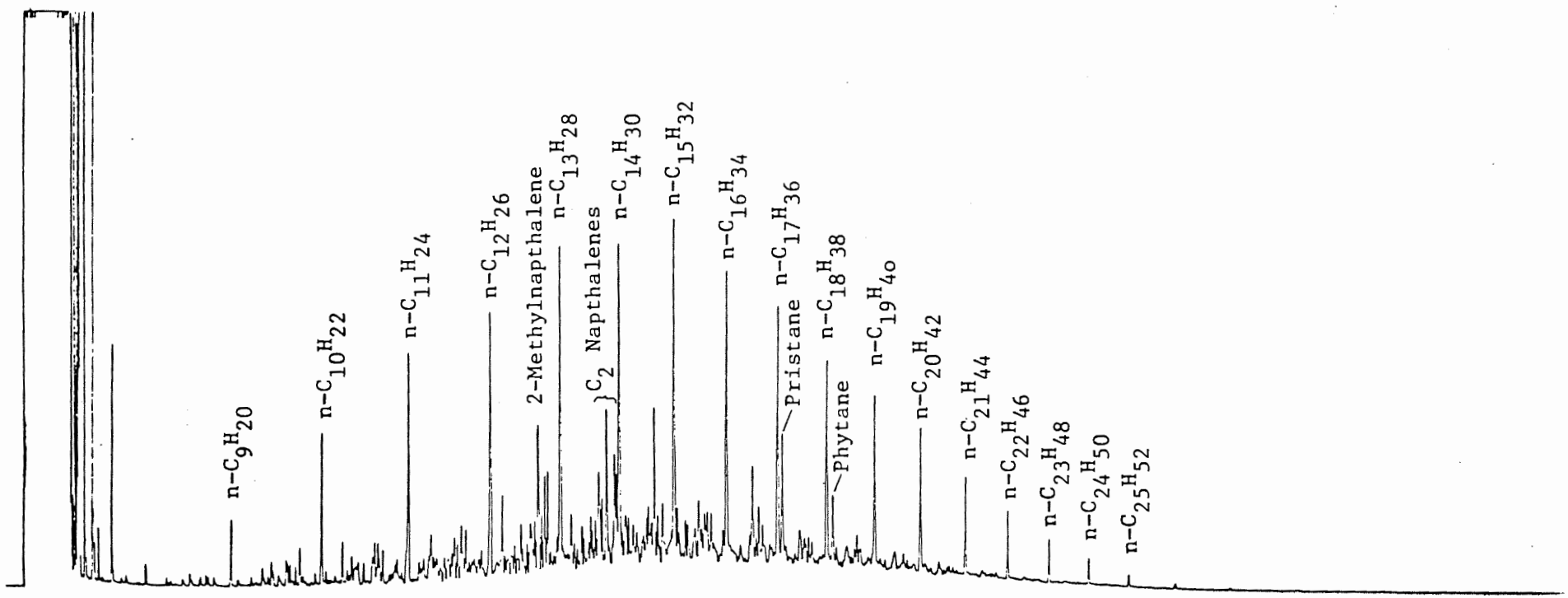

Figure 3.1. Gas chromatogram of no. 2 fuel oil from port no. 3 of barge *Bouchard* # 65, February, 1977.

Table 3.1. Weathered oil samples taken from different field conditions on February 10

Location	Field Condition	Percent Loss Alkanes (85% of cargo)	Approximate Percent Loss Arenes (15% of cargo)	Approximate Total Percent Loss
Wings Neck Tower	Oil underneath ice near edge of rafted ice. Oil was approx. 1.3 cm thick	4	14	6
Wings Neck Tower	Oil in ice sheltered by overlying ice sheet	4	16	6
Wings Neck Cove	Oil in ice near edge of ice floe. Sample taken from top 38 mm of ice core. Medium stained ice (Section 3.2.3 defines light, medium and heavily stained oiled ice)	5	20	8
Wings Neck Cove	Slush oil/snow mixture from shallow oil pool in hummock	7	31	12
Wings Neck Cove	Oil taken from rafted oil pool	7	38	13
Wings Neck Cove	Heavily oil stained ice from ice floe near edge of small oil pool	10	33	15
Wings Neck Tower	Ice piece 0.3 mm thick taken from small pressure ridge. Ice appeared to be medium stained	9	38	15
Wings Neck Tower	Wind blown oil on top of ice	21	54	28
Wings Neck Tower	Wind blown oil on top of ice	25	64	33
Wings Neck Cove	Ice piece rotated in air. Scraped off top of medium stained oily ice	29	58	35
Wings Neck Cove	Ice piece rotated in air. Scraped off top of lightly stained oily ice	37	89	47

Losses of selected aromatic hydrocarbons (arenes) in the samples were similarly calculated with respect to the *Bouchard* cargo. As a group, these arenes are more susceptible to weathering by evaporation or dissolution than alkanes. In this respect, they are less representative of the whole oil than are the alkanes.

The above estimates of weathering indicate that significantly greater percentages of arenes were lost compared to alkanes in all the environmental samples. Moreover, a regression analysis of this data showed that an approximately linear relationship existed between the alkane and arene percentage losses. Thus, in the case of this spill, because samples were collected in the early and middle stages of weathering, it may be possible to estimate one of these parameters for a weathered oil sample, if the other parameter is known.

From those studies, it can be concluded that: (a) the recent *Bouchard* No. 2 fuel oil spilled was not as acutely toxic as the oil from the *Florida* spill (whose aromatic hydrocarbon fraction was two to three times larger); and (b) where the recently spilled No. 2 fuel oil was exposed to evaporation, the aromatic fraction (especially the benzenes and the naphthalenes) tended to dissipate more rapidly than the rest of the oil.

3.2 PHYSICAL PROCESSES

3.2.1 DISTRIBUTION OF THE SPILLED OIL (28 JANUARY - 21 FEBRUARY)

During the two hours that the *(F.E.) Bouchard* #65 remained aground on Cleveland Ledge, approximately 4000 gallons of heating oil were spilled. Most of this oil appears to have moved with the tidal currents 1.0 km east-southeast along the fractures temporarily opened in the ice by the barge, its attending tug, and the Coast Guard cutter *Towline*. Here it collected in an area of brash ice left in the wake of the *Towline's* ship track. This accumulation of approximately 3600 gallons was later used for a burn conducted as part of the Coast Guard cleanup operation. Very lightly discolored brash ice surrounding the grounding area and burn site accounted for the remaining 400 gallons (Appendix V, Figure 1).

The barge left a track of lightly and moderately oil-soaked ice (see Section 3.2.3 for description of these terms) as it traveled to Wings Neck. The major concentrations of oil trapped within the ice resulted from the 16.5 hours of leakage off Wings Neck on 29 January. Because the tide turned during this period, oil flowed into and under the ice both northeast parallel to the shore, and southeast off the point of Wings Neck (Appendix V, Figure 1). Some of the oil flowed immediately into brash ice adjacent to the offloading area (Figure 3.2). Coast Guard personnel on scene for the offloading operation also observed oil building up against the edges of ice floes to a depth of 5 cm before flowing beneath smooth ice to brash ice areas down current. A clear example of this movement beneath smooth floes is provided in Figure 3.3.

An estimated 400 gallons of #2 heating oil worked its way to the shoreline where much of it was caught between the slope of the beach and the underside of the ice. Surveys by the Massachusetts Division of Marine Fisheries revealed that these beaches were nearly saturated with oil to a depth of 10 cm.

The general pattern of oil dispersion within the ice had stabilized by 30 January, 2 days following the spill. Some additional spreading was seen on 31 January in the form of light discoloration of the ice as far as Mashnee Island. This oil was probably carried as sheen along the edge of a large lead and then under broken ice (see Appendix V, Figure 2). Only as fractures and leads such

Figure 3.2. #2 Heating oil in brash ice near the stricken barge, 29 January

as this developed immediately adjacent to heavy oil concentrations, were significant amounts of sheen visibly released. Air temperatures above the freezing point (Appendix II, Figure 2) also greatly accelerated oil release as sheen. The melting presumably accelerated the formation of cracks and small fractures resulting in the release of oil to the water surface.

On 4 February, the first day that sizeable amounts of oil were released as sheen, oil spread northeast into the Cape Cod Canal. A storm on 5 February temporarily reduced the visibility of oiled ice from the air (Figures 3.4 and 3.5). Some areas of light oil discoloration were permanently obscured, but more heavily saturated ice and pooled oil soaked through the snow cover within 2 days (Appendix V, Figures 6-7).

Ambient air temperatures rose from 11-15 February, and aerial surveys recorded a corresponding increase in the volume of oil released as sheen. This release peaked on the 15th as surface coverage of the waters in the spill area, the entrance to the Canal, and Onset Harbor reached 50 - 80% (Appendix V, Figure 15). The following day sheen, reaching 100% surface coverage, was observed flowing out the east end of the Cape Cod Canal in an arc extending 6.5 km into Cape Cod Bay (Appendix V, Figure 17).

This warming trend was paralleled by the breakup of most of the active ice in northern Buzzards Bay. Oiled floes and oil-soaked brash ice were transported throughout Buzzards Bay, into the entrance of Buttermilk Bay, and through the Canal to Cape Cod Bay (Figure 3.6). Tidal currents carried several oiled floes along the south shore of Cape Cod Bay, well into Sandwich and Scorton Creeks (Appendix V, Figure 17). Many floes continuously bled sheen onto the water's surface (Figure 3.7), thereby greatly increasing the overall extent of oil distribution.

Sheen and oiled floes extended as far as 20 km into Cape Cod Bay on 10 February (Appendix V, Figure 9), and to the point of Sandy Neck on 13 February (Appendix V, Figure 11). Oiled floes extended as far south as Nashawena Island in the southern extremity of Buzzards Bay, 24.5 km from the grounding site. Only small patches of oil-soaked ice were still present in Buzzards Bay on 21 February, the final day of aerial reconnaissance.

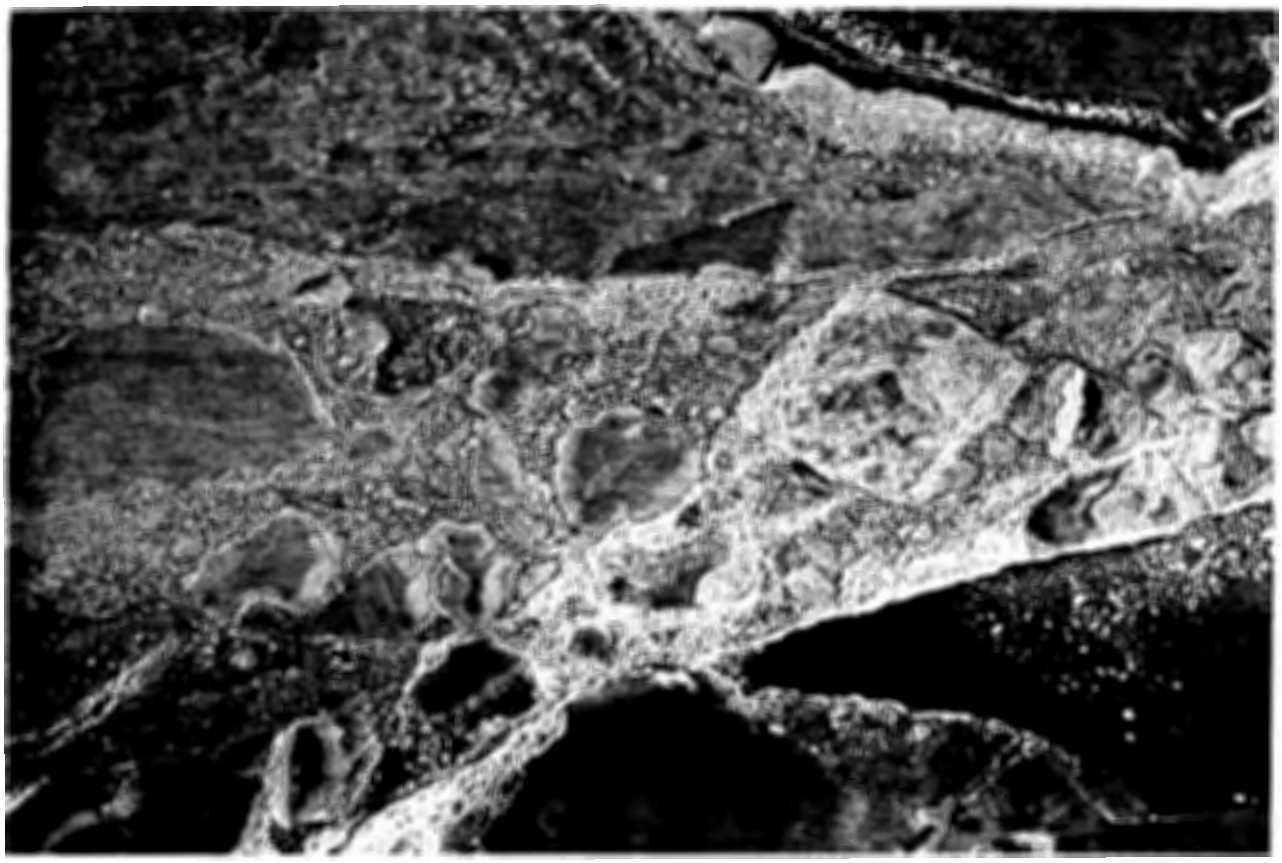

Figure 3.3. Overview demonstrating passage of oil under smooth floes. Note that the barge grounded to right and oil flowed left beneath floes, 2 February.

Figure 3.4. Wings Neck looking toward the southeast prior to the snowfall. The oil appears yellow and the open water is dark blue.

Figure 3.5. Wings Neck looking toward the northwest one day after the snowfall.

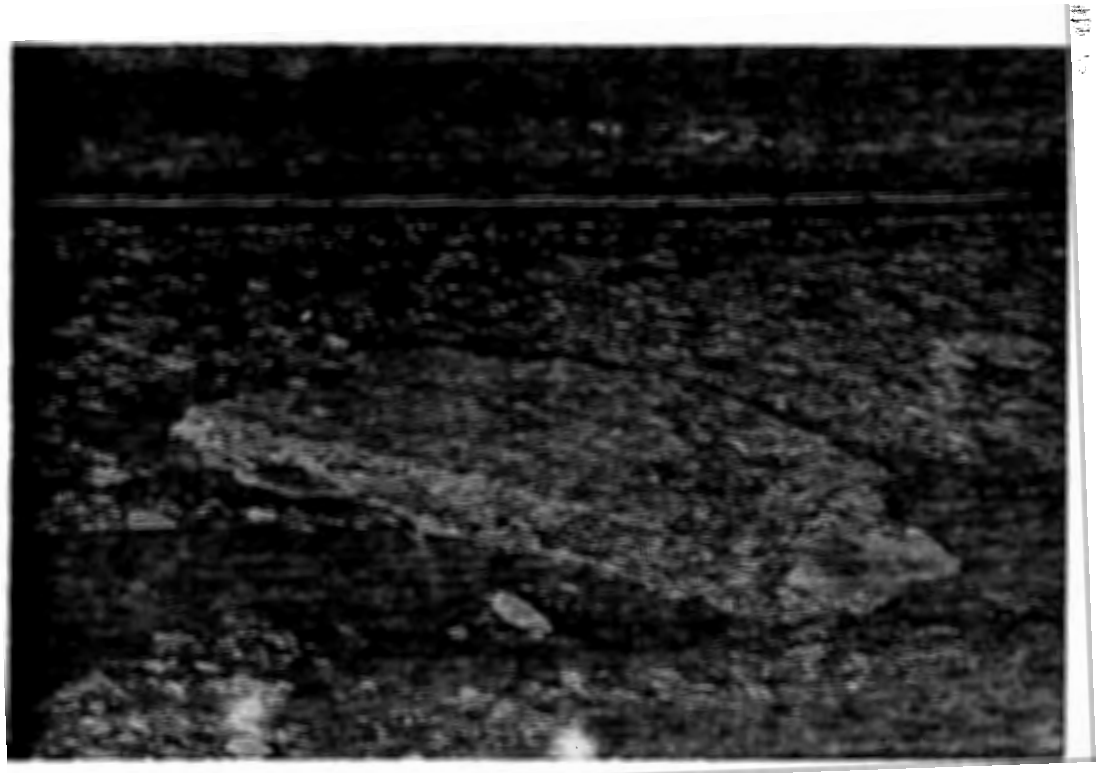

Figure 3.6. Oiled floes and brash ice moving through Cape Cod Canal.

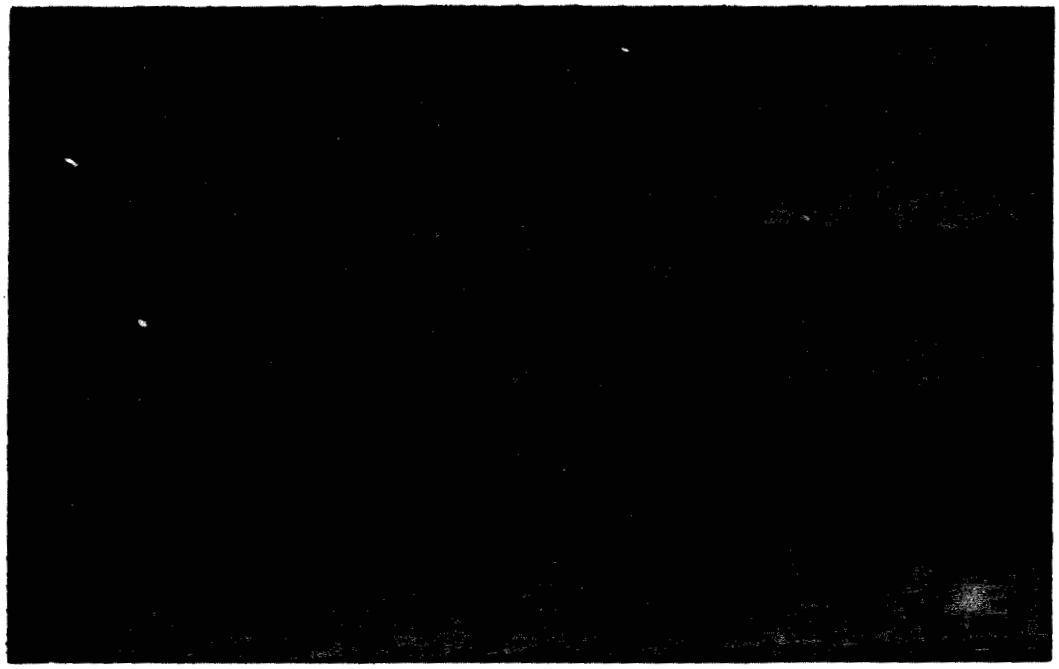

Figure 3.7. Floe bleeding sheen on its down-current side.

3.2.2 OIL/ICE INTERACTIONS

3.2.2.1 INTERACTIONS OF OIL WITH MAJOR ICE FORMATIONS

Movement of Oil Under Ice

Oil spilled from the grounded barge at Wings Neck was initially contained by the ice edge surrounding the barge. Water currents were strong enough, however, to eventually force the oil under the ice. The low porosity of the ice prevented the oil from penetrating the smooth undersurface. Studies have indicated (Uzuner *et al.*, 1975) that current velocities of 0.035 ms^{-1} are sufficient to initiate motion of #2 diesel fuel under smooth ice. Once this movement is initiated, velocity of oil transport (V_o) in ms^{-1} is dependent on the current velocity (V_c) in ms^{-1} according to the following linear relation:

$$V_o = 3.38V_c - 0.0133$$

up to a current velocity of 0.3 ms^{-1}.

Velocities of water currents in Phinneys Harbor during the study period averaged 0.5 ms^{-1}, well above the threshold velocity for oil movement. Velocities of currents at Wings Neck were probably higher as that area is less sheltered from tidal currents than Phinneys Harbor. The smooth undersides of the ice floes appear to have prevented the formation of oil lenses under the ice. Coring demonstrated only sheen under large floes and Geophysical Survey Systems radar surveys indicated no oil lenses under shorefast ice. Oil apparently traveled under the floes and through crack systems, until, it rose into openings in brash ice and rafted ice where it was sheltered from the currents. This under-ice transport was completed by 31 January, when visible concentratio of oil extended as far as Mashnee Island, 4.3 km northwest of the spill site. Thereafter, fluctuations in the amount of oil detected beneath surrounding shorefast ice indicated a limited continuation of oil movement beneath ice in the form of sheen. It is interesting to note that small pieces of brash ice found under most floes did not appear to form a trap for the oil spreading unde the ice. This brash ice either smelled of diesel fuel or was discolored by oil

only in areas where sheen was visible on the surface of the water. Oil did not become frozen into the bottom of the ice because little ice growth occurred following the spill.

Rafted Ice

When a flat sheet of ice is subject to a compressive stress generated by a combination of current and wind forces, the ice breaks by buckling rather than by crushing. If the ice thickness is less than 1 m, and is sufficiently elastic, one sheet will slide over the other to form a raft. The weight of the upper ice depresses the lower sheet to a point where sea water will flow up over the lower sheet to form a wedge-shaped fluid layer (Parmerter and Coon, 1972, and Parmerter, 1974).

Strong west and southwest winds in the days preceeding the *Bouchard* spill created substantial amounts of rafted ice in the active ice zone in Buzzards Bay. As the current carried the oil under the ice, and the oil encountered rafted formations, it collected and was sheltered from the current in the lee of the submerged part of the raft subsequently rising through openings between two ice sheets to replace the heavier sea water already there. Once on the surface of the lower floe, the oil was protected from the currents. As the tidal currents oscillated back and forth, the fuel which was not protected from the currents was swept away. A possible scenario for this process is illustrated in Figure 3.8.

Ground observers and cleanup crews noted fluctuations in pool depths over the course of a day, and cleanup crews reported that pools were sometimes pumped dry only to fill again within a few hours. It is speculated that this was a tidal phenomenon. As tidal currents changed, small quantities of oil, pulled from the pools on the up current side of floes, were shifted to the down current side and into other rafted sections. This appears to have been a gradual shift in the form of oil sheen. Coring in rafted features revealed sheen under smooth floe surfaces in the vicinity of pools (Figure 3.9).

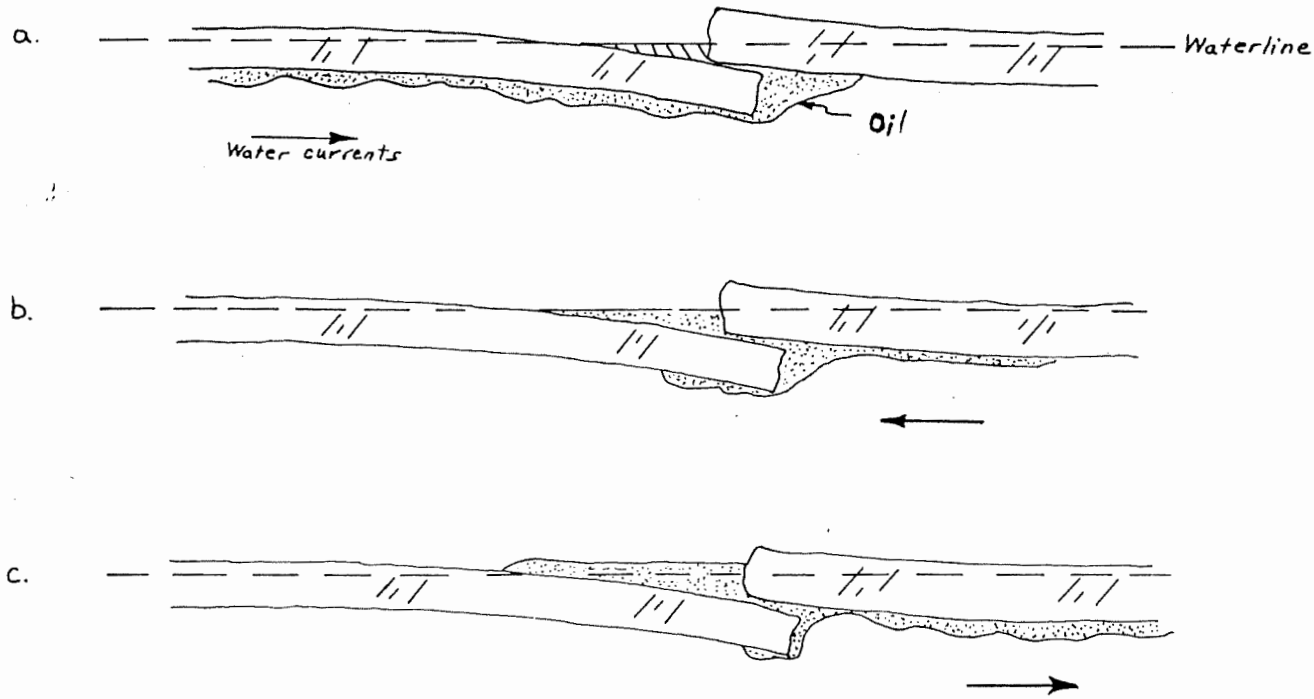

Figure 3.8. Flow of oil in rafted ice, (a) oil flowing underneath the ice comes in contact with rafted ice, (b) current reversal encourages oil filling into rafted ice pocket, and (c) reversal of current sweeps unsheltered oil away, 8-9 February.

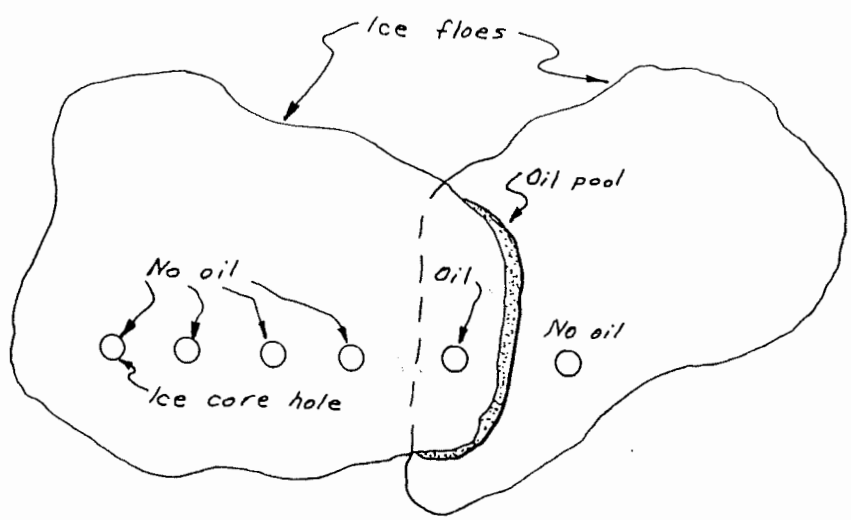

Figure 3.9. Ice cores taken along ice floes consistently revealed no heavy concentration of oil under the ice except along the ice edge, 2-4 February.

Estimates made in the field indicated that a typical pool measured 2 m x 4 m x 0.12 m and yielded a volume of approximately 960 liters (250 gals.). Some unusually large pools south of Wings Neck Point contained an estimated 3750-7500 liters (1000-2000 gals.) (Figure 3.10). Slush ice at the edges of pools was saturated with oil, yielding concentrations of 30% oil by volume.

Pressure Ridges and Rubble Fields

Pressure ridges and rubble fields form in a manner resembling the formation of rafted ice. The ice deformation process, generated by wind, water, or stress from a moving ship, forces ice pieces on top of one another. Unlike rafting, the ice sheet either has been previously broken, or breaks up causing the broken ice to form a ridge extending above and below the water line (Parmerter and Coon, 1972; Weeks and Kovacs, 1972).

Ridges and rubble fields comprised approximately 15% of the surface area of the active ice zone of Buzzards Bay. These features extended in length up to 1 km, had widths of 1-10 m, and an average sail height of 1 m. No evidence of oil pooling in these features was observed, nor was there any concentration of oil under the ice against the ridge keels. The ridges and rubble fields did however contain oiled blocks of ice, the oil having penetrated 1 to 3 cm into the surface of the blocks in concentrations less than 5% (Figure 3.11). In many observations, rubble fields were apparently more porous and contained more oil than did coherent ridges. Features that displayed oiled ice in their sails well above the water line were presumably formed after oil had coated the ice.

Figure 3.10. Aerial view of large pool of oil incorporated in rafted ice formations.

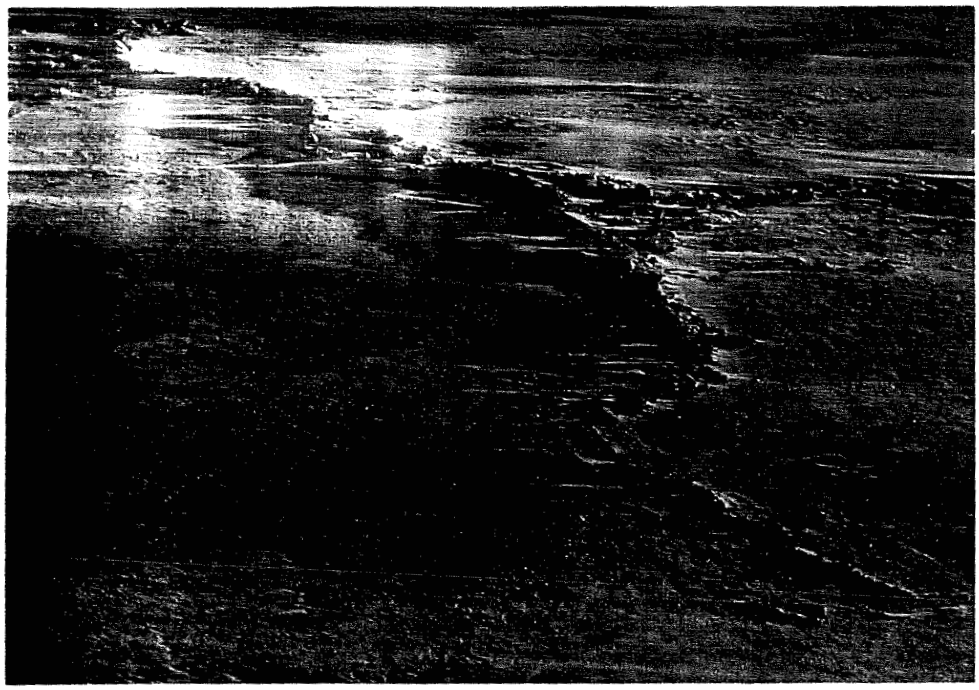

Figure 3.11. Pressure ridge (from lower right to upper left) with oiled ice visible within and surrounding the ridge.

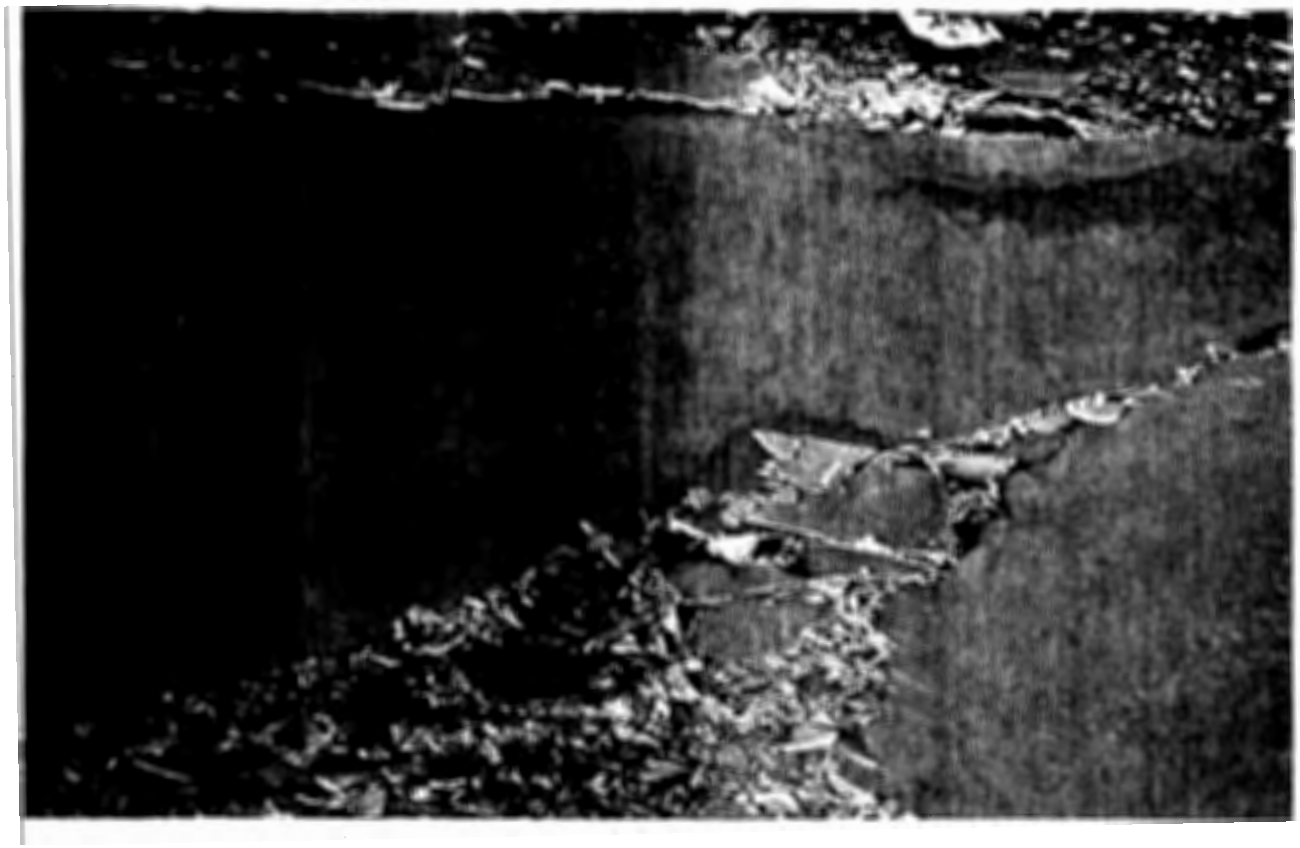

Figure 3.12. Oil on surface of floe.

Floe Surfaces

The upper surfaces of numerous floes were oil-stained during the study period (Figure 3.12). Since little oil was actually spilled on top of the ice, most of this surface oil must have come from large pools. Field observations indicated that two principal mechanisms (either separately or in combination) were probably responsible for spreading oil on the surface of ice floes. First, oil could have been blown from the oil pools by wind action. Second, the movement of ice floes and currents generated a pumping action which could have forced oil in cracks or in pools out onto the ice surface. Once on the surface, the smoothness and low porosity of the ice and combined with the low viscosity of the oil and the strong winds allowed the oil to spread in a thin layer over a considerable area. Penetration into the floe surface did not generally exceed 3 mm.

Albedo levels of this oiled ice were reduced by as much as 75%, causing the affected area to melt more quickly than clean ice. Small rivulets of an oil/water mixture formed, flowing into small depressions in the ice surface resulting in a dark "fishnet" pattern across the ice surface (Figure 3.12). The shallow pools of oil and water that collected on the ice surface would either refreeze or form an oil/ice slush as the temperature dropped at the end of the day.

Throughout the observation period, oil sheen appeared in the leads and fractures that opened through the contaminated ice. There was no indication that the edges of the leads acted as barriers along the down-current edges; rather, the sheen tended to flow under the ice again to collect in adjacent brash ice.

As temperatures warmed after 8 February and the ice began to break up, oiled floes were observed in the Cape Cod Canal and Cape Cod Bay (Appendix V). The oil remained with this ice until it melted, allowing oil to be transported some distance before being released to the water.

3.2.2.2 SMALL SCALE INTERACTIONS OF OIL WITH ICE AND SNOW

Within two days after the snowstorm on 5 February, most of the heavier concentrations of oil were again visible from the air. Areas in Buzzards Bay with heavy concentrations of oil quickly formed an oil/snow slush (Figure 3.13). This slush contained about 30% oil by volume and could be picked up with no oil dripping from the mass (Figure 3.14). These observations are consistent with those of McMinn and Golden (1973) who found, during tests made in Alaska, that snow falling on crude oil produced mulches containing up to 20% oil by volume depending on the rate of snowfall. Cleanup of this mixture was attempted, with little success (Section 3.4).

The poorly defined crystal structure of the ice (Figure 3.16) prevented oil from migrating far into the ice from the oil/ice interface at the surface of smooth floes. In some cases, especially in areas of light oil concentrations, snow partially melted and refroze, creating an ice/oil/ice sandwich (Figure 3.15). The oil in the trapped layer did not migrate further due to the lack of brine channels. Samples taken throughout Buzzards Bay revealed varying degrees of oil absorption into the ice. These variations are presumably due to the volume of oil in contact with and its length of exposure to the ice. A brief description of what was observed by field investigators follows:

1. Solid ice along edges of oil pools and in areas of brash ice contained 5% oil by volume to depths of 5 cm.

2. Stained ice in hummocks and ridges showed depths of penetration from 2.5-6.0 cm, and varied from 0.5-1% oil by volume.

3. Windblown oil penetrated 1-5 mm into the ice; 50% of this surface was saturated with oil.

Figure 3.13. Oil/snow slush containing 30% oil by volume.

Figure 3.14. Oil pool after the snowfall on 5 February.

Figure 3.15. Ice core showing ice/oil/ice sandwich, formed when snow melted and refroze over the oil on the ice surface.

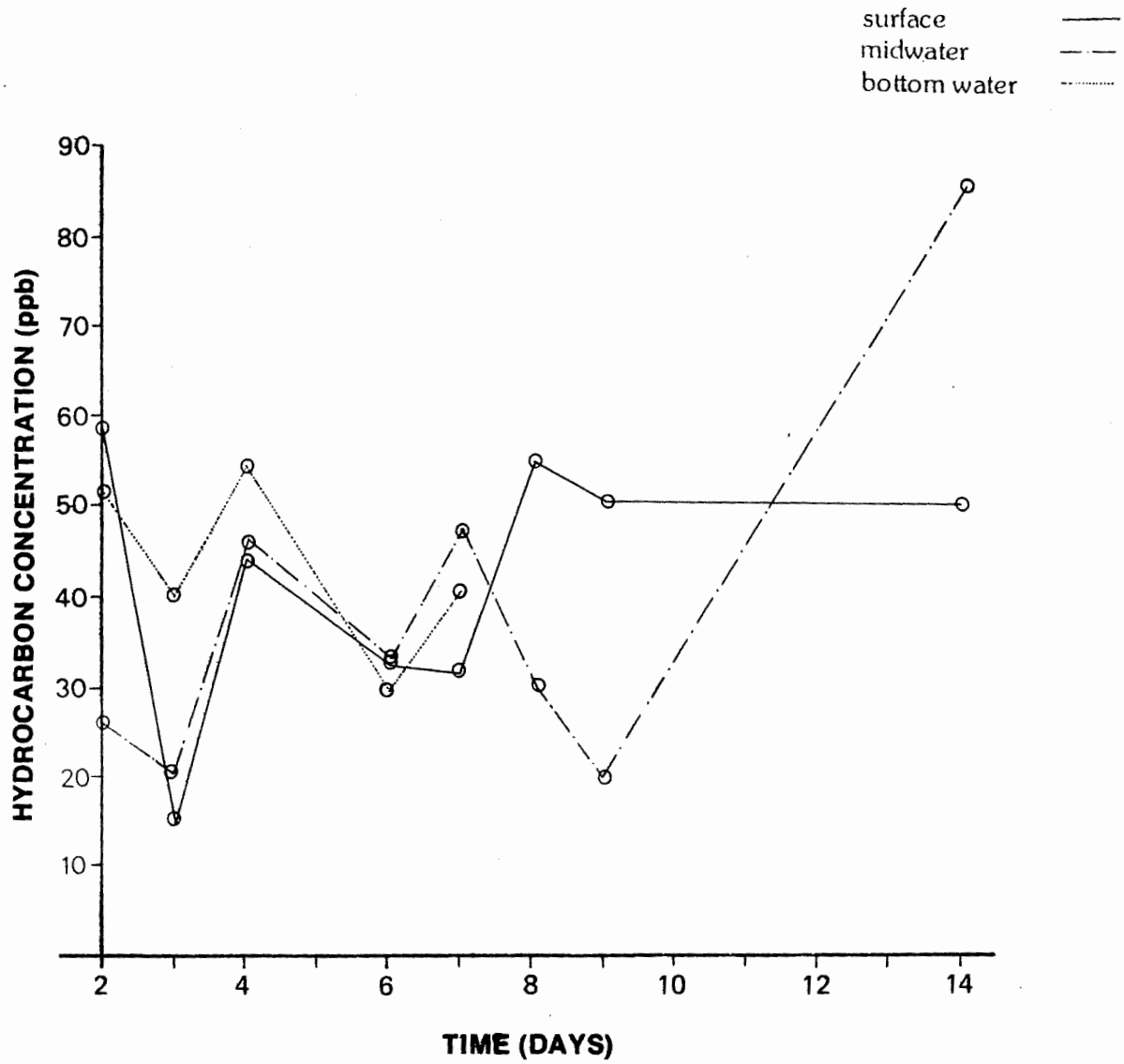

Figure 3.17. Daily average of hydrocarbon concentrations at surface, mid- and bottom water for master station 10, Phinneys Harbor, 2-14 February, 1977.

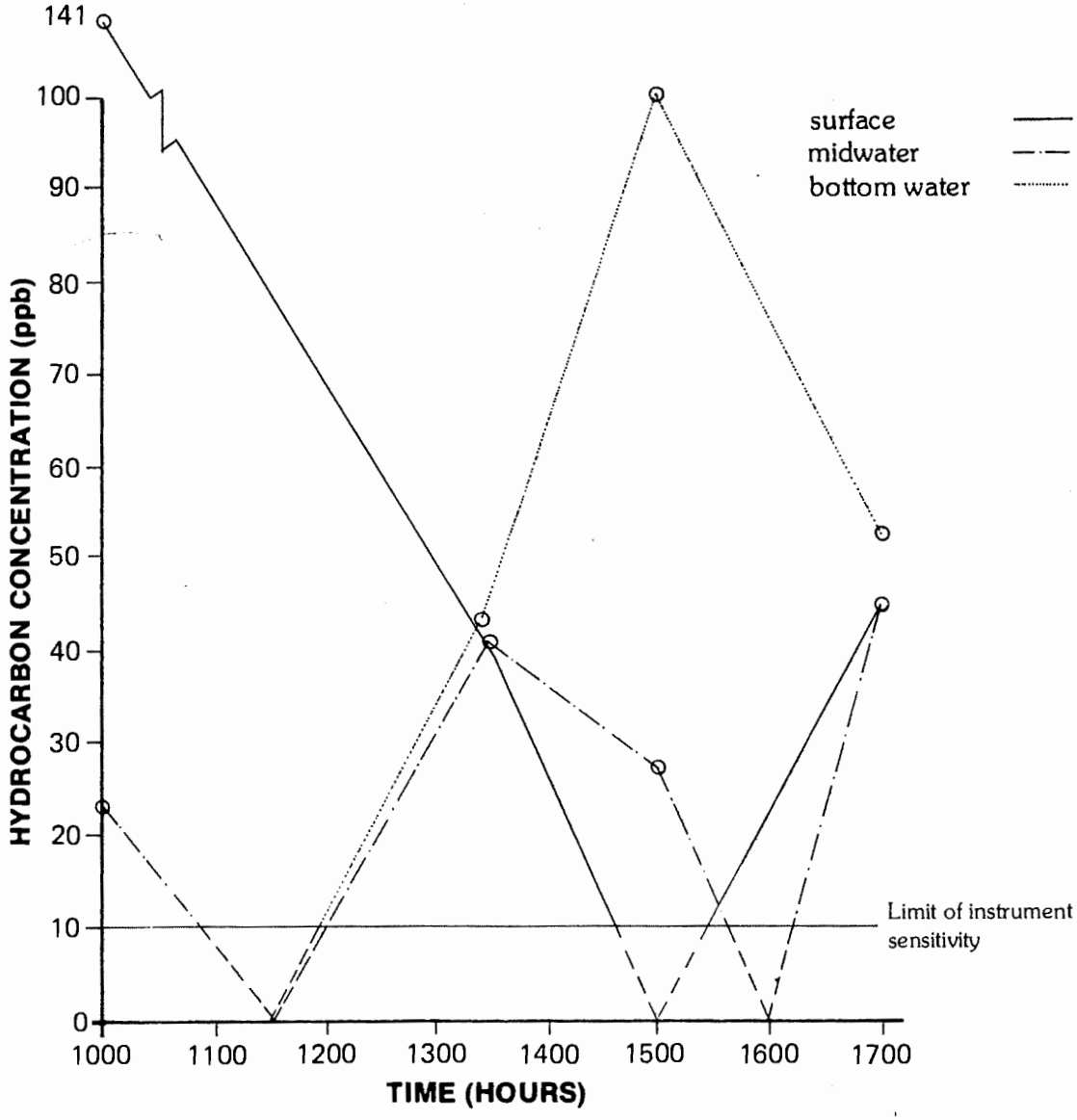

Figure 3.18. Hourly hydrocarbon concentrations at surface, mid- and bottom water for master station 10, Phinneys Harbor, 2 February, 1977.

Figure 3.16. Ice core from Wings Neck showing single brine channel.

3.2.2.3 INCORPORATION OF OIL INTO WATER COLUMN AND SEDIMENTS

Oil was found in all water column stations sampled, with most stations yielding concentrations of 10-200 ppb (Appendix III). In one instance, at station 40, the hydrocarbon levels in the water column could be directly related to the oil on the surface. On 8 February, at that station, where a tug had broken through into oil ice, heavy sheen was seen streaming from under the broken ice. Here, oil concentrations at water depths of 2 and 3 m were approximately 1000 ppb.

From 2-14 February, station 10 at Phinneys Harbor entrance was monitored during the daylight hours. Samples were taken hourly at surface, middepth (4 m) and bottom (8 m), using a Niskin sampler, and then analyzed for hydrocarbon content. Data are presented both as daily averages (Figure 3.17) and as hourly plots for each day (Figures 3.18 - 3.22). Figure 3.17, the daily average, shows little or no trend over the 11 day period. Figures 3.18 - 3.22 suggest that the hydrocarbon levels decrease on the outgoing or southward moving tide, and increase on the incoming tide. The currents recorded at this station show no repeatable pattern (Appendix IV, Figures 1-3). The lack of repeatability and progression of data at the one established station is caused by the station location (on a point adjacent to a strong tidal flow) and by the fact that the sample period was fixed, while the tidal cycles changed.

Most of the oil concentrations in sediments analyzed by fluorescence spectroscopy ranged from 0.7 - 23 ppm, with one isolated station in Wings Cove yielding 770 ppm (Appendix III). A more detailed analysis (described in Section 2) of selected samples showed only two with any evidence of significant oil contamination in the aliphatic fractions; these are samples #102 and #90 (Table 3.2). The contamination appeared to be from a weathered No. 2 oil, but it could not be unambiguously identified as the B #65 oil. A comparison of the reference chromatogram with these samples indicated that whatever light oil was found in the sediments, it certainly was not fresh No. 2 oil from the *Bouchard*. The chromatograms of the other samples showed a preponderance of naturally occurring hydrocarbons (odd *n*-alkanes C_{23}-C_{31}) and background anthropogenic inputs from the region and very little material in the C_{12} through C_{24} range, the typical range of No. 2 fuel oil.

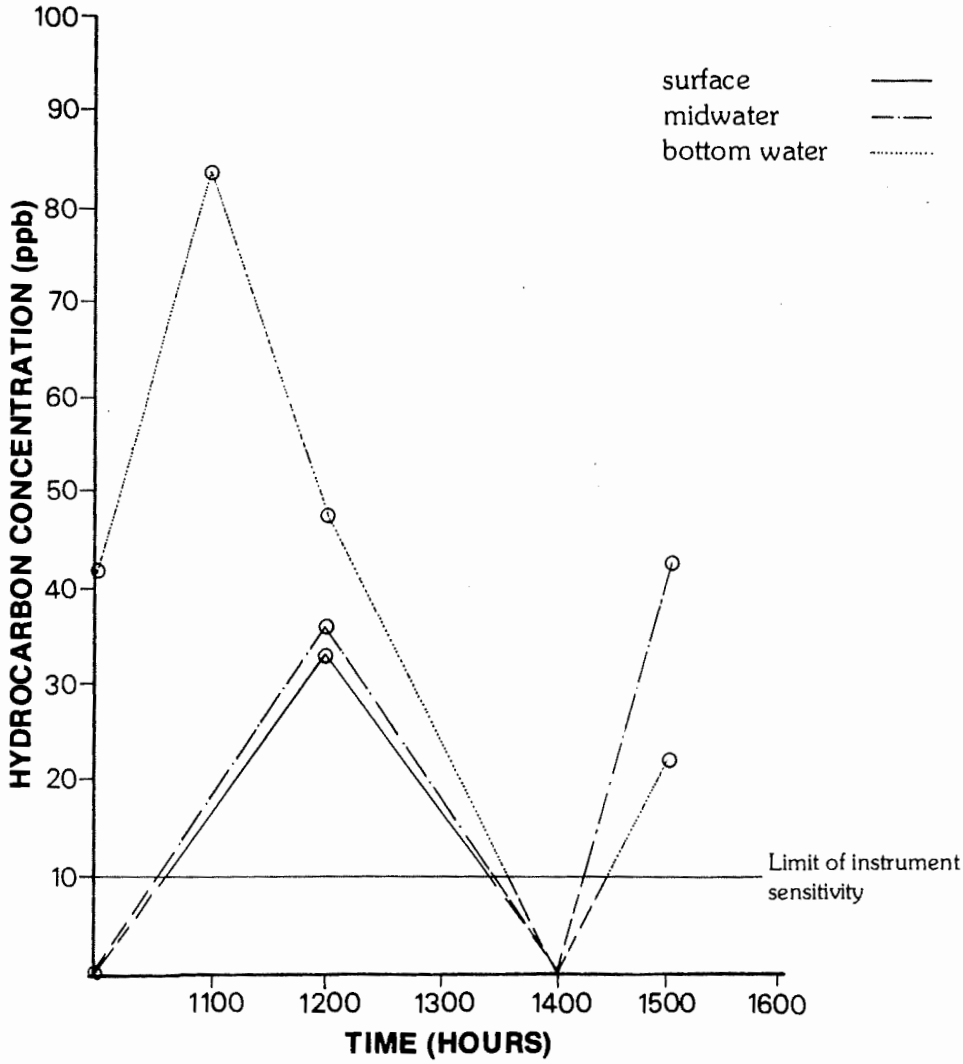

Figure 3.19. Hourly hydrocarbon concentrations at surface, mid- and bottom water for master station 10, Phinneys Harbor, 3 February, 1977.

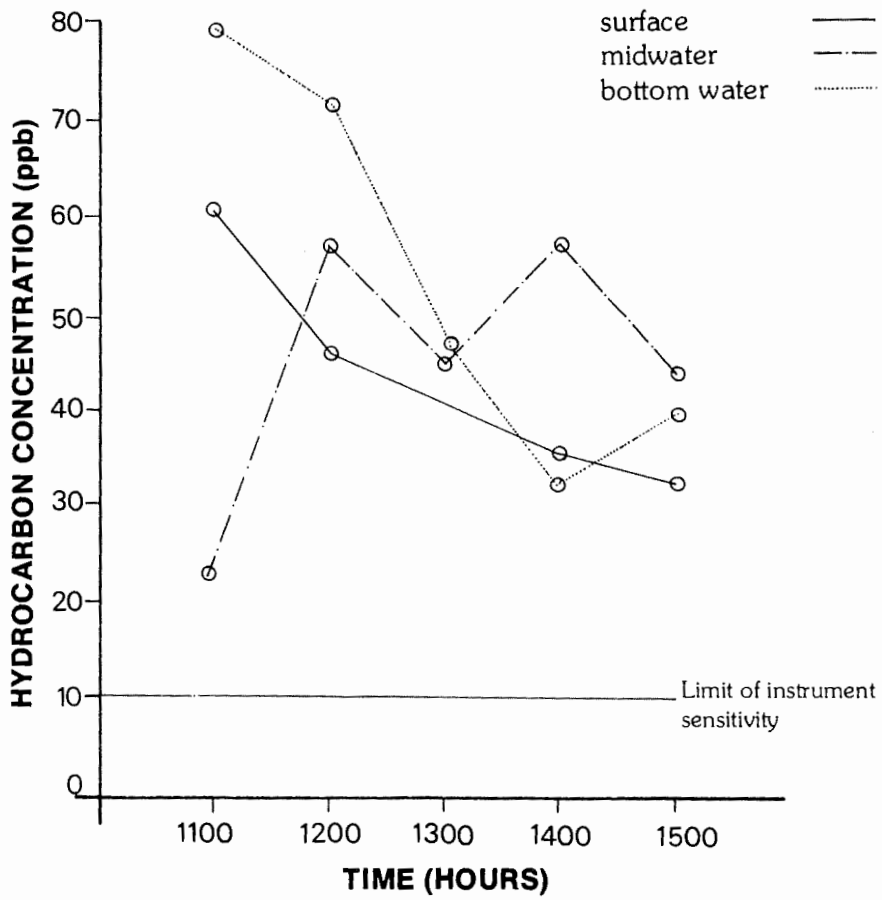

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Figure 3.20. Hourly hydrocarbon concentrations at surface, mid- and bottom water for master station 10, Phinneys Harbor, 4 February, 1977.

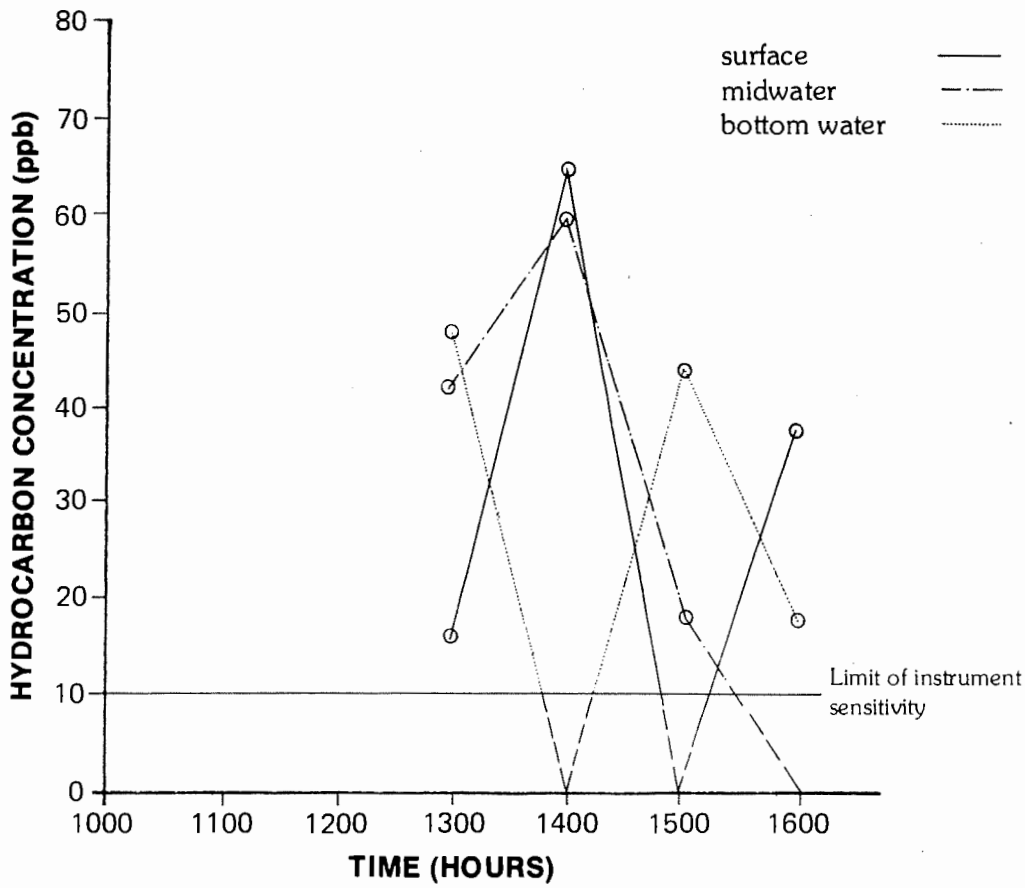

Figure 3.21. Hourly hydrocarbon concentrations at surface, mid- and bottom water for master station 10, Phinneys Harbor, 6 February, 1977.

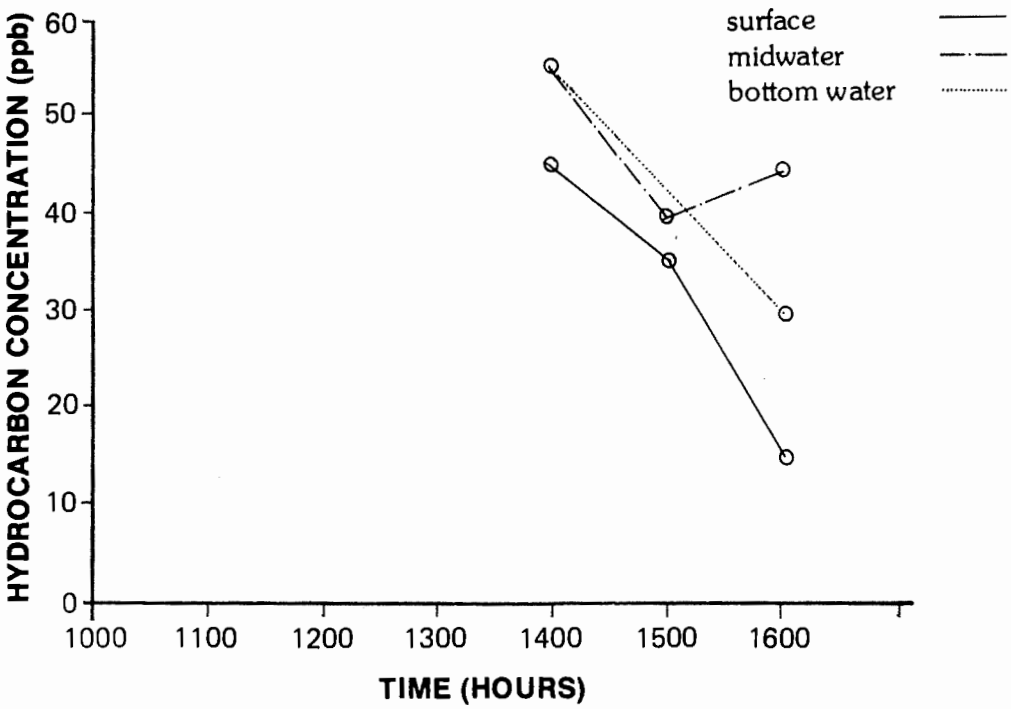

Figure 3.22. Hourly hydrocarbon concentrations at surface, mid- and bottom water for master station 10, Phinneys Harbor, 7 February, 1977.

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1977.

Table 3.2. Hydrocarbon concentrations in f_1 and f_2 fractions in sediments in Buzzards Bay, winter, 1977 (from ERCO).

Master Station # (MBL station #)	Hydrocarbons in f_1 and f_2 Fractions (μg/g)		Dry Sediment Substrat
	f_1	f_2	
69 (#28)	f_1	17.4	silt
	f_2	9.6	
75 (#30)	f_1	37.0	fine sand & silt
	f_2	34.1	
71 (#32)	f_1	157.9	silt
	f_2	150.8	
78 (#36)	f_1	6.6	sand & silt
	f_2	6.1	
Naushon (#47)	f_1	104.0	silt & sand
	f_2	88.7	
99 (#51)	f_1	86.0	silt
	f_2	59.7	
102*(#54)	f_1	19.3	sand & silt
	f_2	14.4	
26 (#63)	f_1	21.2	silt (not sieved)
	f_2	19.1	
50 (#70)	f_1	103.3	silt
	f_2	73.2	
Barnstable #78	f_1	2.5	coarse sand (not sieved)
	f_2	2.7	
Sandwich #79	f_1	5.2	sand
	f_2	2.7	
105 (#80)	f_1	3.2	sand
	f_2	3.0	
106 (#81)	f_1	8.0	sand
	f_2	6.6	
90*(#82)	f_1	39.3	silt & sand (not sieved)
	f_2	7.3	

*Evidence of No. 2 fuel oil contribution to these samples.

3.2.3 MASS BALANCE

An understanding of the mechanisms surrounding oil transport in Buzzards Bay requires that an oil budget or mass balance analysis be attempted. This analysis serves several purposes:

1. Aids in the description of the types of oil/ice involvement, thereby leading toward the design of a workable predictive model for spilled oil transport in cold regions;

2. Assesses the effectiveness of the cleanup operation by estimating the amount of accessible oil; and,

3. Serves as a basis for the development of more effective data collection techniques and improved cleanup operations.

The oil budgeting process for the Buzzards Bay spill began in the field with a series of aerial photo mosaics designed to document the location of all major concentrations of oil visible on the surface of the ice and water on 2 and 4 February (Figure 2.1). These mosaics were combined with lower altitude and ground level photographs in order to compile the best possible description of the oil's involvement within ice. The photographic record was combined with sampling of oiled ice surface and slush to determine the percent oil/ice composition by volume and depths of ice penetration by No. 2 oil.

Analysis following field work involved the reconstruction of aerial mosaics and the correlation of lower altitude photos to these composite overviews. Through photographic observation and review of field notes, general classifications of visibly yellowed ice were separated. These include the following:

1. <u>Deep oil pools</u>. These were pools of oil ranging in depth from 0.1-0.15 m, which were associated with rafted ice and were the primary sites of clean-up operations (Section 3.2.2.1 for discussion of rafted floes).

2. Shallow oil pools. These pools ranged in depth from 0.01-0.04 m and were located in brash ice.

3. Heavy oil concentrations in active ice. This was darkly stained ice amidst brash ice and small floes (not rafted) in areas of pooled oil. Oil penetration typically measured 0.05 m with a concentration of 5% by volume.

4. Medium oil concentrations in active ice. The ice surface was clearly saturated with oil but lighter in color than heavy oil concentrations as viewed from aerial mosaics. Oil penetration reached 0.05 m in concentrations of 1% by volume.

5. Light oil concentrations in active ice. This ice was not uniformly saturated, and barely visible from air. Oil penetration reached a depth of 0.05 m in concentration of 0.5% by volume.

6. Oil on surface of ice. This included all oiled floes, whether oiled by barge dumping, cleanup operations or wind-blown oil. Depth of penetration ranged from 0.001-0.003 m, in concentrations of 50% by volume.

Casual estimations of the amount of discolored brash ice were extremely misleading. When viewed from high altitude or at low oblique angles, actual coverage was exaggerated by 300-400 %. In order to quantify the actual oiled surface area involved, color slides of aerial mosaics were carefully traced onto gridded paper, and clear acetate grids were superimposed over some prints. Surface areas within each gridded section were scaled using known landmarks visible in high altitude photos.

From the mosaics, each square meter of colored ice was subdivided into one of the six categories. Then, best estimates were made as to the average oil pool depth, and for the discolored ice, estimates were made of the depth of oil penetration and the percent oil concentration to that depth. In the choice of these numbers, use was made of the field results presented in the preceding section.

oil

Table 3.3. Oil budget for *Bouchard* #65 oil spill, **2-4 February, 1977.**

Type of Oil/Ice Configuration	Area from Mashnee Island to Wings Neck Tower (m^2)	Area from Wings Neck tower to Cleveland Ledge (m^2)	Total Area (m^2)	% Saturation	Ice Surface Involved	Depth of Saturation (m)	Volume (liters)	Volume (gallons)	% of Total
Deep oil pools in rafted ice	400	300	700	100	-	0.13	91,000	24,000	29
Shallow oil pools in brash ice and small floes	1,500	300	1,800	100	-	0.025	45,000	12,000	14
Heavy oil concentrations	7,400	2,400	9,800	5	2	0.05	49,000	13,000	16
Medium oil concentrations	26,600	3,200	29,800	1	2	0.05	30,000	8,000	10
Light oil concentrations	28,700	3,800	32,500	0.5	2	0.05	16,000	4,000	5
Oil on ice surface	2,100	12,600	14,700	50	-	0.003	22,000	6,000	7
Burn site (heavy) oil concentration)	-	-	5,600	5	-	0.05	14,000	4,000	5
Evaporation losses (see Table 3.2)	-	-	-	-	-	-	44,000	12,000	14
TOTALS	∿ 66,700	∿ 22,600	94,900				311,000	83,000	100

Results are presented in Table 3.4.3. The first column lists the six categories plus the burn site, and provides an estimate of losses to evaporation. The next three columns list the areal coverage; first, the oil area between Mashnee Island and Wings Neck; second, the oiled area between Wings Neck and Cleveland Ledge; and third, the total area. The fourth column gives the percent of oil saturation, which for the oil ice categories is our estimate of the oil concentration in the depth of oil penetration; and the fifth column shows the surface area of the ice which is affected by the oil. If there is a '2' in this column, it means that more than one surface of the ice was oiled; otherwise, only one surface was oiled. The sixth column shows an estimate of the mean depth of oil pools and penetration into ice. The remaining columns give the resultant oil volume and the percentage distribution of the total oil spilled.

The amount of oil evaporated from each type of oil/ice involvement was estimated on the basis of samples taken from representative areas and analyzed for percent loss of their volatile portions. Section 3.1.2 contains details of that analysis. The percent loss of alkanes and arenes when combined with a knowledge of the original make up of the B #65 cargo (approximately 85% alkanes and 15% arenes) provided a reasonable estimation of the total loss by volume to weathering. A summary of these calculations and losses within each type of oil/ice involvement is provided in Table 3.4.

The data show that, of the six categories, the largest amount (29%) of oil was contained in the deep oil pools. Further, the combination of the deep and shallow pools contained approximately 45% of the total oil spilled. This strongly suggests that the choice of pumping from the oiled pools was the only effective recovery technique.

Table 3.4. Weathered losses of oil (gallons) computed from percent losses in Table 3.1.

Type of oil/ice involvement	Approximate total percent loss (averages from Table 3.1)	Total gallons in each type of oil/ice (from Table 3.3)	Weathered losses (gallons)
Deep oil pools	13	24,000	3,100
Shallow oil pools	12	12,000	1,400
Heavy oil concentrations	15	13,000	2,000
Medium oil concentrations	19	8,000	1,500
Light oil concentrations	47	4,000	1,900
Oil on ice surface	31	6,000	1,900
Burn site (heavy concentration)	15	4,000	600
TOTALS		70,000	12,400
			∿ 12,000

3.3 BIOLOGICAL PROCESSES

Sediments and benthos in commercially important shellfish beds and areas in the predicted path of the oil were sampled in order to monitor for fresh input of petroleum hydrocarbons. Sampling began 2 days after the spill and continued through June. From 30 January to 2 March, intensive surveys were carried out as weather permitted. Samples were collected using Peterson, Eckman and Boston grabs, and in one case a diver went through the ice with a sealed sampler in an effort to avoid contamination from the water column. The Massachusetts Division of Marine Fisheries conducted diving surveys in March and April in the vicinity of the wreck site off Wings Neck to determine whether there was any visible mortality.

All samples collected by EPA, Massachusetts Division of Marine Fisheries and the Marine Biological Laboratory at Woods Hole were analyzed using flourescence spectrometry. (This method is described in Section 2. Technical Approach). Shellfish samples from four sites were then selected for analysis by gas chromatography and mass spectrometry to attempt to determine the source of petroleum hydrocarbons in their tissues.

Results of flourescence indicated that, within the limits of the instrumentation, no petroleum hydrocarbons were evident in shellfish samples (Appendix III, Table 4). Results of gas chromatographic analysis of shellfish are provided in Table 3.5. A wide range of hydrocarbons were found in samples of *Mya* and *Mercenaria* from Buzzards Bay; however, no fresh #2 oil input was evident. Gas chromatograms of these samples had large unresolved envelopes originating from man-related activities in the area (i.e. chronic oil spillage, sewage effluent, urban air fallout, and urban runoff). Values of hydrocarbon contamination for these shellfish fell within the ranges reported previously for shellfish in other polluted areas of the bay (Table 3.5).

Common species of waterfowl identified during surveys in the bay and canal region included greater and lesser scaup, common eider, Canada geese, double-crested cormorants, mergansers, herring gulls and blackbacked gulls. Total numbers of birds seen on any one day ranged from 700-2000, averaging about 1200. On 4 February, birds were seen swimming through sheen in the

canal, apparently unaffected by the oil. No oiled birds were seen, and no dead oiled birds were found washed ashore. By 15 February, these concentrations of waterfowl had dispersed, presumably due to the break up of the ice and subsequent availability of more attractive feeding areas.

Preliminary studies seem to indicate that there was no single area where large quantities of the spilled oil had accumulated in Buzzards Bay. There was no conspicuous or prolonged mortality associated with this spill during the winter or following spring. These investigations have not revealed the spectacular effects associated with other spills in Buzzards Bay (Blumer et al., 1971; Burns, 1970; Sanders et al., 1972; Stegeman 1976; Michael et al., 1975). While no definite cause for this is known the reduction of oil-water mixing due to the ice cover was undoubtedly a strong factor.

Table 3.5. Hydrocarbon contents of shellfish taken in Buzzards Bay February, 1977*

Location	Species	Fraction 1 (μg/g dry weight)	Fraction 2	Total
Little Bay	*Mercenaria mercenaria*	57.9	57.7	115.6
Barlows Landing	*M. mercenaria*	32.0	2.8	34.8
Hospital Cove	*Mya arenaria*	179.9	100.1	280.0
West Falmouth Harbor	*M. mercenaria*	29.0	23.1	52.1
Narragansett Bay (a)	*M. mercenaria*			
	Providence River	--	--	160.0
	Lower W. Passage	--	--	26.0
W. Falmouth Harbor (b)	*Aequipecten irradians*	--	--	∿ 70.0
Wild River Harbor (b)	*Crassostrea virginica*	--	--	∿ 690.0
W. Falmouth Harbor (c)	*Mya arenaria*	--	--	∿ 260.0

*Results of analysis of homogenate of 12 individuals.
(a) From Farrington and Quinn (1973).
(b) From Blumer *et al.*, (1970a) Marine Biology, 5.
(c) From Blumer *et al.*, (1970b) WHOI Techn. Report.

3.4 CLEANUP OPERATIONS

Cleanup operations following the spill of the *F.E. Bouchard* #65 were directed by the Coast Guard Marine Safety Office in Boston. Four basic techniques, listed below in order of effectiveness, were employed in the cleanup:

1. Direct suction of pooled oil into storage tanks (12,886 gallons recovered),

2. Burning of oil trapped within ice (1500-2000 gals.),

3. Removal of oil-soaked ice (negligible amount recovered),

4. Skimming of oil sheen by mechanical devices (negligible amount recovered).

The use of direct suction of pooled oil was the most successful cleanup method (Figures 3.23 and 3.24). The major difficulty with this technique was the repeated freezing of oil mixed with ice chunks and slush inside the vacuum hoses. Hose diameters had to be restricted to approximately 10 cm to compensate for loss of pressure in the great lengths of hose (up to 300 m) required to reach isolated pools. This narrow aperture often became clogged with small ice chunks, resulting in the suction of considerable amounts of air, promoting freezing in the lines.

Vacuum trucks operating from shore were used during most of the cleanup, but as ice deteriorated enough in the Bay to allow limited ship traffic, tugs carrying pumping systems, hoses, and storage tanks were deployed to work in areas not accessible from land (Figure 3.25). Unfortunately, the snowfall of 5 February greatly reduced the effectiveness of tug operations attempted on 7, 8, and 10 February. Snow combined with oil to form a slush which was difficult to suction, and which froze rapidly in the hoses. As a result, 75% of the 12,886 gallons recovered was gathered by land-based tank trucks prior to 5 February.

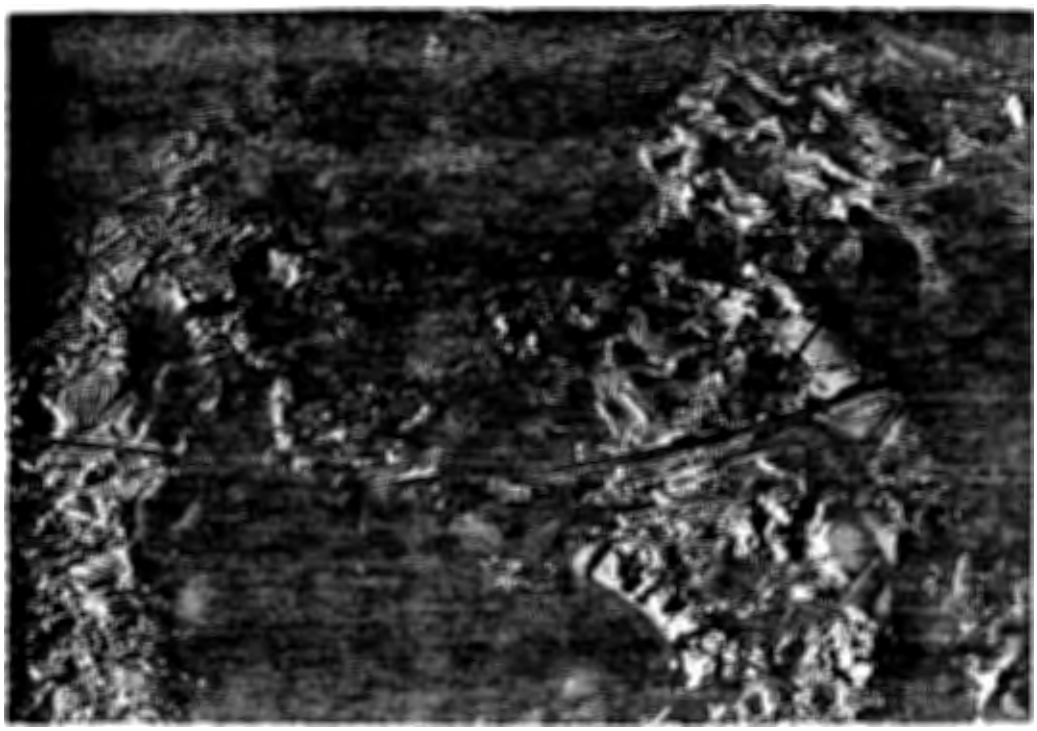

Figure 3.23. Aerial view of cleanup using direct suction technique, 11 February.

Figure 3.24. Close-up of workman using hose for direct suction of oil/snow slush, 8 February.

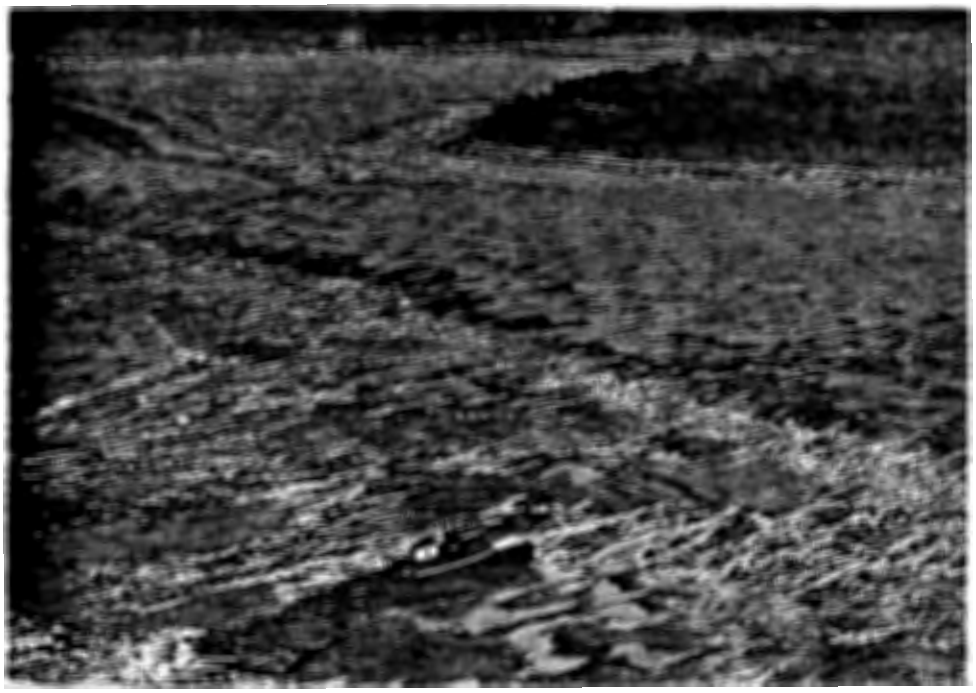

Figure 3.25. Aerial view of tug wedged in ice allowing work crews to clean up oil inaccessible from land, 11 February.

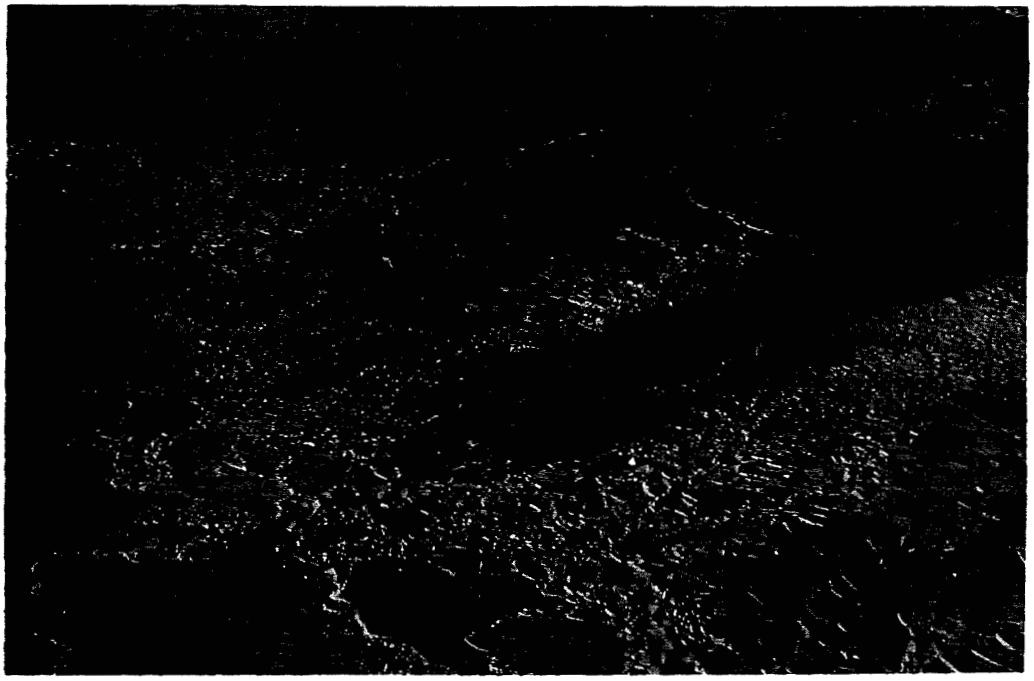

Figure 3.26. Aerial view of burn, 31 January.

A test burn of the diesel fuel which was concentrated 1.0 km east-southeast of Cleveland Ledge Light was attempted by the Coast Guard on 31 January (Figure 3.26). Estimates indicated that one third to one half of the 3600 gallons of No. 2 oil in that area was burned. Attempts were initially made to ignite the oil with a material impregnated with a wicking agent called "Tullanox". This agent proved unsuccessful and the pretreated material finally had to be dipped in gasoline for the final ignition. Large clouds of smoke quickly developed, spreading a plume of soot several kilometers long across the ice toward the northeast (Figure 3.27).

Heavy construction equipment was used to remove oil-soaked ice from the water near shore just north of Wings Neck Point. A crane swinging a large "I" beam dragged piles of oiled ice onto the beach and front end loaders placed some of this in trucks for transport to a sanitary landfill (Figure 3.28). Oil concentrations in this ice were generally less than 5% to a depth of 4 cm and much of this oil drained onto the beach once removed from the water. No appreciable amounts were recovered in this manner and damage to the beach and surrounding private lands may have overshadowed the benefits of the operation.

Two mechanical oil skimmers, the Marco Navy Skimmer and the Lockheed Arctic Boat (Figure 3.29) were used in the latter stages of the cleanup. Neither device recovered any quantity of oil due in part to interference with the drum mechanisms by small ice floes. Another factor in their poor performance may have been the slow release of oil from the active ice zone in a very fine sheen approximately 2×10^{-4} cm thick. Sheen thickness was estimated on the basis of aerial observations of sheen color. This method of measurement has been established by the American Petroleum Institute (1963). One gallon of oil in this concentration would cover nearly 2 km^2 of water surface, making skimming highly impractical.

In all, 18.3% of the spilled #2 oil was recovered or disposed of. The ice proved to be both a benefit and a hindrance to the cleanup operations. While serving as an effective containment system for the oil, it created dangerous working conditions and severe logistics problems for cleanup crews. Recommendations concerning cleanup can be found in Secion 3.4.

Figure 3.27. Plume of soot visible from burn (lower left to upper right of photo).

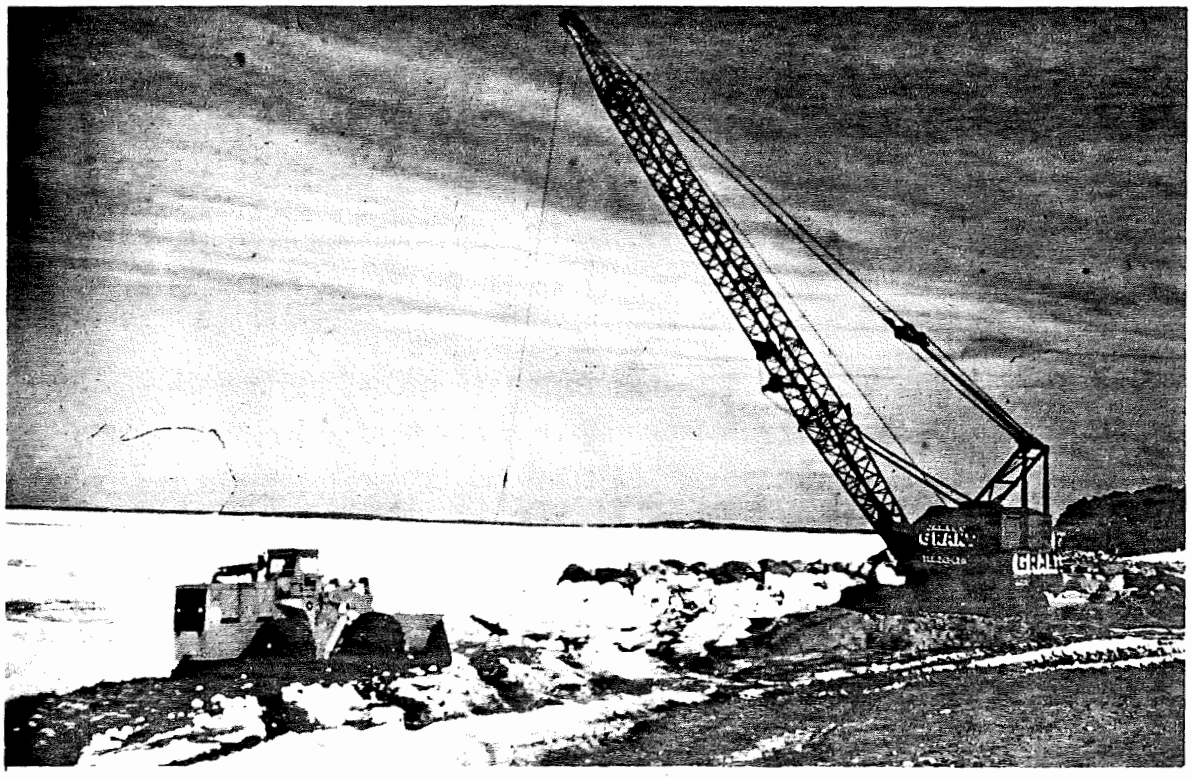

Figure 3.28. Mechanical ice removal at Wings Neck Point.

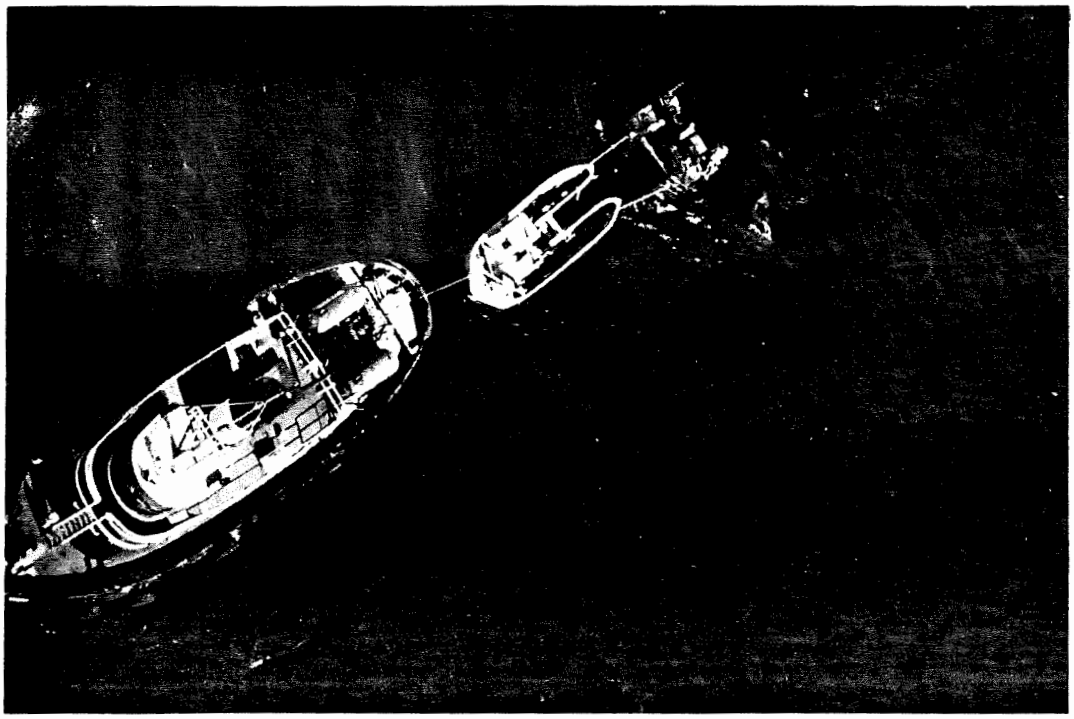

Figure 3.29. Marco Navy Skimmer and Lockheed Arctic Boat (on right) being towed to site of cleanup.

4. CONCLUSIONS

4.1 SUMMATION OF RESULTS

The major conclusions which can be drawn from the 1977 Buzzards Bay oil spill on the behavior of oil spilled in ice-covered waters are as follows:

A. Rafted ice led to the formation of oil pools with depths of up to 0.15 m on the ice surface. These pools held approximately 45% of the spilled oil. The presence of these pools made possible the recovery of 15% of the spill by direct suction into vacuum trucks. Further, the formation of these pools occurred within a day of the spill and was unexpected on the basis of previous work on oil spills in ice.

B. A comparison of the 1977 spill in ice-covered waters with previous open water spills in Buzzards Bay showed that the ice served as a containment mechanism against the extensive spread of oil into the nearshore areas which were covered with shorefast ice. The presence of ice also prevented wave action from distributing large amounts of oil into the water column and sediments.

C. During breakup, oiled ice floes were exported throughout the bays and coves of Cape Cod where they subsequently distributed the slightly weathered oil as they melted. These oily ice floes could not have been contained by conventional mechanisms. This, therefore, appears to be a mechanism for the long-range transport of oil, one which will likely be important in Arctic oil spills.

D. Oil was not contained by the ice edge, rather, it was transported underneath the ice by the strong tidal currents. Small amounts of oil sheen were detected moving underneath the ice even in shorefast ice zones. Nearly all the oil being transported underneath the ice settled within two days into hummocks, ridges, and rafted ice where it was sheltered from the strong tidal currents. The oil remained fairly stable in these formations until the ice began to breakup.

E. Weathering of the oil occurred despite the ice, snow, and cold temperatures. Sample analyses showed that the more exposed the oil was to the air, the more it weathered. Much of the oil was contained within ridges and sheltered from the wind and, therefore, probably weathered at a slower rate than it would have on open water. This meant that relatively unweathered oil was constantly being released to the open water throughout the duration of the spill.

F. Most discolored ice represented penetrations of less than 5 cm at volumetric concentrations of 5% or less. The greatest mixing of #2 oil occurred in the oil/snow mixtures where concentrations reached 30% oil by volume.

G. Because of the formation of oil pools, the best cleanup technique proved to be direct suction of the oil using vacuum hoses. Burning of the oil was about 50% effective, but a large plume of soot was generated in the process. Mechanical recovery of oiled ice was extremely inefficient.

H. Impact assessment indicates that within the limits of the short-term field study, there have been no demonstrated impacts of the *Bouchard* oil on benthic organisms, fish or birds. However, it would be premature to assume that no long-term impacts will develop as a result of the spill.

I. Although *Bouchard* #65 oil was found in the water column and trapped in the ice of Buzzards Bay, positive identification of this cargo in the sediments has not been made.

J. The severity of impact for this spill, when compared with past spills of similar cargoes, was minimal. Ice formations responsible for entrapment of the oil at the surface and its gradual release into Cape Cod Bay appears to have mitigated impact.

4.2 COMPARISON OF BUZZARDS BAY SPILL CONDITIONS WITH THOSE OF THE COASTAL REGIONS OF ALASKA

The Buzzards Bay spill of 1977 drew a great deal of scientific attention, largely because of the potential applications of the experience gained there to oil spills in Arctic waters. Some comparisons should therefore be made to aid the reader in understanding the differences and similarities between the two regions.

There are several important environmental differences between the waters of Buzzards Bay and those of Coastal Alaska. First, the ice growth season in the Bay during the winter of 1977 was relatively short, lasting approximately two months, from 1 January to 22 February. Second, by Arctic standards, the ice in the Bay was thin, approximately 0.3 m, even though rafting and ridging in the center of the channel increased the thickness to at least 1 m. Third, the ice was nearly fresh, and therefore much less porous than Arctic sea ice. Fourth, and most importantly, Buzzards Bay is an enclosed bay, with Cape Cod Canal extending from the northern end of the bay through the Cape Cod Peninsula to Cape Cod Bay. Due to the three hour time difference in the phase of the tides between Buzzards Bay and Cape Cod Bay, there is a strong flow of water through the canal, with current velocities as high as 2.3 ms^{-1} in the Canal, and 0.5 ms^{-1} at the end of Stony Point Dike (Wilcox, 1958).

In spite of the difference in scale, geometry, and climate, many of the observed ice features in Buzzards Bay are duplicated in the Bering and Chukchi Seas, where many of the ice characteristics are also determined by a combination of the shore geometry and the presence of ocean currents. Figure 4.1 shows the average ice conditions in the Bering and Chukchi Seas for March and April of 1973 and 1974 (Burns, Shapiro, and Fay, 1976). During these months, cold, strong northeast winds dominate the ice movement and deformation, resulting in a strong buildup of ice to the north of Saint Lawrence, Saint Matthew, and Nunivak Islands, and the formation of large polynyas, or areas of open water, both to the south of the islands and on the north side of Norton and Kotzebue Sounds. The figure also shows a region of highly deformed and broken ice to the north of the Bering Strait caused by the action of the wind

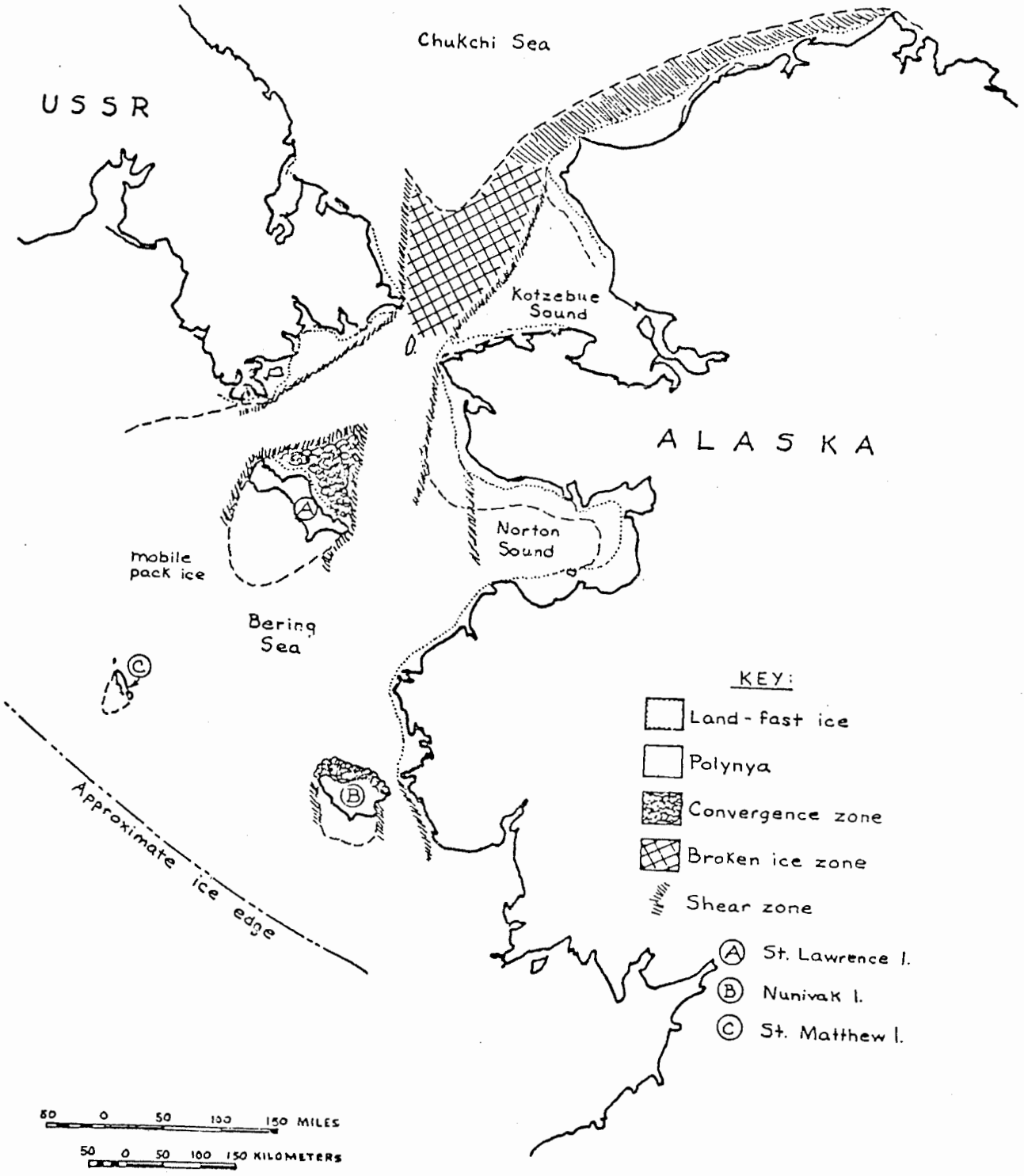

Figure 4.1. Average ice conditions in Bering and Chukchi Seas during March and April, 1973 and 1974.

and the currents. Here the ice is broken into large floes similar in appearance to those observed in Buzzards Bay. Similar floes occur throughout the southern Bering Sea (Kondratyev, 19__). The strong winds and currents deform the ice into rafts, hummocks, and pressure ridges, and could cause gross transport of the ice. In marginal seas, such as the Bering, typical ice velocities have been found to be 7.4 km/day (0.1 ms^{-1}) and may range as high as 37-44 km/day (0.4 - 0.5 ms^{-1}) during storms (Weeks, 1976).

Due to the wind and current stresses in Buzzards Bay, particularly at the time of the spill and because of the ice-breaking efforts of the Coast Guard, the ice in the center of the Bay was broken into many small floes which rafted or were forced into rubble fields and small pressure ridges. Nearshore, the ice was divided into regions of shorefast ice and a deforming shear zone (active ice zone). The sharp boundary between the shorefast ice and the shear zone, as Figure 4.1 shows, also occurs in the Bering and Chukchi Seas, particularly along the Chukchi coast. Aerial observations and mass balance estimates demonstrated clearly that the majority of oil spilled in the shear zone of Buzzards Bay was almost immediately forced to the surface and exposed to the atmosphere in pools or oil-soaked ice. Similar surface entrainment may occur for oil spills in the shear zones of the Bering and Chukchi Seas.

In addition to these environmental differences and similarities, the properties of the spilled oil are important. The #2 heating oil spilled in the ice covered waters of Buzzards Bay was highly volatile and had a low specific gravity, viscosity, and surface tension as compared to crude oil. Because these properties were not very temperature dependent, the oil flowed easily, was thinly spread, and could penetrate into snow and ice. Crude oil properties are normally very temperature dependent and the surface tension, specific gravity, and particularly the viscosity, increase significantly with decreasing temperature. This means that crude oil would not flow as easily into cracks and would tend to adhere to, rather than penetrate into, the snow and ice.

To make a statement that all spills occurring in the active ice zone or shear zone will be similar to the Buzzards Bay spill would be inaccurate. However, for No. 2 oil spilled underneath ice where rafted ice, rubble fields, pressure ridges, and leads have formed, the oil most probably will find its way to the surface if the relative velocity between the ice and the sea water exceeds the threshold of velocity necessary to transport the oil and low temperatures do not freeze the oil into the ice. Oil pooling on rafted ice may prove very useful when cleanup attempts are made. Oil transport by oily ice floes will also extend the range of an Arctic spill. A more detailed prediction of oil spill behavior along the Alaskan Coast cannot be made without further research on oil spill behavior in cold regions.

5. RECOMMENDATIONS

In light of the potential applications this spill may have to Arctic spills, the authors felt it important to provide a series of recommendations for use by workers in future spills in cold regions. It is hoped that these suggestions will help to make the study and cleanup of oil in cold waters easier.

Recommendations on the research aspects are aimed at providing the means for a coordinated plan of action so as to avoid improper emphasis in surveillance, inadequate collection and sample preparation procedures, and non-uniform analysis techniques. Cleanup recommendations are aimed at improving present techniques as well as pointing out areas where new techniques must be developed.

Surveillance:

Clear objectives for surveillance programs should be established following the first overflight of a spill in ice. At that time, the limits of spread within the ice should be estimated in order to establish the altitude, scale, format, mosaic pattern, and best aircraft for each photographic task. The following specific suggestions can be made:

1. High altitude single-frame overviews of the spill should be taken, possibly requiring shallow oblique photography. Resolution of the oil itself may be poor due to the altitude required but these photographs will serve to document gross ice movement.

2. If the area involved does not make the operational cost prohibitive, vertical or near-vertical mosaic coverage should be designed for two altitudes. The first mosaic should reveal the general pattern of spill coverage while the second reveals sufficient detail at intermediate altitude (300 m) to coordinate with low altitude and ground

level photography. All mosaics should include 30% overlap in adjacent frames. Conventional daylight films are suitable for the purpose but use of a blue filter will remove much of the blue tint from ice and water.

Rapid film processing is essential in these operations. Where possible, provisions should be made for 24-hour film turnaround. The inspection of these initial transparencies can have major input in both research and cleanup. One full-time staff member should be placed in charge of monitoring film collection, transport, processing, cataloguing and filing.

Only limited ice-tracking success was achieved through the use of flat, numbered plaques. These were difficult to position and were too easily covered by snow. It is suggested that large fluorescent cones of the type used in highway construction, conspicuously numbered and anchored through the center to a hole in the ice would be far more useful.

Sampling:

Due to high manpower and time demands in a crisis spill situation, it is necessary to provide for the best coordination of research goals, so as to eliminate unnecessary duplication of effort.

Sampling schemes should correlate with stated research objectives and should take into account naturally occurring cyclic phenomena. Samples taken in Phinneys Harbor during this spill suggest changes in hydrocarbon levels with tidal cycles, but, because the sampling period did not coincide with the cycles, no conclusions can be drawn. Sample collection, preparation and analysis should also be coordinated so as to provide for comparable results at time of final interpretation. Chain of custody procedures should be established for all samples if there is any possibility that they will be used as evidence in court proceedings. Full-time personnel should be provided to coordinate this effort during the field sampling period.

At this time, few instruments have been developed which permit the acquisition of an uncontaminated sample and can be handled with ease in cold conditions. As a result of this field experience, it is recommended that the type 885 vacuum tube sampler undergo further testing to establish levels of contamination during sampling. This sampler appeared to demonstrate the best possible combination of speed in sampling, ease in handling, and sterility of technique.

Ice coring instruments used were effective because the ice in Buzzards Bay was thin enough to permit the use of hand augers and unoiled chainsaws. Power augers must be used in Arctic situations due to ice thicknesses. When using power augers, it is suggested that great care be taken to clean the blades before each use and prevent leakage of gasoline and lubricants onto the instrument.

The use of benthic grabs may be inappropriate for oil spill research due to the great possibility for contamination during passage through the oil-water interface and water column. Collection by divers is the preferable method for benthic sampling. This technique was used successfully by researchers from the University of Rhode Island, but in general is expensive and can be hazardous.

During the initial study period, some provision must be made for verification of the source of oil found in samples. Until this analysis is completed, researchers cannot carry out sampling schemes with the assurance that they are studying impacts of the spill in question.

Cleanup:

Emphasis should be placed on improving vacuum removal of oil from ice as this technique has proved most successful. The limitations of this method center around the lack of mobility available to men and machines on the uneven, broken ice surface. The development of a light, highly mobile ice-touring vehicle capable of carrying its own storage tanks, pumps, hoses, and

three-man crew should be encouraged. This vehicle must be secure on both water and ice and should be able to move freely from one to the other. Storage should be provided for 500 gallons of fuel. Much of the trouble with clogging and freezing in the recovery hoses would then be surmounted because shorter hoses of wider diameter might be employed.

The burning of a No. 2 oil in ice is entirely feasible when the proper wicking agent is employed and concentration of oil is high enough. However, no general recommendation can be made to use this technique. The decision to burn must be made balancing the hazards of the production and sinking of toxic materials produced by burning against the toxicity of original cargo.

The direct removal of oiled ice to sanitary landfills should be discouraged in most cases. The energy expenditure and environmental disruption involved will overshadow the benefits unless the required cranes and trucks can move directly to the spill area along piers or paved roads. In addition, the drainage of oil from the ice as it is picked up reduces the effectiveness of the effort. This difficulty might be less serious for oil of a higher viscosity than a No. 2 oil. It should be noted that McMinn and Golden (1973) report that physical removal (by shovelling) of snow-oil mulches is an effective technique due to 20-30% concentrations of oil by volume. This technique should be attempted where limited access, transport problems and the heavy manpower requirements do not make the attempt impractical.

Unfortunately, the effect of the ice in interaction with open water was to release the oil as a thin sheen on the water which frustrated attempts to recover oil by skimming. This was true even of equipment specifically designed for Arctic application. Sheen thickness can be established effectivel through aerial observation (Section 3.4). Skimming equipment should, therefo not be used without a careful evaluation of sheen thicknesses.

Contingency Research Planning:

Recommendations on contingency planning are of the utmost importance if research on oil spills in cold regions is to continue. A national crisis team should be established, in which members are free to participate in spills of scientific interest. Members of this team would serve as coordinators/liaisons for local research interests as well as pursuing their own research goals. In order to provide a well rounded group, the team should include an administrative coordinator as well as technical personnel with engineering, chemical, physical, and biological backgrounds.

Stockpiling of hard-to-obtain equipment may be necessary to alleviate critical shortages during sampling. Alternatively, a master list of locations and availability of equipment should be compiled so that equipment is easily located for use in the field. This list should include: ice corers and ice augers, sterile bag, and vacuum tube samplers, exposure suits for use by field personnel, photographic equipment, and miscellaneous equipment such as gloves, rope, glass jars, hexane, and fluorescent tracking cones.

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PHOTO CREDITS

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BAXTER, DESLAURIERS, MORSON

MESA Special Report

The Bouchard #65 Oil Spill, January 1977 Appendices

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Paul C. Deslauriers
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Marine EcoSystems Analysis Program

Boulder, Colorado

April 1978

U.S. DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

National Oceanic and Atmospheric Administration
Richard Frank, Administrator

Environmental Research Laboratories
Wilmot Hess, Director

Prepared by

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Boulder, Colorado

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APPENDIX II

METEOROLOGY

Table II.1. Hourly weather conditions at Wings Neck Station, January 28-February 21, 1977 (from Army Corps of Engineers daily logs)

DATE/TIME	TEMP (^{o}C)	WIND SPEED (KNOTS) AND DIRECTION	WEATHER
1/28 0000	-7	WNW 14	Clear
0400	-8	WSW 9	"
0800	-7	SW 2	"
1200	-1	SSW 5	"
1600	2	SSE 20	"
2000	3	SSE 28	Overcast
1/29 0000	-1	NW 35	Overcast
0400	-12	WNW 23	Clear
0800	-12	WSW 21	"
1200	-2	SW 22	"
1600	-7	WSW 20	"
2000	-13	SWS 17	"
1/30 0000	-12	SW 12	Clear
0400	-13	NW 12	"
0800	-12	SW 12	"
1200	-6	NW 14	"
1600	-8	WNW 18	"
2000	-11	WSW 15	"
1/31 0000	-11	SW 18	Clear
0400	-13	SW 18	"
0800	-12	W 14	"
1200	-7	WSW 13	"
1600	-8	WSW 26	"
2000	-8	WSW 15	"

DATE/TIME		TEMP (^{0}C)	WIND SPEED (KNOTS) AND DIRECTION	WEATHER
2/1	0000	-9	SW 14	Clear
	0400	-10	SW 15	"
	0800	-9	WSW 16	"
	1200	-1	W 17	"
	1600	-3	WSW 22	Cloudy
	2000	-8	WNW 22	Overcast
2/2	0000	-10	NW 15	Clear
	0400	-12	NW 12	"
	0800	-11	W 22	"
	1200	-4	WNW 14	"
	1600	-4	NNW 14	Scattered Clouds
	2000	-6	NW 8	Overcast
2/3	0000	-8	WSW 7	Clear
	0400	-8	WSW 3	"
	0800	-6	SSW 12	Overcast
	1200	-1	SW 15	"
	1600	-2	SW 16	Flurries
	2000	-6	SW 15	Overcast
2/4	0000	0	W 19	Cloudy
	0400	-2	W 12	Clear
	0800	-1	WNW 14	Overcast
	1200	1	WNW 13	"
	1600	2	NW 6	Clear
2/5	0000	-2	SW 6	Overcast
	0400	-1	NE 4	"
	0800	0	NE 5	Snow
	1200	1	NNE 9	"
	1600	1	NNE 10	"
	2000	0	NNW 11	"

DATE/TIME		TEMP (^{o}C)	WIND SPEED (KNOTS) AND DIRECTION		WEATHER
2/6	0000	-3	NW	18	Flurries
	0400	-3	NW	18	Clear
	0800	-8	NW	18	"
	1200	-3	NW	17	"
	1600	-4	WNW	23	"
	2000	-10	NNW	13	"
2/7	0000	-11	SW	12	Clear
	0400	-11	NW	16	"
	0800	-9	WSW	12	Overcast
	1200	-3	NW	15	Clear
	1600	-5	WNW	15	"
	2000	-7	WNW	12	"
2/8	0000	-9	NW	12	Clear
	0400	-11	NW	8	"
	0800	-7	NW	14	"
	1200	-1	NW	9	"
	1600	1	WNW	11	"
	2000	-5	WNW	8	"
2/9	0000	-9	SW	5	Clear
	0400	-12	SW	8	Fog
	0800	-4	SW	10	Clear
	1200	0	SW	16	Cloudy
	1600	0	SW	18	"
	2000	-1	SSW	17	Overcast
2/10	0000	-1	SW	14	Overcast
	0400	-2	SW	9	"
	0800	1	WSW	3	"
	1200	6	NW	12	Cloudy
	1600	7	NW	8	Clear
	2000	0	SW	4	"

DATE/TIME		TEMP (^{o}C)	WIND SPEED (KNOTS) AND DIRECTION	WEATHER
2/11	0000	-3	Calm	Clear
	0400	-4	WSW 2	Overcast
	0800	-1	SSE 7	Clear
	1200	5	SSW 12	Cloudy
	1600	3	SW 18	"
	2000	1	SSW 15	"
2/12	0000	0	SW 9	Clear
	0400	-1	NW 1	"
	0800	1	SSW 6	"
	1200	9	SSW 6	"
	1600	3	SSE 4	Overcast
	2000	2	SSW 10	"
2/13	0000	2	SE 6	Rain
	0400	2	SE 12	Overcast
	0800	3	SE 16	"
	1200	7	SE 12	"
	1600	6	SW 6	Fog
	2000	2	SW 5	Fog
2/14	0000	2	SW 10	Overcast
	0400	2	SW 12	Clear
	0800	2	WSW 11	"
	1200	4	W 5	"
	1600	3	SW 17	"
	2000	-1	SW 11	"
2/15	0000	1	SW 8	Clear
	0400	1	SW 8	"
	0800	2	Calm	Overcast
	1200	1	NE 2	"
	1600	1	NE 13	"
	2000	2	NE 16	"

DATE/TIME		TEMP (^{o}C)	WIND SPEED (KNOTS) AND DIRECTION	WEATHER
2/16	0000	-4	NW 10	Clear
	0400	-8	NW 12	"
	0800	-4	NW 11	Lt. Overcast
	1200	-1	NW 4	Lt. Clouds
	1600	-1	NW 7	"
	2000	-4	NW 8	Cloudy
2/17	0000	-8	NW 9	Clear
	0400	-11	NW 16	"
	0800	-10	NW 15	"
	1200	-5	NW 14	"
	1600	0	NW 15	"
	2000	-8	NW 18	"
2/18	0000	-8	WNW 11	Clear
	0400	-10	NW 11	"
	0800	-8	NW 6	"
	1200	-1	S 2	"
	1600	-2	SSW 12	"
	2000	-4	SSW 7	Lt. Clouds
2/19	0000	-5	SW 3	Clear
	0400	-3	SE 10	Cloudy
	0800	-2	SSE 10	Overcast
	1200	2	S 8	"
	1600	1	SSW 7	"
	2000	1	SSW 3	"
2/20	0000	0	NE 2	Fog
	0400	0	NE 5	Hazy
	0800	2	NE 8	Cloudy
	1200	2	NE 11	Snow
	1600	2	NE 11	Rain
	2000	2	NNE 18	Drizzle

DATE/TIME		TEMP (^{o}C)	WIND SPEED (KNOTS) AND DIRECTION	WEATHER
2/21	0000	1	NE 16	Drizzle
	0400	0	NW 15	Cloudy
	0800	0	NW 22	Clear
	1200	3	WNW 20	Lt. Overcast
	1600	1	WNW 23	Cloudy
	2000	-3	WNW 18	Clear

Table II.2. Daily range and average of air temperatures at Wings Neck Station, Buzzards Bay, Massachusetts, January 28 - February 25, 1977

DATE	AVERAGE (^{o}C)	MAXIMUM/MINIMUM (^{o}C)
January 28	-3.0	2/-8
29	-7.8	-1/-13
30	-10.3	-6/-13
31	-9.8	-7/-13
February 1	-6.7	-1/-10
2	-7.8	-4/-10
3	-5.2	-1/8
4	0.0	0/-2
5	-0.2	0/-2
6	-5.2	-3/-10
7	-7.7	-3/11
8	-5.3	1/-11
9	-4.3	0/-12
10	1.8	7/-2
11	0.2	5/-4
12	2.3	9/-1
13	3.7	7/2
14	2.0	4/-1
15	0.7	2/1
16	-3.7	-1/-8
17	-7.0	0/-11
18	-5.5	-1/-10
19	-1.0	1/-5
20	1.3	2/0
21	0.3	3/-3
22	-2.5	2/-9
23	0.4	3/-2
24	3.5	6/0
25	4.9	7/3

Table II.3. Daily range and average of wind speed (knots) at Wings Neck Station, Buzzards Bay, Massachusetts, January 28 - February 25, 1977

DATE	AVERAGE WIND SPEED	MAXIMUM/MINIMUM WIND SPEED
January 28	13.0	28/2
29	23.0	35/17
30	13.8	18/12
31	17.3	26/13
February 1	17.7	22/14
2	14.2	22/8
3	11.3	16/3
4	10.7	19/6
5	7.5	11/4
6	17.8	23/13
7	13.7	16/12
8	10.3	12/8
9	12.3	18/5
10	8.3	14/3
11	9.0	18/0
12	6.0	10/1
13	9.5	16/5
14	11.0	12/5
15	7.8	16/0
16	8.7	12/4
17	13.5	18/9
18	8.2	12/2
19	6.8	10/3
20	9.2	18/2
21	19.0	23/15
22	9.1	15/0
23	5.1	12/0
24	11.6	18/7
25	14.3	28/6

Table II.4. Daily weather conditions for January 1-27, 1977 at Wings Neck Station, Buzzards Bay, Massachusetts (Army Corps Engineers)

DATE	TEMP (^{o}C)	WIND DIRECTION & SPEED (KNOTS)		WEATHER CONDITIONS
January 1	-8	NW	10-21	Clear
2	-4	NW	7-22	Clear
3	-3	W	1-10	Clear → overcast
4	-1	SW	5	Snow
5	-3	NW	7-16	Overcast
6	-3	NE	5-8	Overcast
7	1	E	15-30	Rain, snow
8	-4	NW	12-30	Clear
9	-6	NW	10-15	Clear
10	4	SSE	24	Rain
11	-6	W	20-30	Clear
12	-9	WSW	10-16	Overcast
13	-9	WNW	10-18	Clear
14	-5	W	1-10	Snow
15	-4	W	10-20	Snow
16	-6	WNW	10-25	Clear + snow
17	-12	NW	15-25	Clear
18	-14	W	18-30	Clear
19	-8	W	10-20	Clear
20	-4	WNW	10-20	Clear
21	-2	WNW	3-15	Clear → overcast
22	-6	NW	10-20	Clear
23	-7	W	5-18	Clear
24	-3	SW	5-15	Overcast
25	2	NW	5-15	Overcast
26	-2	W	10-20	Clear
27	-2	SW	10-30	Clear

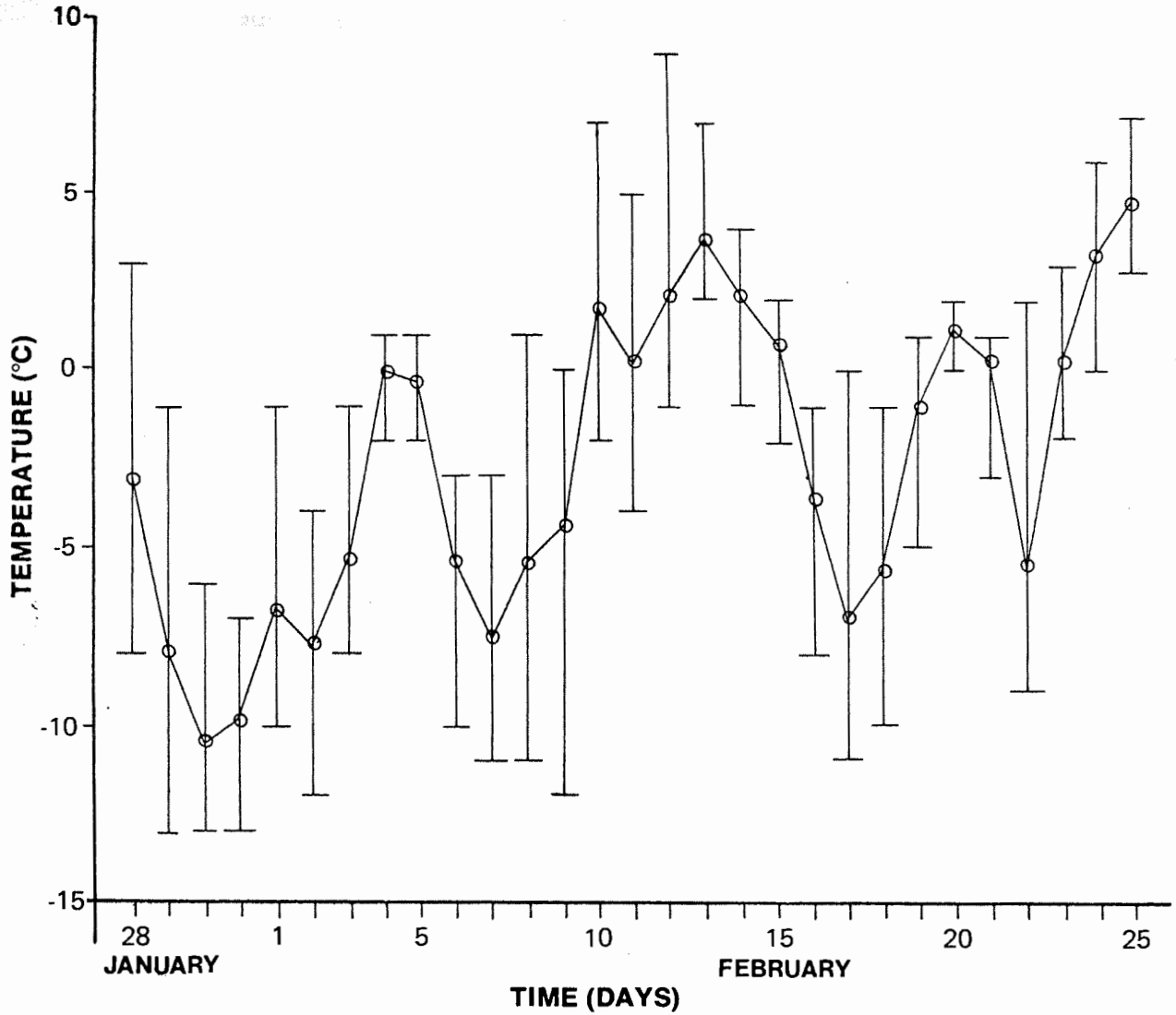


Figure 1. Daily mean and range of air temperatures at Wings Neck Station, 28 January - 25 February, 1977.

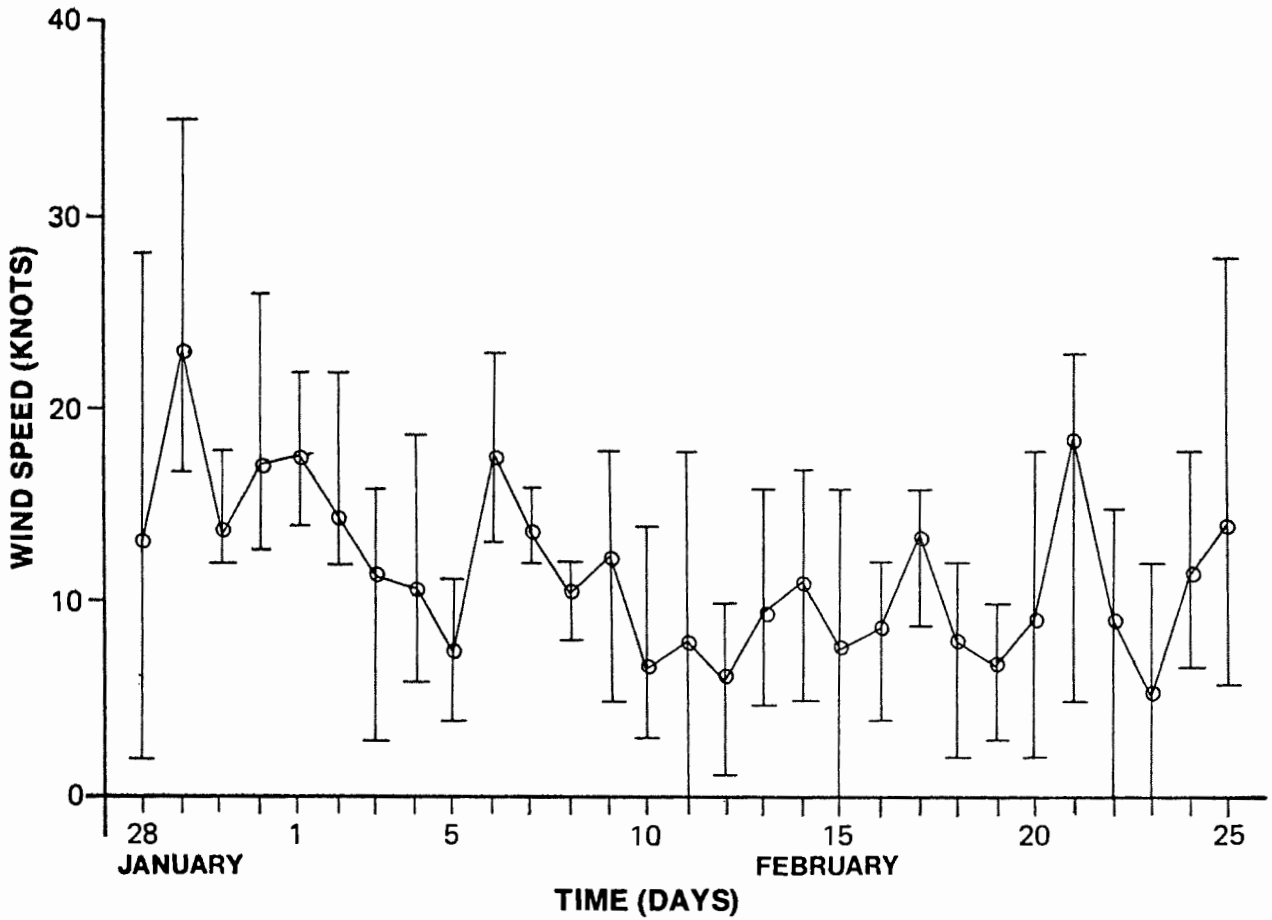


Figure 2. Daily mean and range of wind speeds at Wings Neck Station, 28 January - 25 February, 1977

APPENDIX III

SAMPLE LOCATION AND ANALYSIS

Table III.1. Master sample station list, January 30 - March 2, 1977

Master Chart No. (Map Reference)	Organization (Org. Reference No.)	Date (Time) of Sample	Type of Sample	Analysis of Sampl
1 (H-1)	EPA, MMF (1)	1/30 (1000) 2/7 (1500) 2/24 (0930)	Sediment (2), surface water shellfish	
2 (I-3)	EPA, MMF (2)	1/30 (1110) 2/2 (1310) 2/7 (1530) 2/14 2/24 (0830)	Sediment (2), surface water, shellfish	
3 (H-4)	EPA, MMF (3)	1/30 (1215) 2/2 (1200)	Sediment (2), surface water, shellfish	
4 (H-5)	EPA, MMF (4)	1/30 (0945) 2/7 (1500) 2/24 (0830)	Sediment (2), surface water, shellfish	
5 (H-5)	EPA, MMF (5)	1/30 (1115)	Sediment (2), surface water, shellfish	
6 (G-6)	EPA, MMF (6)	1/30 (1200) 2/7 (1500)	Sediment (2), surface water, shellfish	
7 (G-8)	EPA, MMF (7)	1/30 (1055)	Sediment (2), surface water, shellfish	
8 INSET	EPA, MMF (8)	1/30 (1025)	Sediment (2), surface water, shellfish	
9A (G-3)	MMF (9A)	2/2 (1030)	Sediment, surface water, shellfish	
9B (H-3)	MMF (9B)	2/2 (1400)	Sediment, surface water, shellfish	
10 (H-4)	ENDECO (3)	2/2 (1000-1700) 2/3 (1000-1500) 2/4 (1100-1500) 2/6 (1300-1600) 2/7 (1345-1500) 2/8 (1600) 2/9 (1030) 2/14 (1245) 2/17 (1115)	Current meter lowering and multicast water samples	Fluores
11 (H-3)	WHOI (4, 61)	2/3 (1015) 3/10	Sediment, surface water benthos	Fluores

Master Chart No. (Map Reference)	Organization (Org. Reference No.)	Date (Time) of Sample	Type of Sample	Analysis of Sample
12 (E-6)	ENDECO (10)	2/9 (1530) 2/14 (1410) 2/17 (1330)	Water surface, mid-depth	Fluorescence
13 (F-6)	EPA (13)	2/2 (1515)	Sediments (3), benthos (3)	
14 (G-5)	EPA (14)	2/3 (1015)	Sediments (3), benthos (3), surface water, water column (3m)	
15 (H-4)	EPA (15)	2/3 (1245)	Sediments (3), benthos (3), surface water, water column (3m)	
16 (G-6)	EPA (16)	2/4 (1000)	Sediments (3), benthos (3)	
17 (G-6)	EPA (17)	2/4 (1045)	Sediment (3), benthos (3)	
18 (F-6)	EPA (18)	2/4 (1155)	Sediment (3), benthos (3)	
19 (F-6)	EPA (19)	2/4 (1230)	Sediment (3), benthos (3)	
20 (G-5)	NOAA, MBL (12)	2/4 (1220)	Surface water, sediments (7)	Fluorescence
21 (G-5)	NOAA, MBL (11)	2/4 (1145)	Surface water, sediments (7)	Fluorescence
22 (G-5)	NOAA, MBL (10)	2/4 (1115)	Surface water, sediments (7)	Fluorescence
23 (G-5)	NOAA, MBL (9)	2/4 (1040)	Surface water, sediments (7)	Fluorescence
24 (F-6)	NOAA (1)	2/6	Surface ice sample	
25 (H-3)	NOAA (2)	2/6	Water column (1.5m)	
26 (H-3)	MBL (13,42,63)	2/7,18,3/10	Sediments (7)	Fluorescence
27 (H-3)	MBL (14,43)	2/7,18	Sediments (7)	Fluorescence
28 (H-3)	MBL (15)	2/7	Sediments (7)	Fluorescence
29 (H-3)	MBL (16,65)	2/7, 3/10	Sediments (7)	Fluorescence
30 Canal	NOAA (3)	2/6 (1445) 2/9 (1305)	Surface water, water column (6 m)	Fluorescence
31 Canal	NOAA (4)	2/6 (1505) 2/9 (1245)	Surface water	Fluorescence
32 Canal	NOAA (5)	2/6 (1545)	Surface Water	Fluorescence

Master Chart No. (Map Reference)	Organization (Org. Reference No.)	Date (Time) of Sample	Type of Sample	Analysis of Sample
33 Canal	NOAA (6)	2/6 (1610) 2/9 (1315)	Surface water	Fluoresce
34 (F-6)	URI, NOAA (7)	2/8	Surface water, ice scrapping, water column (6 m)	
35 Sandwich	MMF (35)	2/8 (0830) 2/14 2/24 (1100)	Surface water, sediment, shellfish	
36 (H-3)	MBL, WHOI (17,41,62)	2/8 (1130) 2/18, 3/10	Benthos, sediments (7)	Fluoresc
37 (H-3)	MBL (18, 75)	2/8, 3/10	Benthos, sediments (7)	Fluoresc
38 (H-4)	MBL (19,76)	2/8, 3/10	Benthos, sediments (7)	Fluoresc
39 (F-5)	NOAA (8)	2/8 (1030)	Surface water, water column (2 and 3 m)	Fluoresc
40 (F-5)	NOAA (9)	2/8 (1350)	Surface water, water column (2,3 and 5 m)	Fluoresc
41 (G-7)	ENDECO (12)	2/8 (1530)	Surface water, mid-depth (2 m), bottom 4" of ice core	Fluoresc
42 (A-6)	ENDECO (13)	2/8 (1510)	Surface water, mid-depth (2 m), bottom 4" of ice core	Fluoresc
43 (D-7)	ENDECO (14)	2/8 (1450) 2/14 (1600) 2/17 (1545)	Surface water, mid-depth (2 m), bottom 4" of ice core	Fluoresc
44 (H-3)	MBL, WHOI (5,64)	2/3 (1115) 3/10	Surface water, sediments benthos (2)	
45 Canal	NOAA (10)	2/9 (1330)	Surface water, water column (2 and 5 m)	Fluoresc
46 Canal	NOAA (11)	2/9 (1345)	Surface water, water column (2 and 5 m)	Fluoresc
47 (F-5)	MBL (31)	2/11	Sediments (7)	Fluoresc
48 (F-5)	MBL (22, 39)	2/10 2/18	Sediments (7)	Fluores

alysis Sample	Master Chart No. (Map Reference)	Organization (Org. Reference No.)	Date (Time) of Sample	Type of Sample	Analysis of Sample
uorescen	49 (G-5)	MBL, WHOI (23)	2/10	Sediments (7)	Fluorescence
	50 (H-4)	MBL, WHOI (6)	2/3 (1445)	Sediments (7), benthos (2)	
	51 (H-4)	MBL, WHOI (7, 71)	2/3 (1500)	Sediments (7), benthos (2)	
	52 (F-5)	MBL (20)	2/9	Sediments (7)	Fluorescence
	53 (G-5)	MBL (21)	2/9	Sediments (7)	
uorescen	54 (F-5)	ENDECO (9)	2/8 (0900) 2/14 (1400) 2/17 (1315)	Surface water, water column (2 m)	Fluorescence
uorescen					
uorescen	55 (F-5)	ENDECO (8)	2/8 (0850) 2/14 2/17 (1300)	Surface water, water column (2 m)	Fluorescence
luorescen					
luorescen	56 (F-5)	ENDECO (7)	2/9 (1400) 2/14 (1345) 2/17 (1245)	Surface water, water column (2 m)	Fluorescence
luorescen	57 (G-5)	ENDECO (6)	2/9 (1430) 2/14 (1330) 2/17 (1200)	Surface water, water column (2 m)	Fluorescence
luorescen	58 (G-5)	ENDECO (5)	2/9 (1500) 2/14 (1315) 2/17 (1145)	Surface water, water column (2 m)	Fluorescence
luorescen	59 (H-4)	ENDECO (4)	2/9 (1120) 2/14 (1300) 2/17 (1130)	Surface water, water column (2 m)	Fluorescence
	60 (H-4)	ENDECO (2)	2/9 (1100) 2/14 (1645) 2/17 (1000)	Surface water, water column	Fluorescence
luorescen	61 (H-3)	NOAA (12)	2/7	Ice core	Fluorescence
luorescen	62 (H-4)	NOAA (13)	2/7	Surface water	Fluorescence
luorescen	63 (G-4)	NOAA (14)	2/7	Surface water, bottom 4" of ice core	Fluorescence
luorescen	64 (F-5)	NOAA (15)	2/7	Surface water	Fluorescence
	65 (H-2)	ENDECO (17)	2/14 (1630) 2/17 (1500)	Surface water, water column (2 m)	Fluorescence

Master Chart No. (Map Reference)	Organization (Org. Reference No.)	Date (Time) of Sample	Type of Sample	Analysis of Sample
66 (H-4)	WHOI, MBL (8, 69)	2/3 (1520)	Sediments (7), benthos (2)	Fluoresce
67 (H-6)	MBL (34)	2/14	Sediments (7)	Fluoresce
68 (H-6)	MBL (33)	2/14	Sediments (7)	Fluoresce
69 (G-6)	MBL (28)	2/11	Sediments (7)	Fluoresce
70 (G-6)	MBL (27)	2/11	Sediments (7)	Fluoresce
71 (H-6)	MBL (32)	2/14	Sediments (7)	Fluoresce
72 (G-5)	MBL (25)	2/11	Sediments (7)	Fluoresce
73 (H-4)	MBL (26, 69)	2/11	Sediments (7)	Fluoresce
74 (G-3)	MBL (29)	2/11	Sediments (7)	Fluoresce
75 (G-3)	MBL (30)	2/11	Sediments (7)	Fluoresce
76 (F-5)	WHOI, MBL (24)	2/10 (1340)	Sediments (7), benthos (2)	Fluoresce
77 (H-7)	MBL (35)	2/16	Sediments (7)	Fluoresce
78 (H-7)	MBL (36)	2/16	Sediments (7)	Fluoresce
79 (G-7)	MBL (37)	2/16	Sediments (7)	Fluoresce
80 (G-7)	MBL (38)	2/16	Sediments (7)	Fluoresce
81 (H-1)	ENDECO (16)	2/8	Ice core, surface water, column (2 m)	Fluoresce
82 Sandwich	MMF (100)	2/14 (1200)	Surface water, sediments, shellfish	
83 Sandwich	MMF (101)	2/14 (1100)	Sediments, ice	
84 Barstable	MMF (102)	2/14 (1130)	Sediments	
85 Canal	MMF (103)	2/14 2/24	Shellfish	
86 (J-2)	MMF (105)	2/14 2/24	Surface water, sediments shellfish	

Master Chart No. (Map Reference)	Organization (Org. Reference No.)	Date (Time) of Sample	Type of Sample	Analysis of Sample
87 (H-1)	MMF (106)	2/14	Water	
88 (H-1)	MMF (107)	2/14	Sediment	
89 (H-2)	MMF (108)	2/14 2/24 (0930)	Sediment	
90 (G-2)	ENDECO (18)	2/14 (1615) 2/17 (1515)	Surface water, water column (2 m)	Fluorescence
91 (C-6)	ENDECO (13B)	2/14 (1445) 2/17 (1600)	Surface Water	Fluorescence
92 (G-3)	MMF (109)	2/15	Water	
93 (E-5)	MMF (110	2/15	Water	
94 (C-4)	MMF (111)	2/15	Water	
95 (F-5)	MBL (40)	2/18	Sediments (7)	Fluorescence
96 (H-3)	MBL (44)	2/22	Sediments (7)	Fluorescence
97 (H-4)	MBL (45)	2/22	Sediments (7)	Fluorescence
98 (G-6)	MBL (46)	2/22	Sediments (7)	Fluorescence
99 (G-2)	MBL (51)	3/2	Sediments (7)	Fluorescence
100 (H-2)	MBL (52)	3/2	Sediments (7)	Fluorescence
101 (H-1)	MBL (53)	3/2	Sediments (7)	Fluorescence
102 (H-1)	MBL (54)	3/2	Sediments (7)	Fluorescence
103 (H-1)	MBL (55)	3/2	Sediments (7)	Fluorescence
104 (H-1)	MBL (56)	3/2	Sediments (7)	Fluorescence

Table III.2. Results of hydrocarbon analysis of water column, ice and sediment samples taken in Buzzards Bay, Massachusetts, January 30 - February 24, 1977 (analysis by Environmental Devices Corporation).

Master List No.	Collector Station Code	Location	1977 Date/Time	Type Sample	ppb
10	EN3	Phinneys Harbor Entrance	2-8/1600	WS	55
		"	"	WM5(2)	30
		"	"	ICE	340
		"	"	WSK	ins
55	EN8	500 yd. (457 m) SW Wings	2-8/0940	WSK	1000
		" Cove	2-8/0945	WS	110
		"	2-8/0945	WM5(2)	95
		"	2-8/0850	ICE	280
54	EN9	Wings Neck Lighthouse	2-8/0900	WS	20
		"	"	WM5(2)	70
		"	"	ICE	ins
		"	"	WSK	ins
41	EN12	Megansett Harbor	2-8/1530	WS	40
		"	"	WM5(2)	40
		"	"	WSK	135
		"	"	ICE	170
42	EN13	Sippican Harbor, W. of	2-8/1510	WS	60
		" Bird Is.	"	WM5(2)	30
		"	"	WSK	280
		"	"	ICE	320
43	EN14	Little Bird Island	2-8/1450	WS	40
		"	"	WM5(2)	ins
		"	"	ICE	310
		"	"	WSK	ins
81	EN16	Buttermilk Bay	2-8/1350	WS	30
		"	"	WM5(2)	30
		"	"	ICE	310
		"	"	WSK	1000
60	EN2	Phinneys Harbor Middle	2-9/1100	WS	80
		"	"	WM5(2)	90
		"	"	ICE	ice
		"	"	WSK	190

ins = insufficient sample size for analysis

Master List No.	Collector Station Code	Location	1977 Date/Time	Type Sample	ppb
10	EN3	Phinneys Harbor Entrance	2-9/1030	WS	50
		"	"	WM5(2)	20
		"	"	WSK	85
		"	"	ICE	ins
59	EN4	S. Phinneys Harbor Entrance	2-9/1120	WS	40
		"	"	Wm5(2)	30
		"	"	ICE	ins
		"	"	WSK	165
58	EN5	500 Yds. (457 m) SW of 4	2-9/1500	WS	160
		"	"	W5(2)	50
		"	"	ICE	ins
		"	"	WSK	85
57	EN6	500 Yds. (457 m) SW of 5	2-9/1430	WS	130
		" near buoy	"	WM5(2)	180
		"	"	ICE	505
		"	"	WSK	ins
56	EN7	Wings Cove	2-9/1400	WS	445
		"	"	WM5(2)	ins
		"	"	ICE	ins
		"	"	WSK	1000
12	EN10	1000 Yd. (914 m) SW Wings Neck Light	2-9/1530	WS	280
60	EN2	Phinneys Harbor Inside	2-14/1645	WMS	70
10	EN3	Phinneys Harbor Entrance	2-14/1245	WSK	50
		"	"	WM5(2)	85
59	EN4	S. of Phinneys Harbor Ent.	2-14/1300	WS	110
		"	"	WM5(2)	95
58	EN5	500 Yd. (457 m) SW of 4	2-14/1315	WSK	85
		"	"	WM5(2)	70
57	EN6	500 Yd. (457 m) SW of 5 near buoy	2-14/1330	WSK	1000
		"	"	WM5(2)	350
56	EN7	Wings Cove	2-14/1345	WSK	250
		"	"	WM5(2)	200
55	EN8	500 Yd. (457 m) S. of Wings Cove	2-14/1400	WSK	1000
		"	"	WM5(2)	85

ppb

55
30
340
ins

1000
110
95
280

20
70
ins
ins

40
40
135
170

60
30
280
320

40
ins
310
ins

30
30
310
1000

80
90
ice
190

Master List No.	Collector Station Code	Location	1977 Date/Time	Type Sample	ppb
54	EN9	Wings Neck Lighthouse "	2-14/1415 "	WSK WM5(2)	100 5
12	EN10	S. of Wings Neck Light "	2-14/1410 "	WSK WM5(2)	44 10
42	EN13	E. of Bird Island	2-14/1445	WSK	2
43	EN14	W. of Little Bird Island "	2-14/1600 "	WSK WM5(2)	2 4
65	EN17	Canal West Entrance "	2-14/1630 "	WSK WM5(2)	17 16
90	EN18	Onset Island "	2-14/1615 "	WSK WM5(2)	100 19
60	EN2	Phinneys Harbor Inside	2-17/1100	WM5(2)	24
10	EN3	Phinneys Harbor Entrance "	2-17/1115 "	WSK WM5(2)	in in
59	EN4	S. Phinneys Harbor Entr. "	2-17/1130 "	WSK WM5(2)	10 1
58	EN5	500 Yd. (457 m) SW of 4 "	2-17/1145 "	WSK WM5(2)	1
57	EN6	500 Yd. (457 m) SW of 5, near buoy "	2-17/1200 "	WSK WM5(2)	
56	EN7	Wings Cove "	2-17/1245 "	WSK WM5(2)	
55	EN8	500 Yd. (457 m) SW of Wings Cove "	2-17/1300 "	WSK WM5(2)	
54	EN9	Wings Neck Lighthouse "	2-17/1315 "	WSK WM5(2)	
12	EN10	S. of Wings Neck Light "	2-17/1330 "	WSK WM5(2)	
42	EN13	East of Bird Island "	2-17/1600 "	WSK WM5(2)	
43	EN14	Little Bird Island "	2-17/1545 "	WSK WM5(2)	

Master List No.	Collector Station Code	Location	1977 Date/Time	Type Sample	ppb
65	EN17	Canal West Entrance	2-17/1500	WSK	60
		"	"	WM5(2)	45
90	EN18	Onset Island	2-17/1515	WSK	40
		"	"	WM5(2)	35
30	N03	Mid Canal in front of Coast Guard	2-6/1442	WM20(6)	40
31	N04	Mid Canal Sagamore Bridge	2-6/1505	WS	30
32	N05	50 Yd. (46 m) off dock master Cape Cod Coast Guard	2-6/1545	WS	1000
33	N06	Buoy 3 E. Ent. Canal	2-6/1610	WS	50
39	N08	41° 41' 05" N			
		Tug 1, 70° 39' 25" W	2-8/1055	WS	340
		"	2-8/1030	WM5(2)	320
		"	2-8/1055	WM10(3)	35
40	N09	41° 41' 31" N			
		Tug 1, 70° 39' 00" W	2-8/1350	WM5(2)	1000
		"	2-8/1410	WM10	1000
		"	2-8/1415	WS	ins
		"	2-8/1435	WM15(4)	70
		"	2-6/1515	?	20
30	N03	Canal Sagamore Bridge	2-9/1245	WS	50
		"	"	WM5(2)	90
		"	"	WM15(14)	50
37	N04	Coast Guard Station	2-9/1305	WS	50
		"	"	WM5(2)	45
		"	"	WM15(4)	50
32	N05	Channel Marker 3	2-9/1315	WS	70
		"	"	WM5(2)	30
		"	"	WM15(4)	40
45	N010	Canal North Shore E. End	2-9/1328	WS	40
		"	"	WM5(2)	385
		"	"	WM15(4)	265
46	N011	Canal South Shore E. End	2-9/1345	WS	60
		"	"	WM15(4)	40

* These samples were received with insufficient information on the identification tag

Master List No.	Collector Station Code	Location	1977 Date/Time	Type Sample	ppb
64	N015	Transect 8	2-7/ *	WS	280
62	N013	Transect 2	2-7/ *	ICE	ins
63	N014	Transect 4	2-7/ *	ICE	545
63	N014	Transect 4	2-8/ *	WM5(2)	35
61	N012	Transect 1	2-7/ *	ICE	400
16	EP16	Scraggy Neck N.	2-4/1000	WS	225
17	EP17	Scraggy Neck N.	2-4/1045	WS	75
18	EP18	Scraggy Neck N.	2-4/1155	WS	40
18	EP18	Scraggy Neck N.	2-14/1200	ICE	380
19	EP19	Scraggy Neck N.	2-4/1230	WS	45
13	EP13	Wings Cove	2-2/1415	WM9	50
15	EP15	Phinneys Harbor	2-3/1415	WS	30
14	EP14	Wings Cove	-23/1015	WS	50
15	EP15	Phinneys Harbor	2-3/1245	WB	ins
11	WH4	Mouth of Back River	2-3/1015	Sed.	4.7*
11	WH4	"	"	W	15
44	WH5	Head of Old Cape Cod Canal	2-3/1130	WS	20
44	WH5	"	"	Sed.	5.6*
51	WH7	Monks Cove Little Bay	2-3/1500	Sed.	10.0*
66	WH8	In Channel of Little Bay	2-3/1520	Sed.	1.8*
23	MB9	----	2-4/1040	WS	150
		----	"	Sed.	2.3*
22	MB10	Wings Cove	2-4/1115	WS	70
		"	"	Sed.	770*

* These samples were received with insufficient information on the identification tag

Master List No.	Collector Station Code	Location	1977 Date/Time	Type Sample	ppb
21	MB11	Wings Cove	2-4/1145	WS	40
		"	"	Sed.	11.5*
20	MB12	Wings Cove	2-3/1220	WS	ins
		"	"	Sed.	8.6*
70	MB27	Bassetts Island	2-11/1130	Sed.	2.0*
69	MB28	Bassetts Island	2-11/1200	Sed.	2.1*
71	MB32	"	"	Sed.	14.8*
67	MB34	"	"	Sed.	5.6*
68	MB33	"	"	Sed.	8.6*
48	MB39	Off Wings Cove	2-18/1005	Sed.	2.0*
78	MB36	Squeleque Harbor	2-16/1050	Sed.	5.8*
79	MB37	Cove Ly Scraggy Neck Meganset Harbor	2-16/1155	Sed.	0.7*
95	MB40	Wings Cove	2-18/1034	Sed.	1.6*
80	MB38	Meganset Harbor	2-16/1234	Sed.	1.6*
27	MB43	Phinneys Hrbr. Mid Channel	2-18/1220	Sed.	23.2*
77	MB35	Squeakage Harbor	2-16/1020	Sed.	8.1*
26	MB42	Mashnee Island	2-18/1150	Sed.	8.1*
36	MB41	Mouth of Back R.	2-18/1115	Sed.	17.1*

* These samples were received with insufficient information on the identification tag

Table III.3. Results of Hydrocarbon analysis of sediment samples taken in Buzzards Bay, Massachusetts, February 3 - March 2, 1977. (Collection and analysis by Woods Hole Marine Biological Laboratories.)

Master List # (MBL Station #)		Sample Date	Ug OIL/g WET SEDIMENT WGT.
44	(5)	2/3	3.5
23	(9)	2/4	1.8
22	(10)	2/4/	2.2
21	(11)	2/4	5.3
20	(12)	2/4	2.0
26	(13)	2/7	2.0
27	(14)	2/7	1.8
28	(15)	2/7	5.6
29	(16)	2/7	2.8
52	(20)	2/9	274.0
48	(22)	2/10	1.4
49	(23)	2/10	0.4
76	(24)	2/10	3.0
72	(25)	2/11	0.4
73	(26)	2/11	2.9
70	(27)	2/11	0.7
69	(28)	2/11	0.4
74	(29)	2/11	2.1
75	(30)	2/11	130.0
47	(31)	2/11	1.1
68	(33)	2/14	0.8
67	(34)	2/14	2.3
77	(35)	2/16	2.7
78	(36)	2/16	0.5
79	(37)	2/16	0.4
80	(38)	2/16	2.5
48	(39)	2/18	0.4
36	(41)	2/18	3.1

(continued)

Table III.3. (continued) Results of Hydrocarbon analysis of sediment samples taken in Buzzards Bay, Massachusetts, February 3 - March 2, 1977. (Collection and analysis by Woods Hole Marine Biological Laboratories.)

Master List # (MBL Station #)	Sample Date	Ug OIL/g WET SEDIMENT WGT.
26 (42)	2/18	2.3
27 (43)	2/18	4.7
96 (44)	2/22	5.0
97 (45)	2/22	0.7
98 (46)	2/22	5.1
Control (47)	2/28	N.D.
Control (48)	2/28	N.D.
Control (49)	2/28	N.D.
Control (50)	2/28	N.D.
99 (51)	3/2	4.4
100 (52)	3/2	5.1
101 (53)	3/2	3.4
102 (54)	3/2	2.1
103 (55)	3/2	1.9
104 (56)	3/2	19.0

N.D. = not detectable

Table III.4. Results of hydrocarbon analysis of water column, sediment and shellfish samples taken in Buzzards Bay, Massachusetts, January 30 - February 24, 1977. (Collection and analysis by Massachusetts Division of Marine Fisheries.)

Master List #	(Org. Ref. #)	Sample Date	Sample Type	Hydrocarbon Content
1	(1)	1/30	water	negative
		2/7	water	"
		2/24	quahogs	"
2	(2)	1/30	water	negative
		2/2		
		2/7	water	"
		2/14	sediment	positive
		2/24	quahogs	negative
3	(3)	1/30	water	negative
		2/2		
4	(4)	1/30	water	negative
		2/7	water	"
		2/24	oysters	"
5	(5)	1/30	water	negative
6	(6)	1/30	water	negative
		2/7	water	"
7	(7)	1/30	water	negative
8	(8)	1/30	water	negative
9A	(9A)	2/2	water	negative
9B	(9B)	2/2	water	negative
35	(35)	2/8	water	negative
		2/14	sediment	"
		2/24	water	"
82	(100)	2/14	sediment	positive (old #2 oil)
			water	positive
83	(101)	2/14	water	positive
			sediment	"
84	(102)	2/14	sediment	positive

(continued)

Table III.4. (continued) Results of hydrocarbon analysis of water column and shellfish samples taken in Buzzards Bay, Massachusetts, January 30 - February 24, 1977. (Collection and analysis by Massachusetts Division of Marine Fisheries.)

Master List # (Org. Ref. #)	Sample Date	Sample Type	Hydrocarbon Content
85 (103)	2/14	mussels	positive (old #2 oil)
	2/24	mussels	" " " "
86 (105)	2/14	sediment	negative
	2/24	mussels	positive
87 (106)	2/14	sediment	negative
89 (108)	2/14	sediment	positive (old #2 oil)
	2/24	quahogs	negative

Table III.5. Results of Hydrocarbon analysis of sediment samples taken in Buzzards Bay, Massachusetts, January 20 - February 4, 1977.

(Collection and analysis by Environmental Protection Agency.)

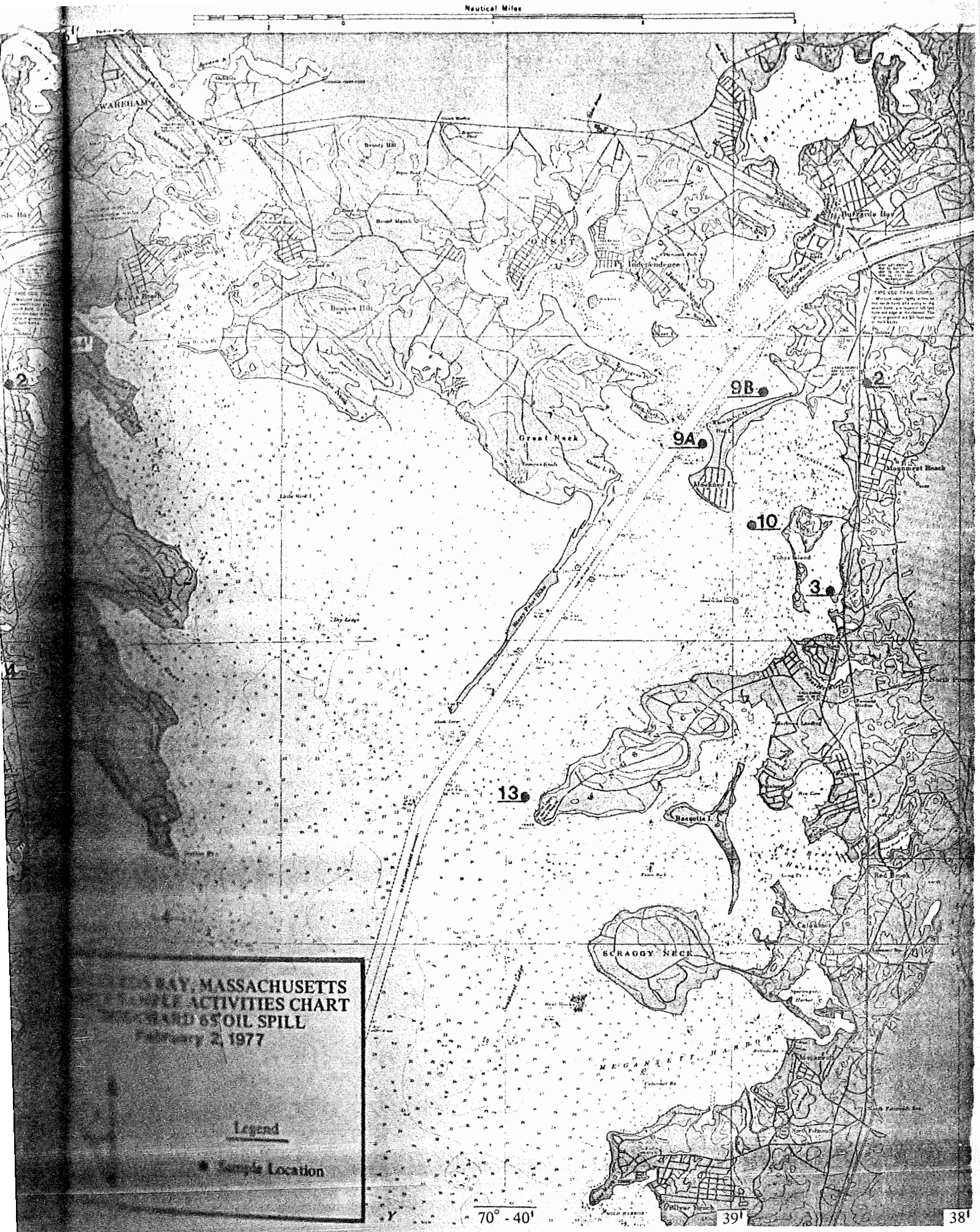
Station #	(Master List #)	Sample Date	Conc. #2 Fuel Oil in Sediments - ppm Dry wgt.
1	(1)	1/30/77	<2
2	(2)	"	<2
3	(3)	"	<5
4	(4)	"	<3
5	(5)	"	<5
6	(6)	"	<2
7	(7)	"	<2
8	(8)	"	<6
2	(2)	2/2/77	<8
3	(3)	"	<4
13	(13)	"	<1
14	(14)	2/3/77	<2
17	(17)	2/4/77	<2
18	(18)	"	<1
19	(19)	"	<1

Table III.6 Hydrocarbon content of water at Phinneys Harbor entrance, Buzzards Bay, Massachusetts, February 2-7, 1977 (Environmental Devices Corporation)

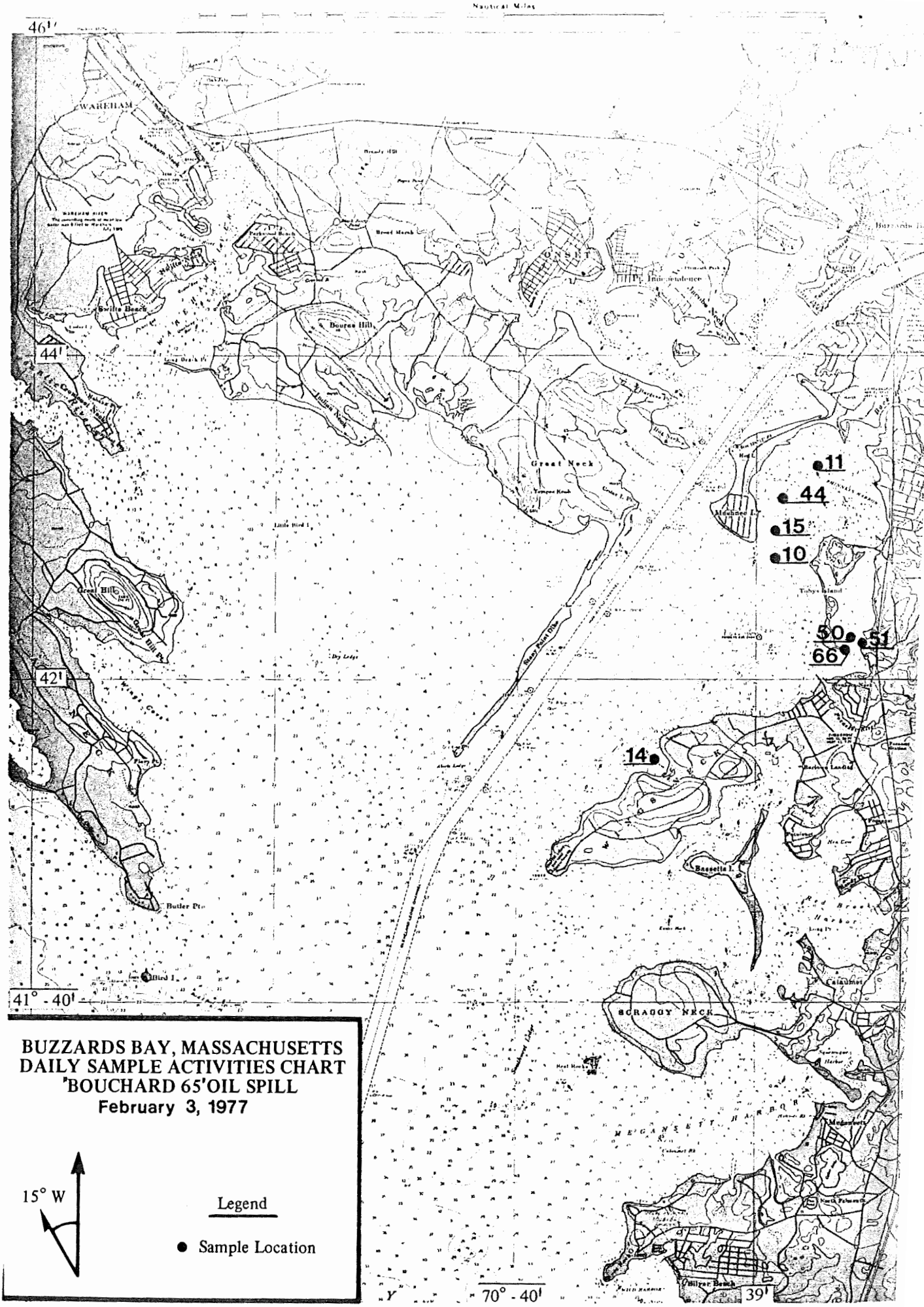
DATE/TIME		SURFACE WATER	MID-WATER (4m)	BOTTOM (8m)
2/2	1000	141 ppm	23 ppm	ins
	1130	ins	<10	<10 ppm
	1330	39	41	45
	1500	8	27	120
	1600	ins	10	ins
	1700	45	45	53
2/3	1000	<10	<10	40
	1100	<10	<10	84
	1200	33	36	47
	1400	<10	40	<10
	1500	<10	43	22
2/4	1100	61	24	50
	1200	46	58	72
	1200	ins	45	49
	1400	36	58	33
	1500	33	44	40
2/5	1300	17	43	48
	1400	65	60	<10
	1500	<10	19	44
	1600	38	<10	18
2/7	1345	45	55	55
	1445	35	40	40
	1530	15	45	30

ins = insufficient sample for analysis

BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
January 30, 1977



BUZZARDS BAY, MASSACHUSETTS
SAMPLE ACTIVITIES CHART
BARGE ARD 65 OIL SPILL
February 2, 1977

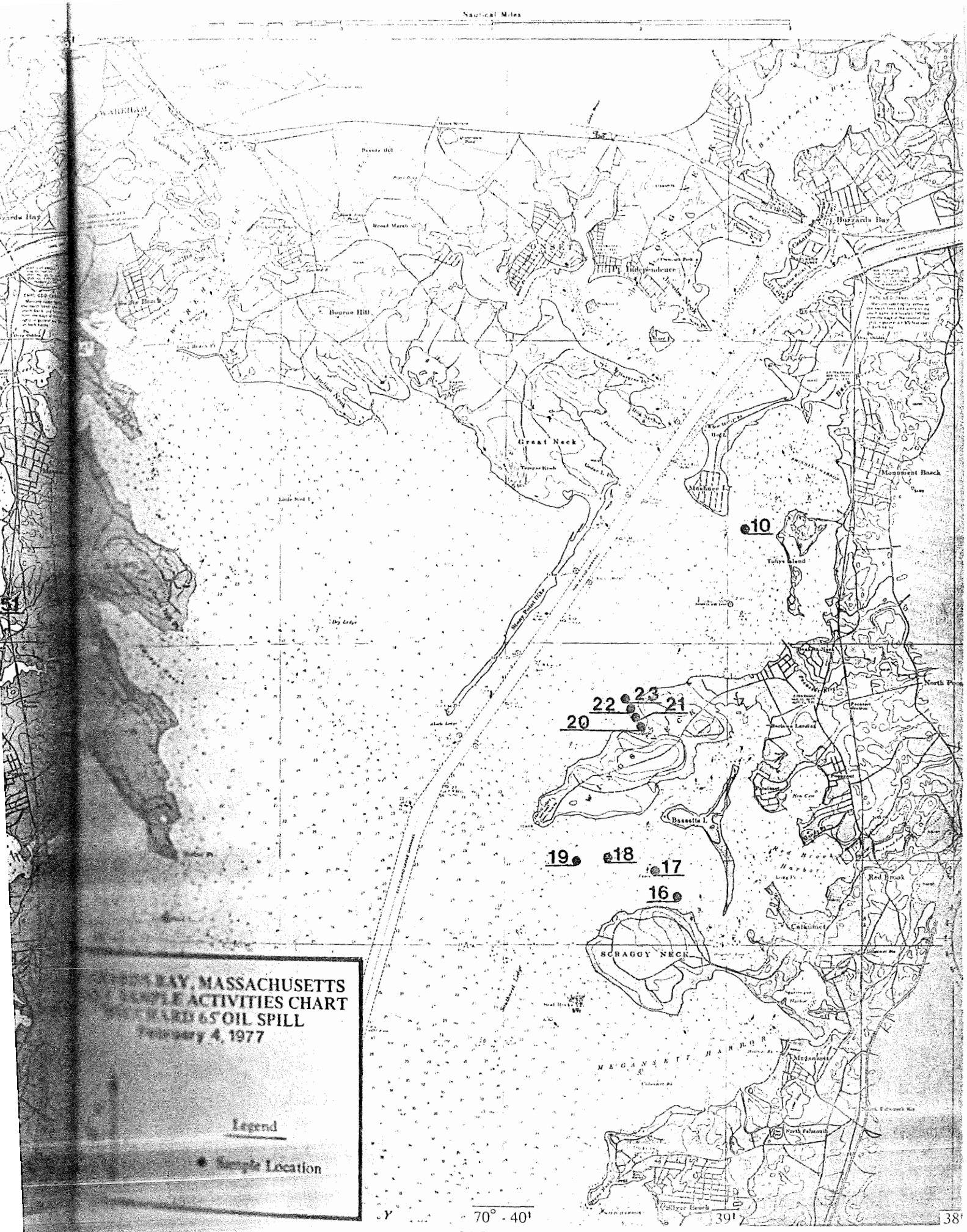


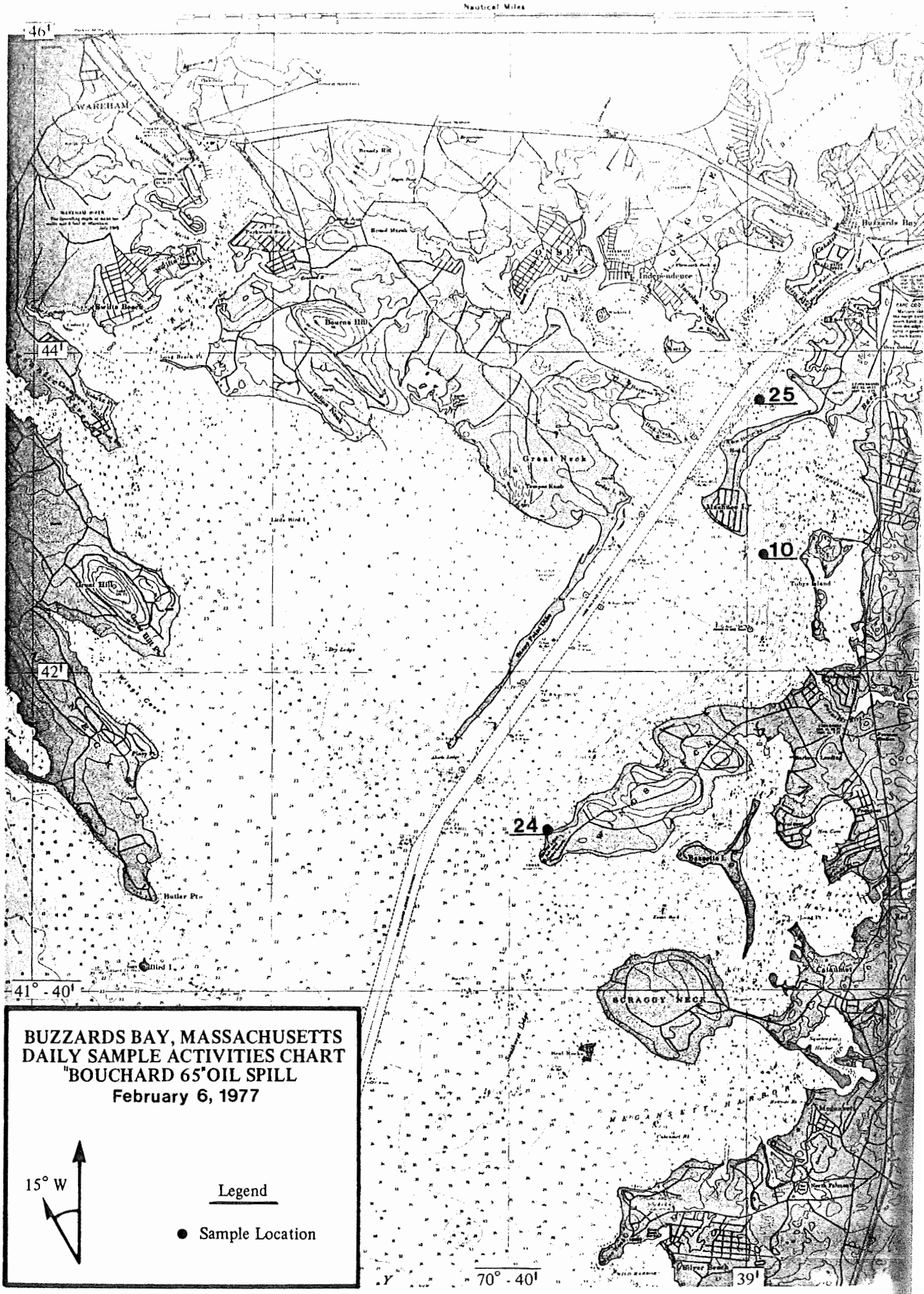
BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
BOUCHARD 65' OIL SPILL
February 3, 1977

15° W

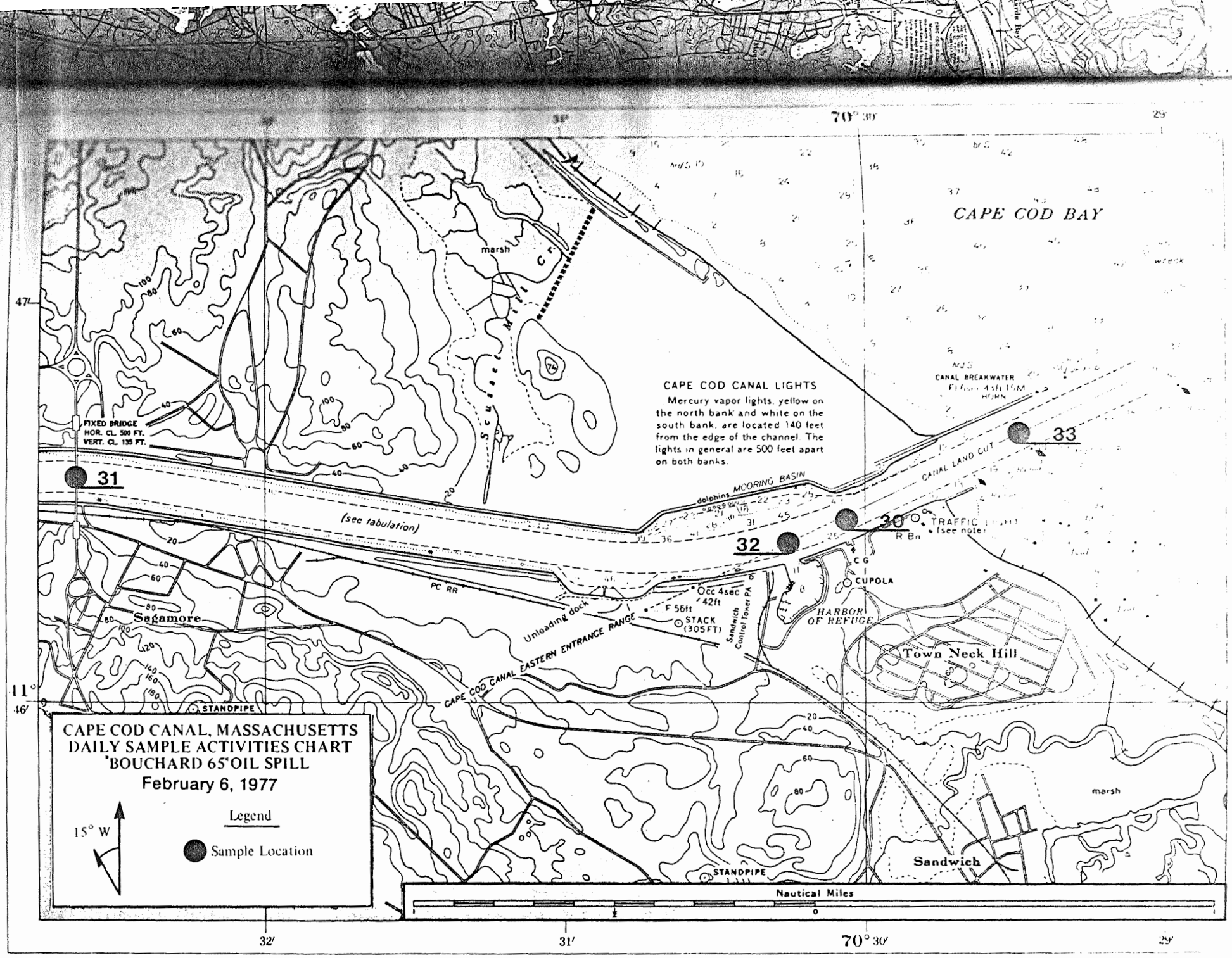
Legend

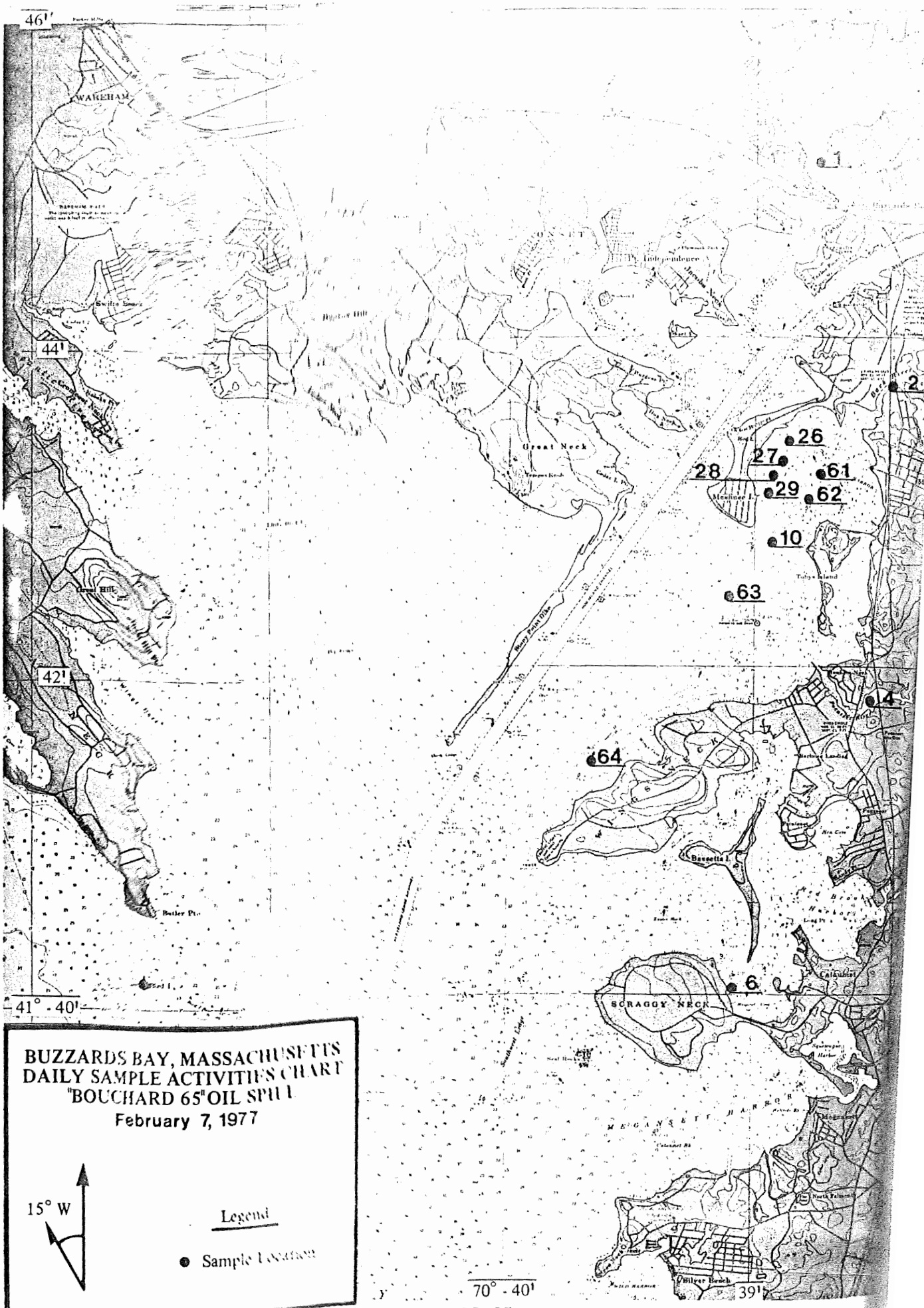
● Sample Location

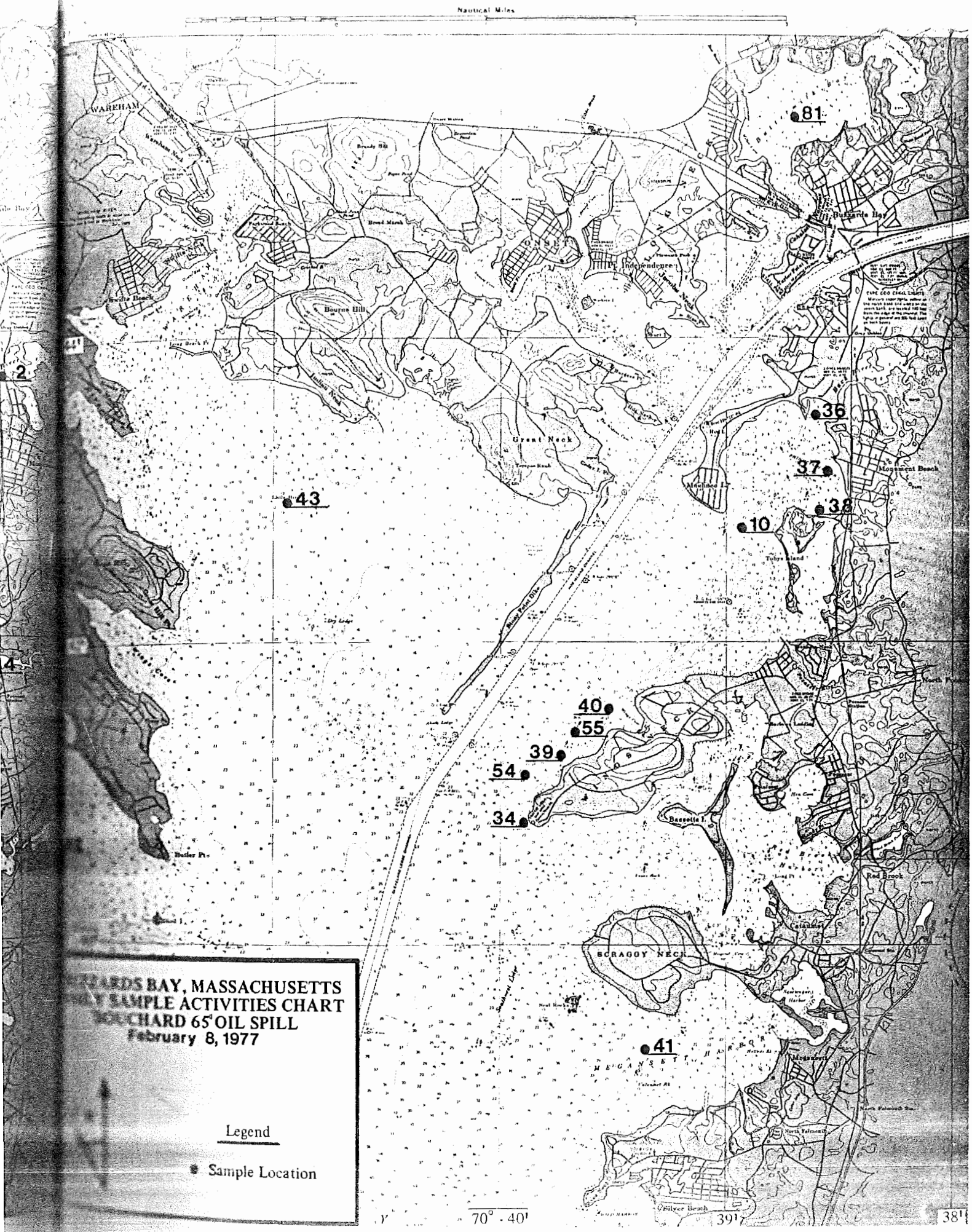

Nautical Miles
BUZZARDS BAY, MASSACHUSETTS
SAMPLE ACTIVITIES CHART
OIL SPILL
February 4, 1977
Legend
Sample Location
Buzzards Bay
Bourne Hill
Great Neck
Monument Beach
Tuckers Island
Basketts I.
SCRAGGY NECK
MEGANSETT HARBOR
Red Brook
Harbor
10
22
23
21
20
19
18
17
16
70° - 40'
39'
38'



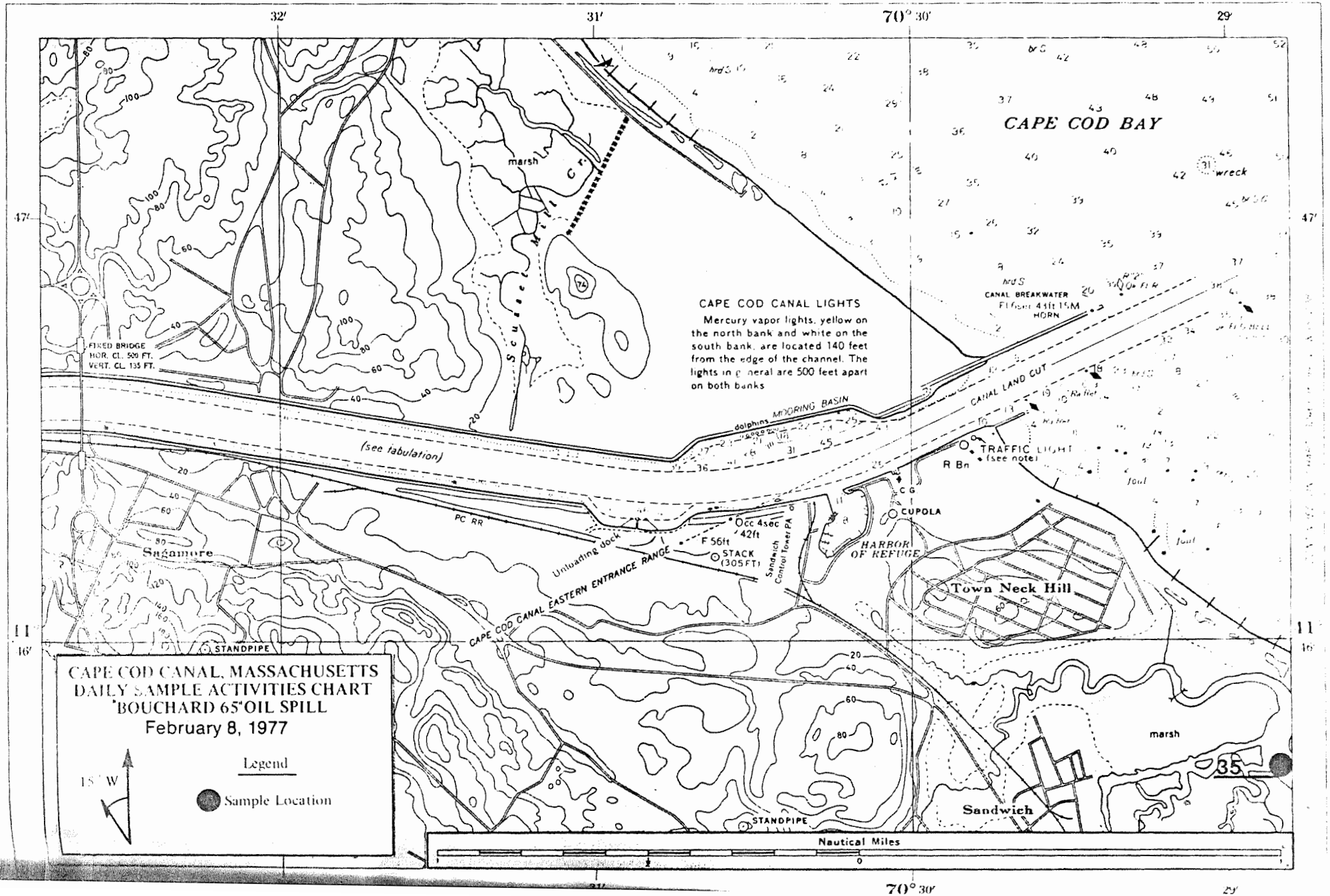
BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65"OIL SPILL
February 6, 1977

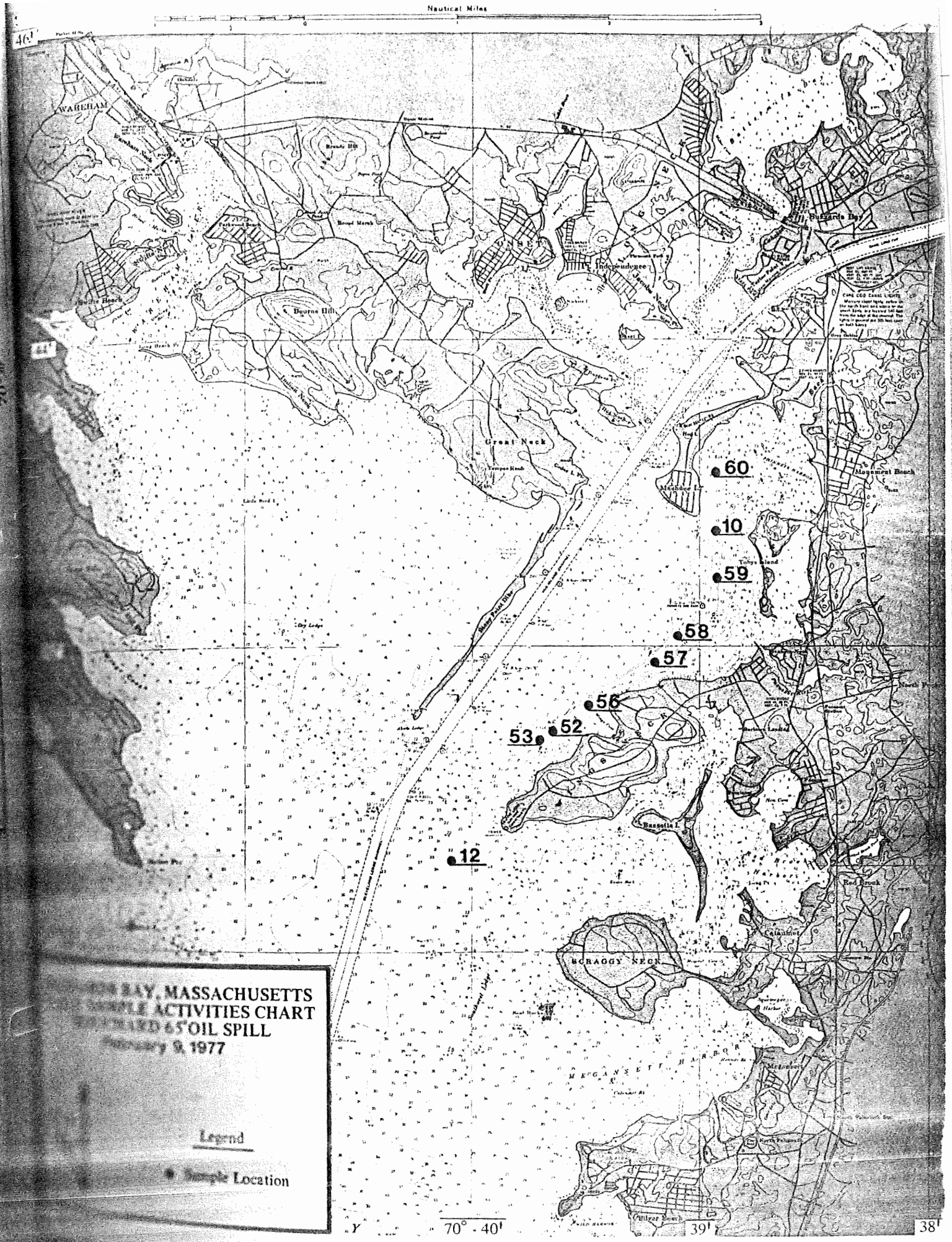

CAPE COD CANAL, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 6, 1977
15° W
Legend
Sample Location
CAPE COD BAY
CAPE COD CANAL LIGHTS
Mercury vapor lights, yellow on the north bank and white on the south bank, are located 140 feet from the edge of the channel. The lights in general are 500 feet apart on both banks.
FIXED BRIDGE
HOR. CL. 500 FT.
VERT. CL. 135 FT.
31
32
33
30
(see tabulation)
MOORING BASIN
dolphins
CANAL LAND CUT
CANAL BREAKWATER
TRAFFIC
(see note)
R Bn
CG
CUPOLA
HARBOR OF REFUGE
Occ 4sec
42ft
F 56ft
STACK
(305FT)
Sandwich Control Tower PA
Unloading dock
PC RR
CAPE COD CANAL EASTERN ENTRANCE RANGE
Sagamore
Town Neck Hill
Sandwich
marsh
STANDPIPE
Nautical Miles
70° 30'
47'
11°
46'
32'
31'
29'

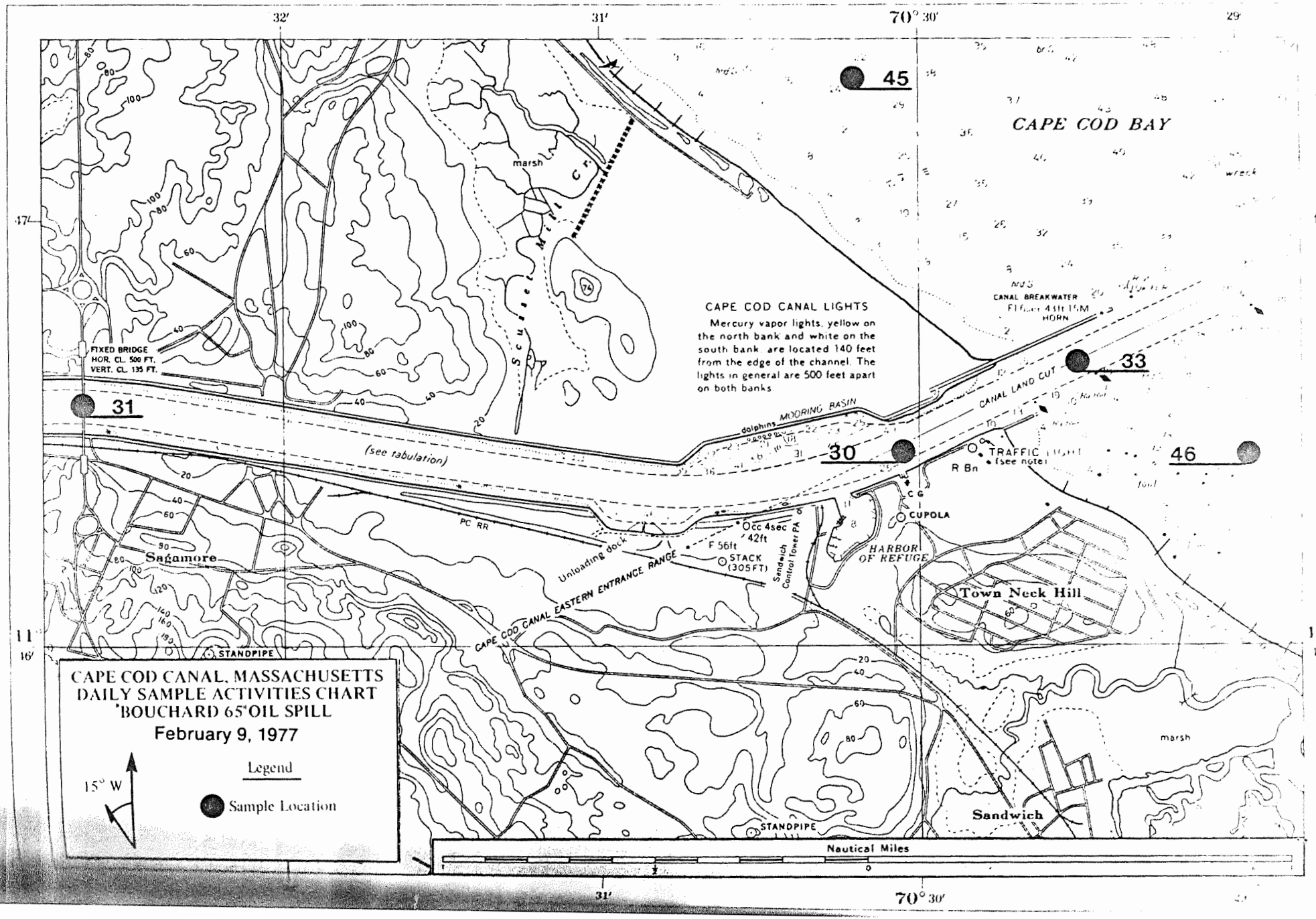

46'
44'
42'
41° - 40'
70° - 40'
39'
WAREHAM
Great Neck
Great Hill
Butler Pt.
Scraggy Neck
Silver Beach
1
2
26
27
28
29
61
62
10
63
4
64
6
BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 7, 1977
15° W
Legend
Sample Location

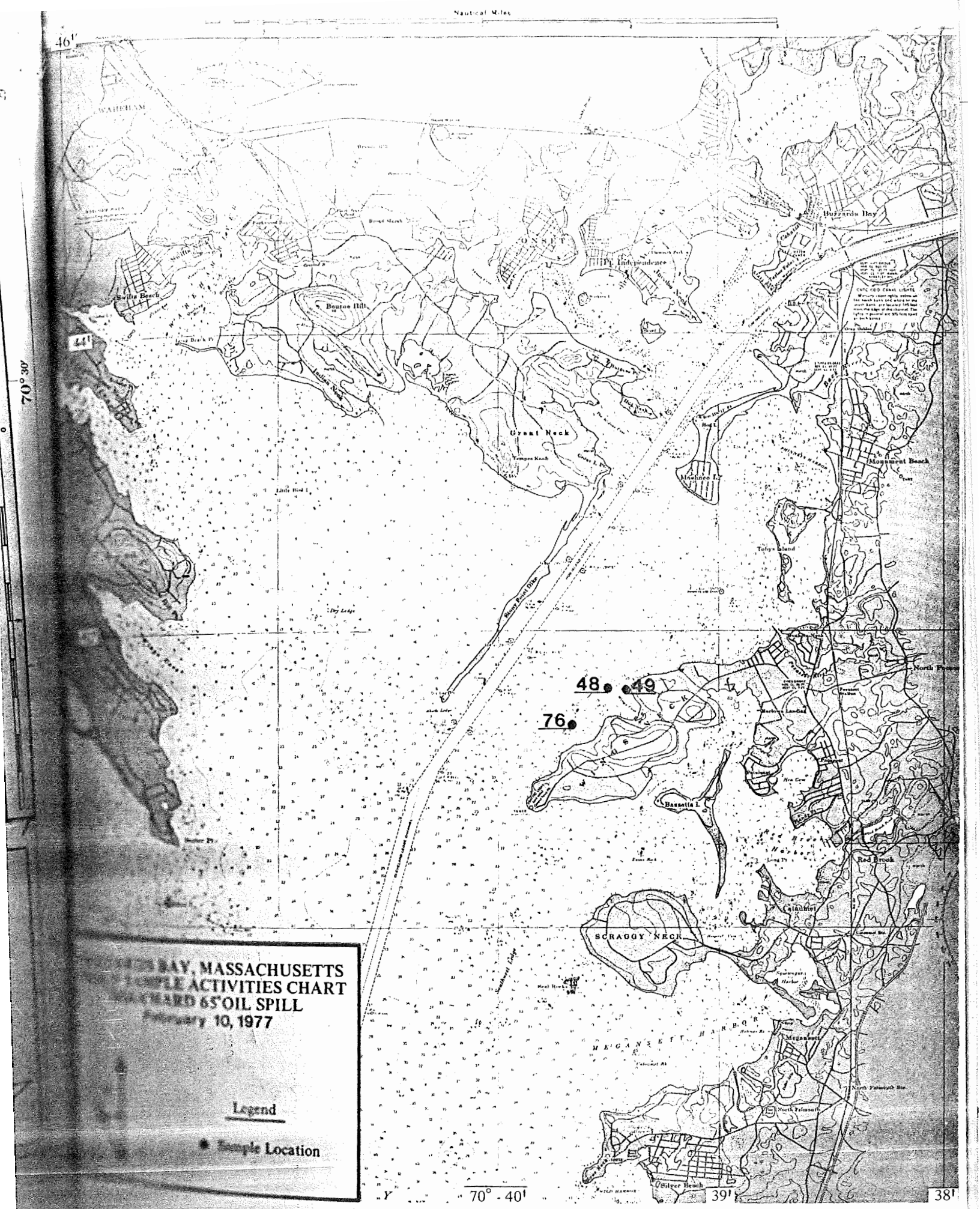


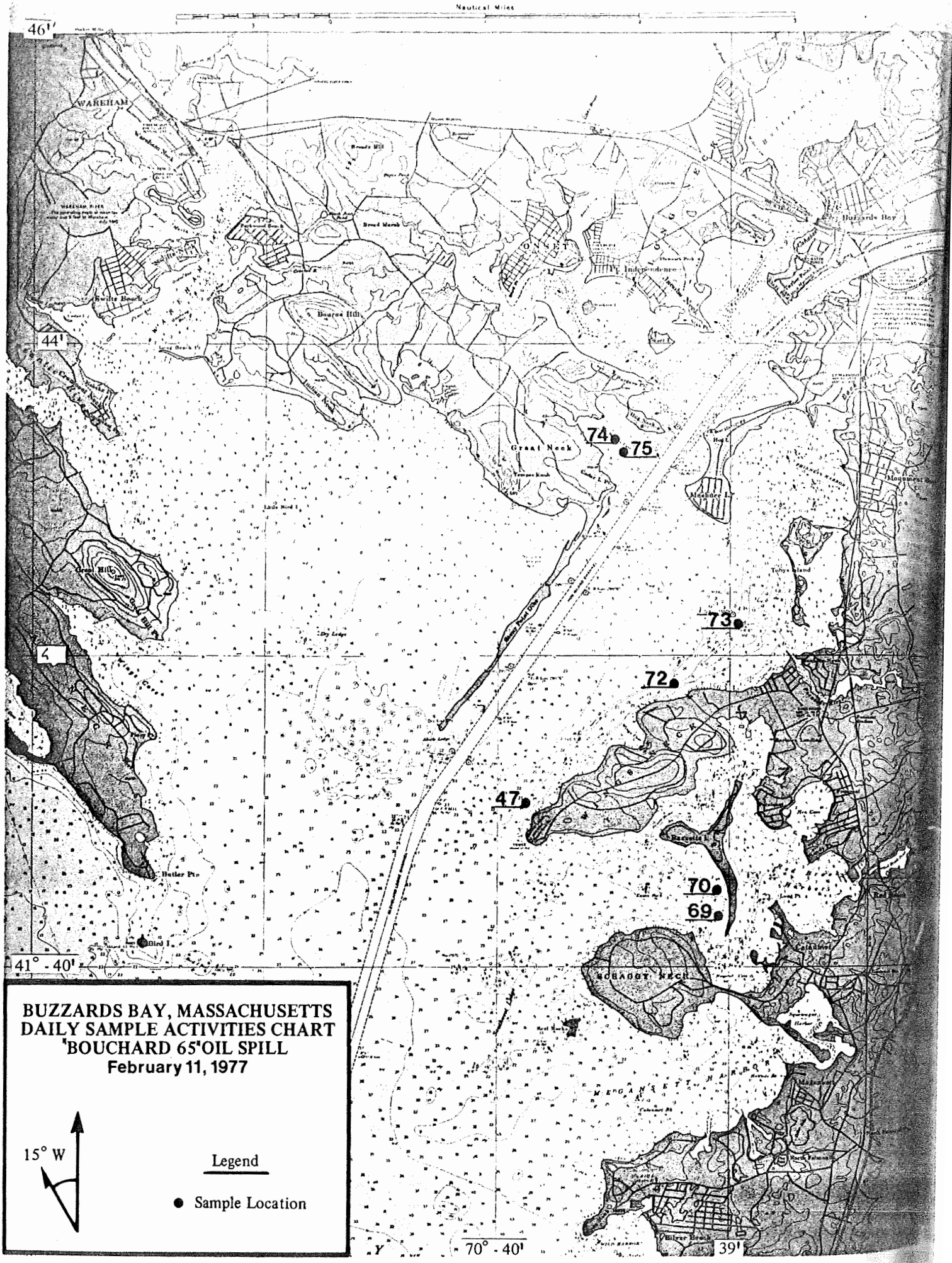
WARDS BAY, MASSACHUSETTS
Y SAMPLE ACTIVITIES CHART
CHARD 65' OIL SPILL
February 8, 1977


CAPE COD CANAL, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 8, 1977
Legend
Sample Location
15° W
CAPE COD BAY
CAPE COD CANAL LIGHTS
Mercury vapor lights, yellow on the north bank and white on the south bank, are located 140 feet from the edge of the channel. The lights in general are 500 feet apart on both banks
FIXED BRIDGE
HOR. CL. 500 FT.
VERT. CL. 135 FT.
marsh
Scusset River
wreck
CANAL BREAKWATER
HORN
CANAL LAND CUT
dolphins
MOORING BASIN
(see tabulation)
TRAFFIC LIGHT
(see note)
R Bn
CG
CUPOLA
HARBOR OF REFUGE
Town Neck Hill
Sandwich
Sagamore
PC RR
Unloading dock
CC 4sec
42ft
F 56ft
STACK
(305 FT)
Sandwich Control Tower PA
CAPE COD CANAL EASTERN ENTRANCE RANGE
STANDPIPE
STANDPIPE
marsh
35
Nautical Miles
0
32'
31'
70° 30'
29'
47'
11'
16'

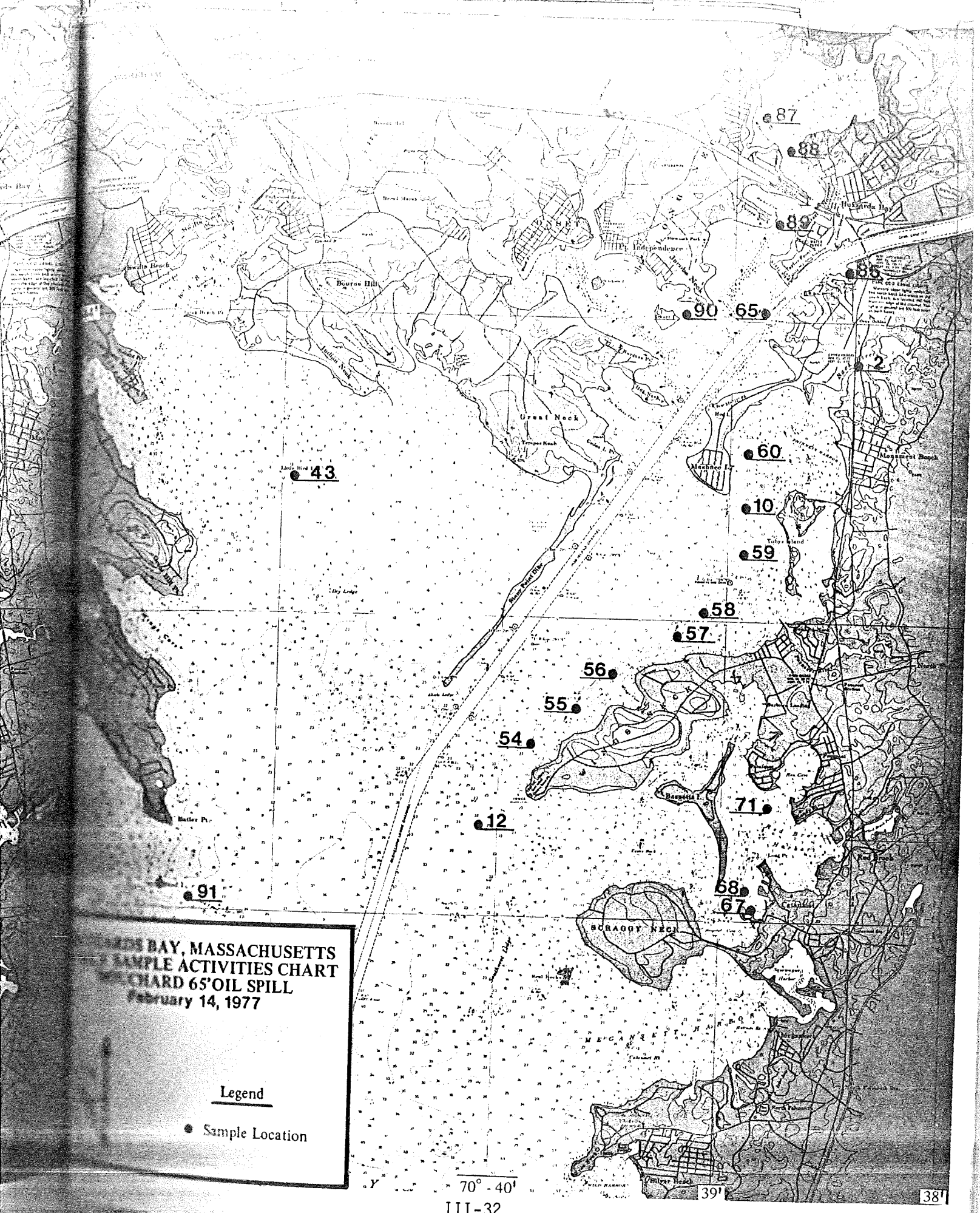

Nautical Miles
WAREHAM
Buzzards Bay
Bourne Hill
Great Neck
Monument Beach
Tobys Island
Sagamore Point Dike
Bassetts I.
Red Beach
BORAGGY NECK
MEGANSETT HARBOR
Pulitzer Beach
60
10
59
58
57
56
52
53
12
70° - 40'
39'
38'
MASSACHUSETTS
ACTIVITIES CHART
65' OIL SPILL
1977
Legend
Sample Location


CAPE COD CANAL, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 9, 1977
15° W
Legend
Sample Location
CAPE COD CANAL LIGHTS
Mercury vapor lights, yellow on the north bank and white on the south bank, are located 140 feet from the edge of the channel. The lights in general are 500 feet apart on both banks.
CAPE COD BAY
45
33
31
30
46
CANAL BREAKWATER
HORN
FIXED BRIDGE
HOR. CL. 500 FT.
VERT. CL. 135 FT.
MOORING BASIN
dolphins
CANAL LAND CUT
(see tabulation)
TRAFFIC LIGHT
(see note)
R Bn
C G
CUPOLA
HARBOR OF REFUGE
Town Neck Hill
Sagamore
Sandwich
marsh
PC RR
Unloading dock
Occ 4sec
42ft
F 56ft
STACK
(305FT)
Sandwich Control Tower PA
CAPE COD CANAL EASTERN ENTRANCE RANGE
STANDPIPE
Nautical Miles
32'
31'
70° 30'
29'
47'
11'
16'


Nautical Miles
46'
44'
70° 30'
WAREHAM
Swifts Beach
Bourne Hill
Indian Neck
Great Neck
Tempest Knob
Little Bird I.
Heavy Boat Dike
Dry Ledge
Buzzards Bay
Independence
Monument Beach
Hoskins I.
Tobys Island
48
49
76
Bassetts I.
Red Brook
Cataumet
SCRAGGY NECK
MEGANSETT HARBOR
Megansett
North Falmouth
Quissett Beach
70° - 40'
39'
38'
MASSACHUSETTS
ACTIVITIES CHART
65' OIL SPILL
February 10, 1977
Legend
Sample Location



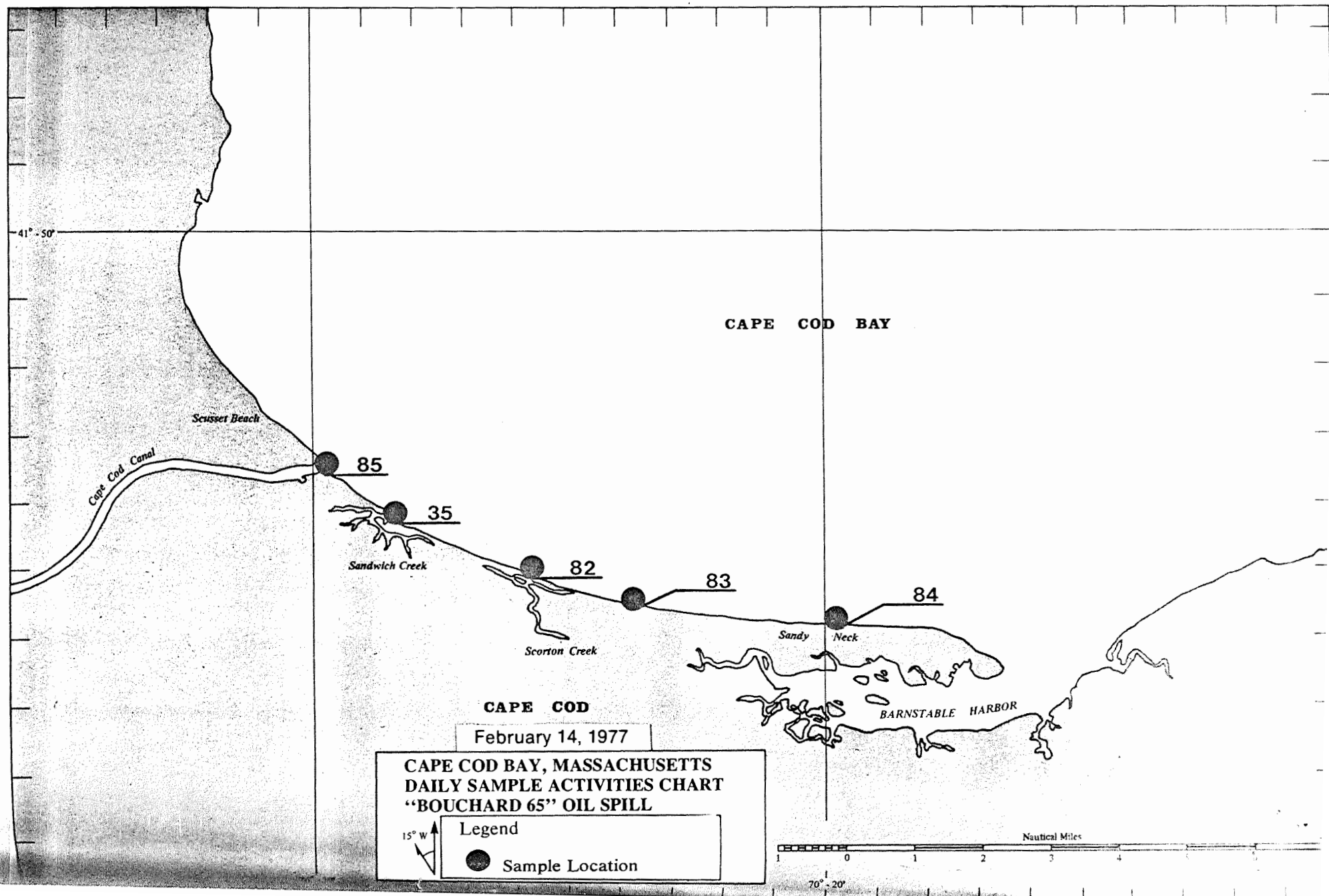
BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 11, 1977



BAY, MASSACHUSETTS
SAMPLE ACTIVITIES CHART
CHARD 65'OIL SPILL
February 14, 1977

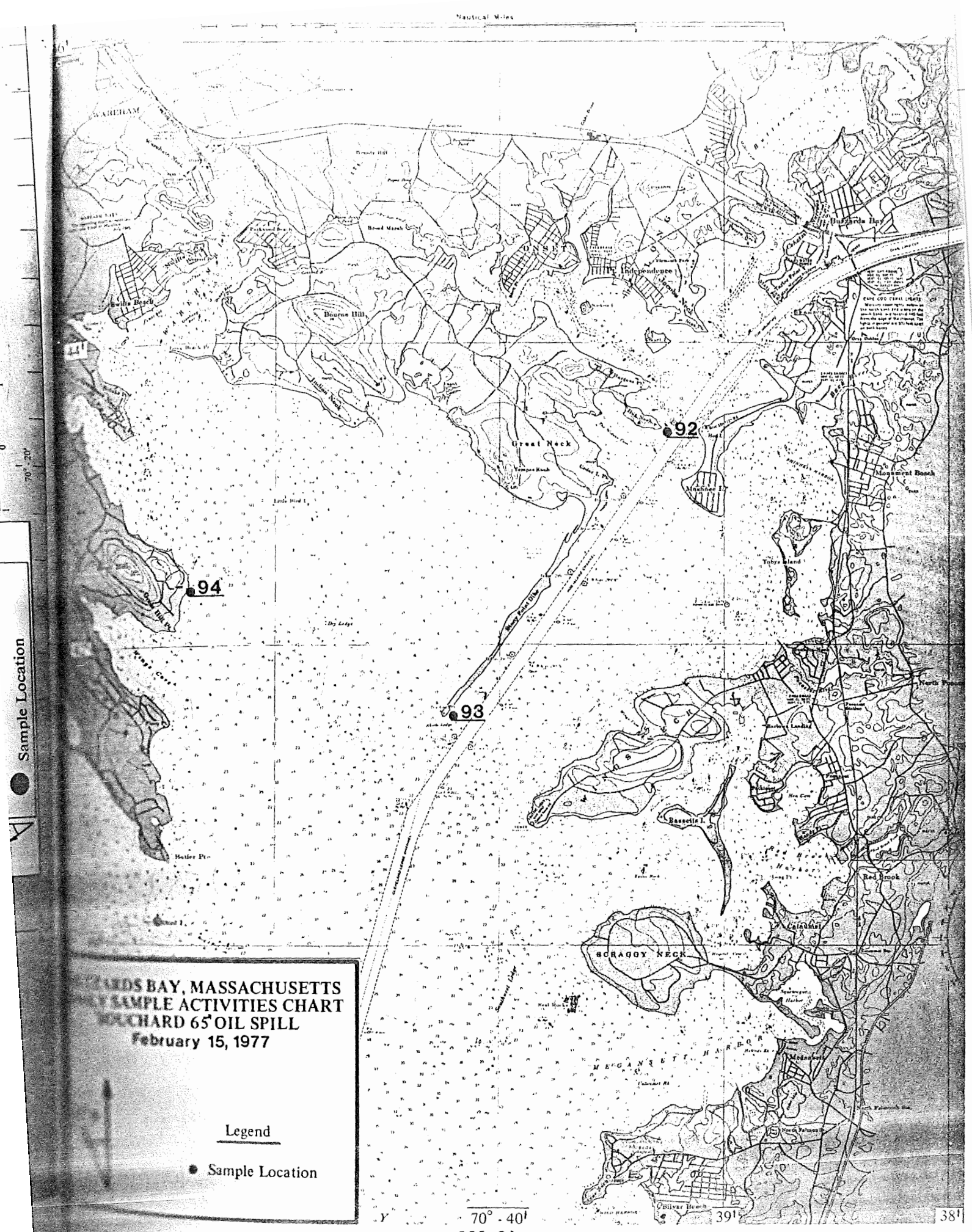
Legend

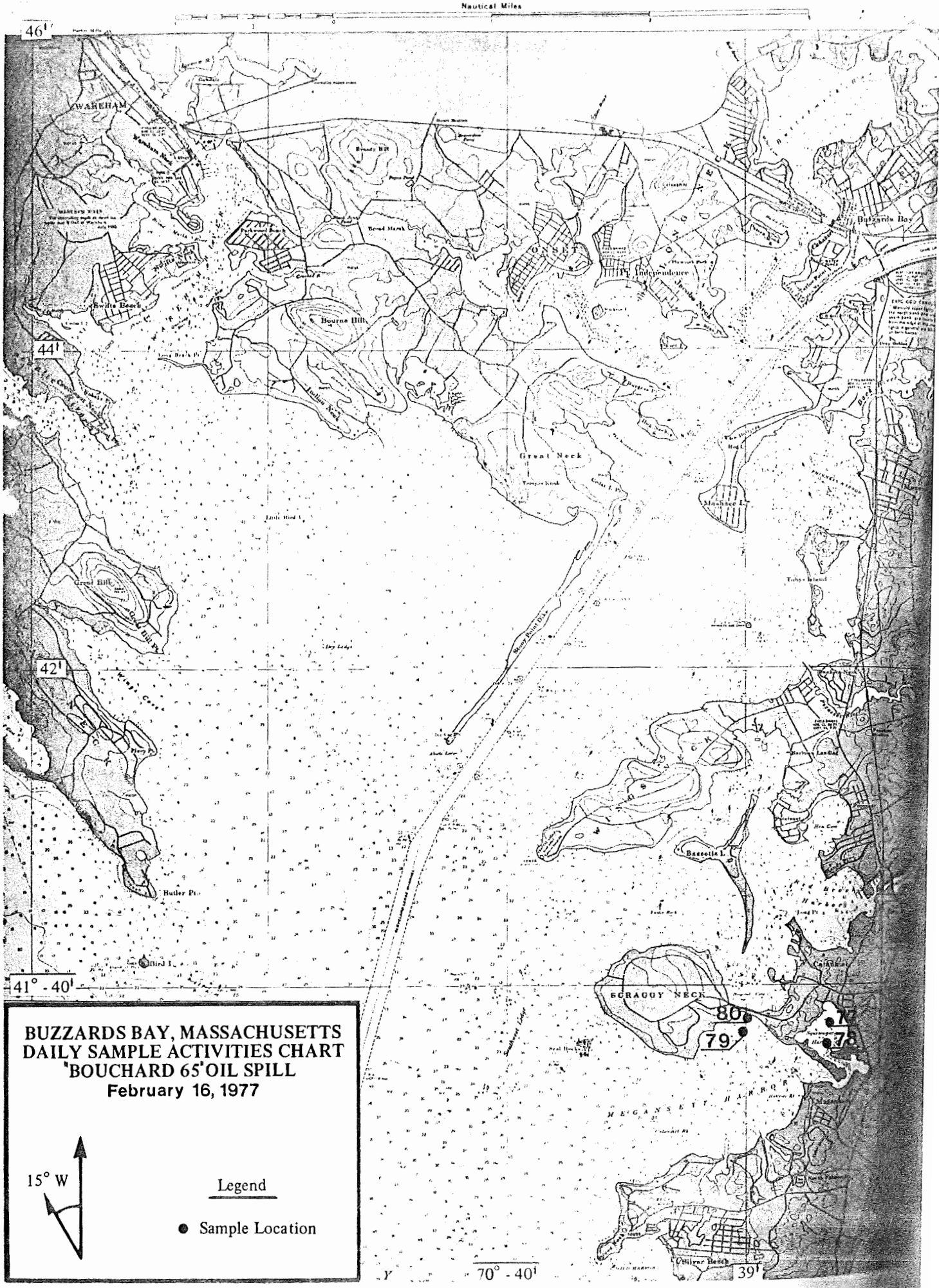
● Sample Location

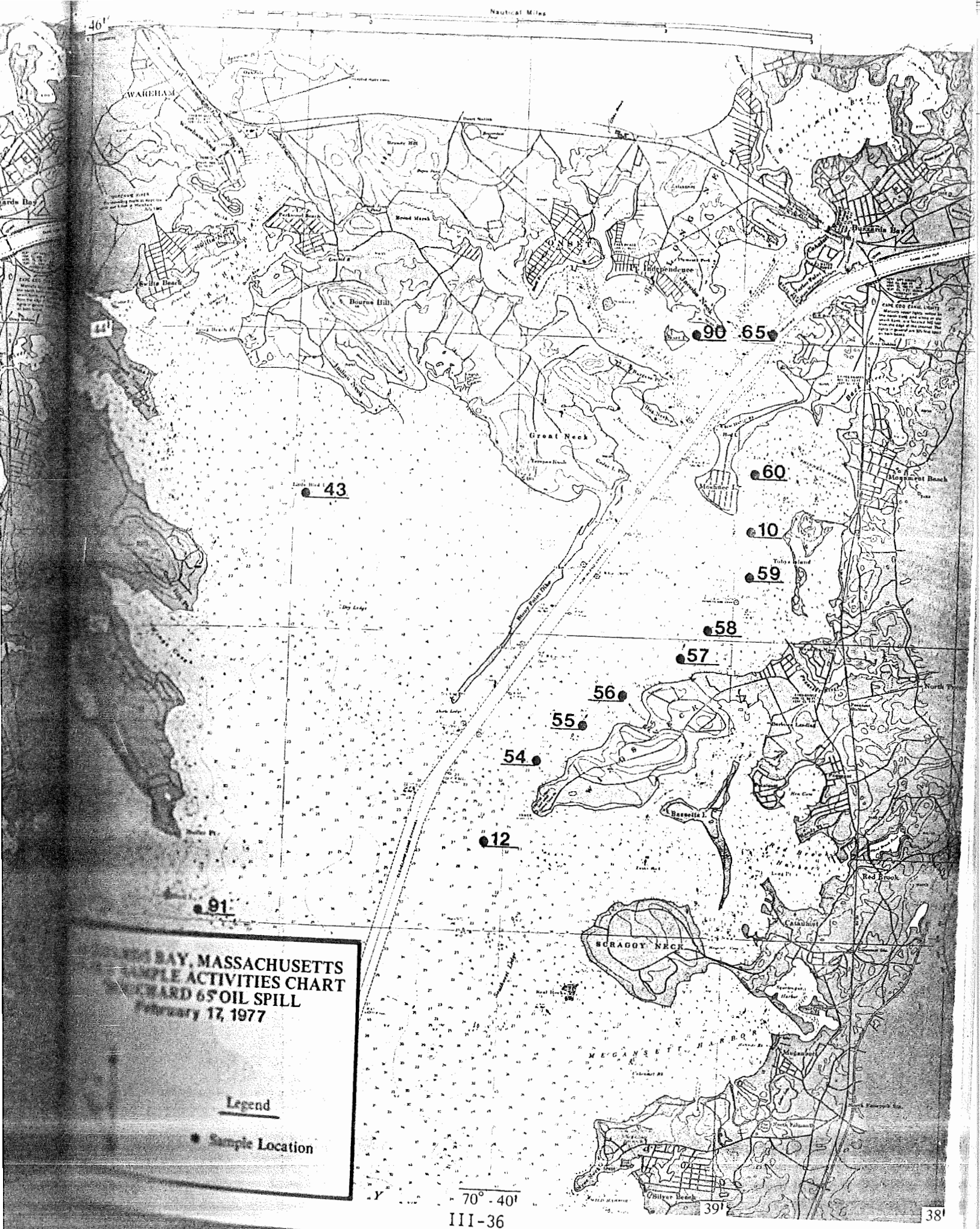


February 14, 1977

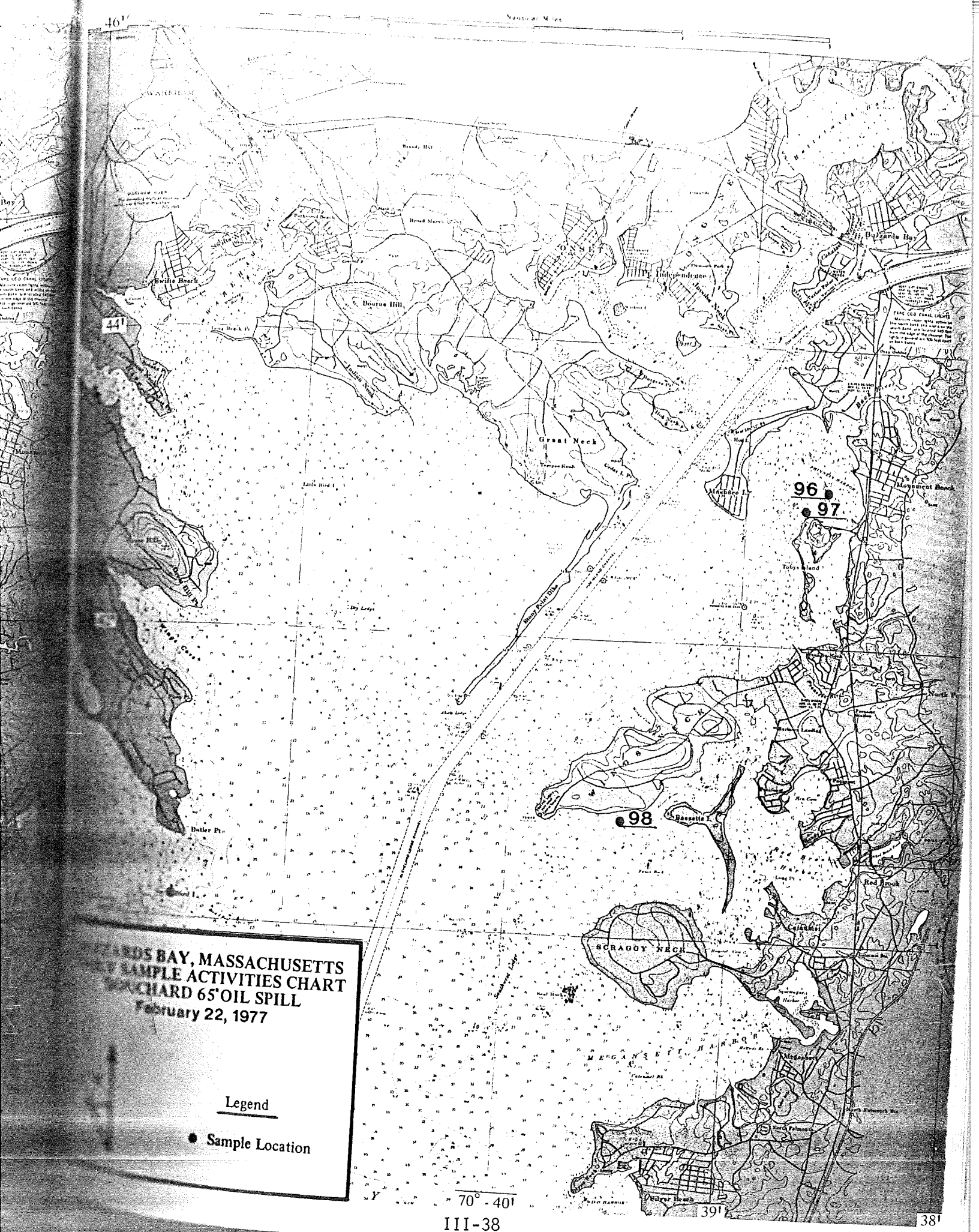
CAPE COD BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL

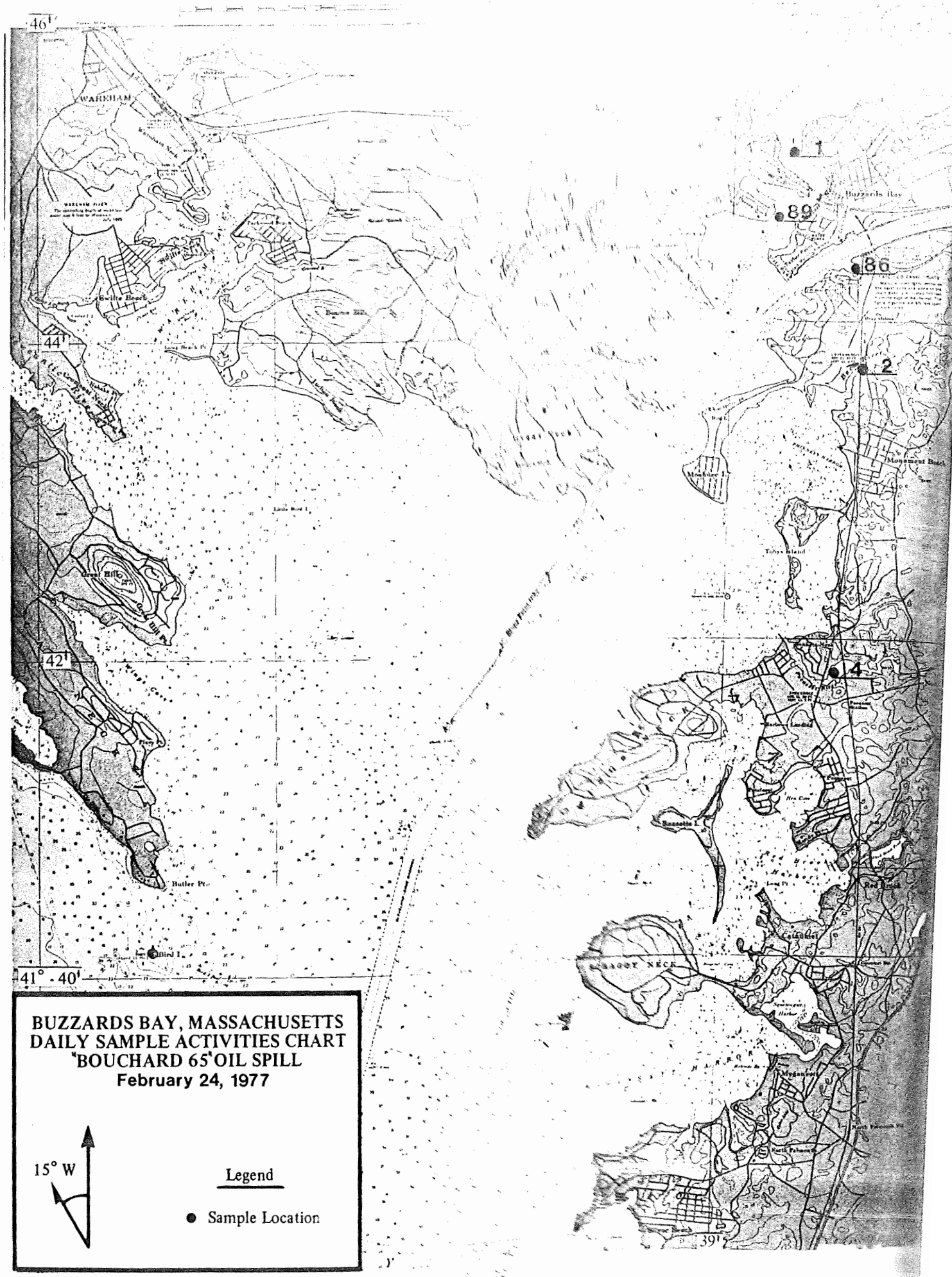

Nautical Miles
WAREHAM
ONSET
Independence
Buzzards Bay
Bourne Hill
Great Neck
Monument Beach
Tobys Island
Bassetts I.
Red Brook
SCRAGGY NECK
MEGANSETT HARBOR
Sample Location
92
93
94
BUZZARDS BAY, MASSACHUSETTS
SAMPLE ACTIVITIES CHART
BUCHARD 65' OIL SPILL
February 15, 1977
Legend
Sample Location
70° - 40'
39'
38'


Nautical Miles
46'
44'
42'
41° - 40'
70° - 40'
39'
WAREHAM
Bourne Hill
Great Neck
Buzzards Bay
Butler Pt.
SCRAGGY NECK
80
79
77
78
BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 16, 1977
15° W
Legend
Sample Location


Nautical Miles
46'
WAREHAM
Buzzards Bay
Bourne Hill
Independence
Great Neck
Mosquitoe I.
Mosquitoe Beach
Tobys Island
Bassetts I.
Red Brook
SCRAGGY NECK
MEGANSETT HARBOR
Silver Beach
90
65
60
43
10
59
58
57
56
55
54
12
91
70° - 40'
39'
38'
BAY, MASSACHUSETTS
SAMPLE ACTIVITIES CHART
WARD 65 OIL SPILL
February 17, 1977
Legend
Sample Location


BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 18, 1977
15° W
Legend
Sample Location
46'
44'
42'
41° - 40'
70° - 40'
39'
36
26
27
95
48
WAREHAM
Great Neck
Bourne Hill
Great Hill
Butler Pt
Bird I.
Basketts I.
SCRAGGY NECK
NEGANSETT HARBOR
Silver Beach


BUZZARDS BAY, MASSACHUSETTS
SAMPLE ACTIVITIES CHART
CHARD 65' OIL SPILL
February 22, 1977
Legend
Sample Location
96
97
98
Great Neck
Tobys Island
Monument Beach
Buzzards Bay
Bourne Hill
Indian Neck
Butler Pt.
SCRAGGY NECK
MERGANSETT HARBOR
Red Brook
Falmouth
Wings Point Dike
Independence
Pocasset
Cedar Beach
70° - 40'
39'
38'
44'
46'

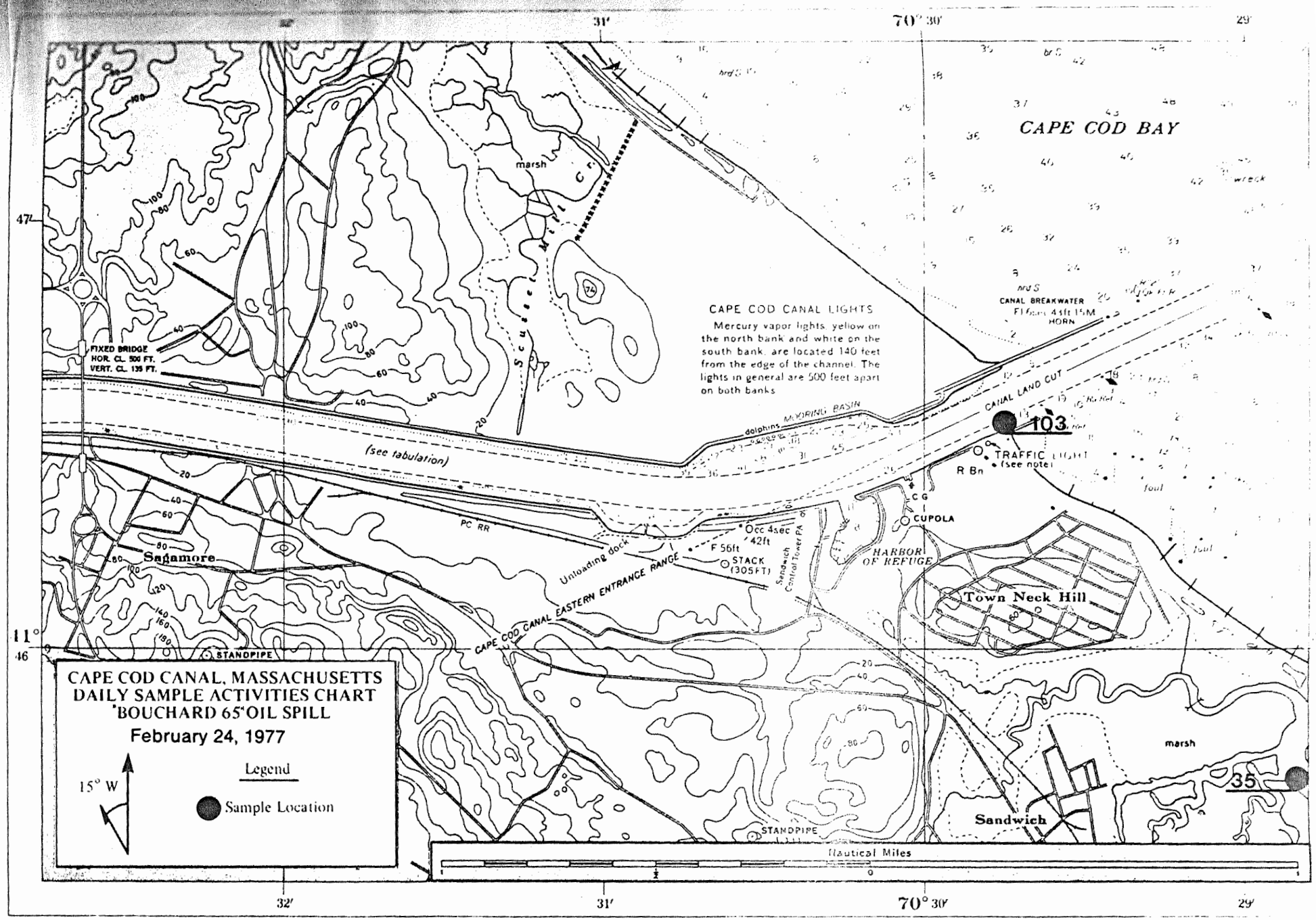


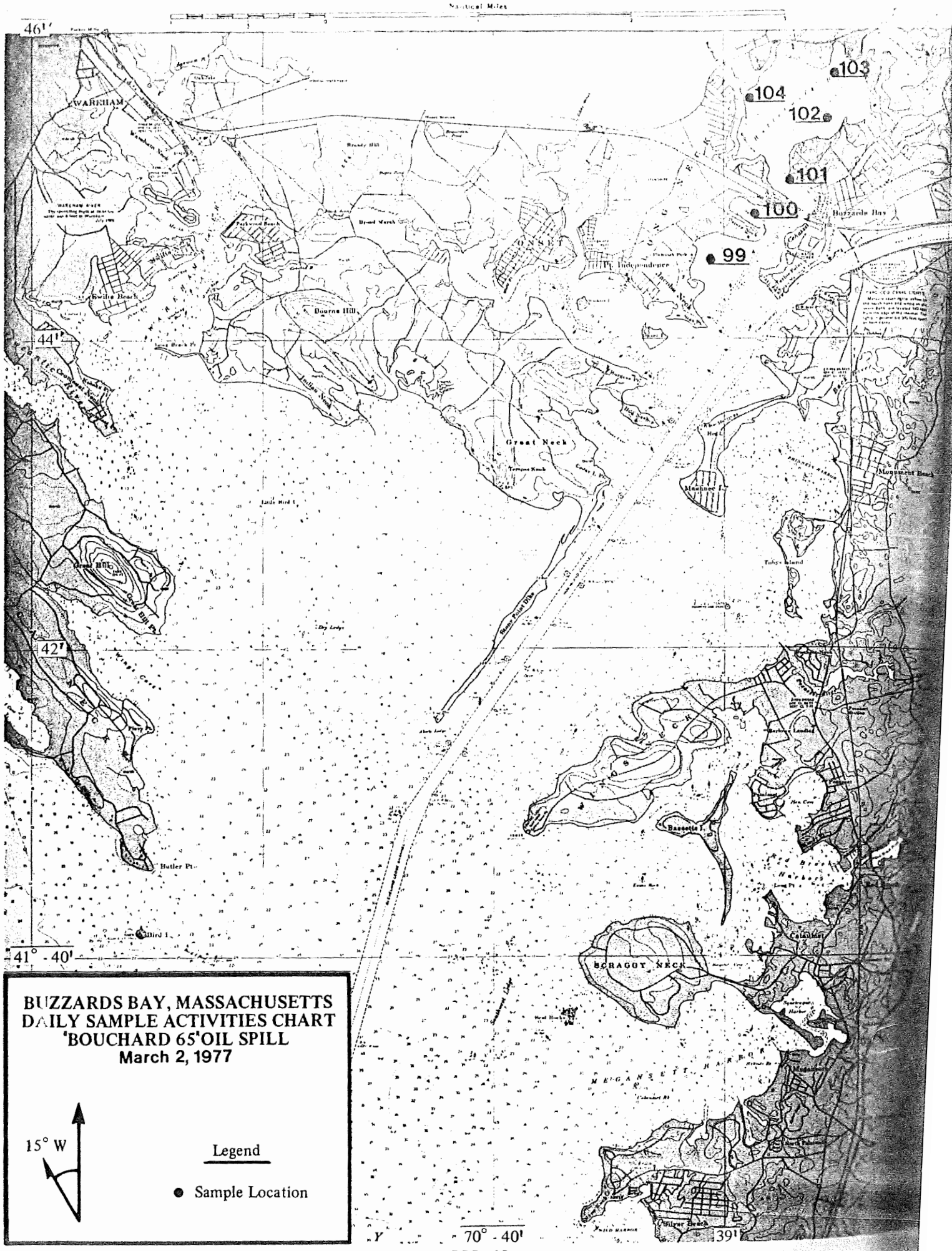
BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 24, 1977

15° W

Legend

● Sample Location


CAPE COD BAY
CAPE COD CANAL LIGHTS
Mercury vapor lights, yellow on the north bank and white on the south bank, are located 140 feet from the edge of the channel. The lights in general are 500 feet apart on both banks
FIXED BRIDGE
HOR. CL. 500 FT.
VERT. CL. 135 FT.
CANAL BREAKWATER
HORN
CANAL LAND CUT
MOORING BASIN
dolphins
(see tabulation)
PC RR
Unloading dock
CAPE COD CANAL EASTERN ENTRANCE RANGE
Occ 4sec
42ft
F 56ft
STACK
(305FT)
Sandwich Control Tower PA
HARBOR OF REFUGE
CUPOLA
TRAFFIC LIGHT
(see note)
R Bn
Town Neck Hill
Sagamore
Sandwich
STANDPIPE
marsh
Nautical Miles
103
35
CAPE COD CANAL, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
"BOUCHARD 65" OIL SPILL
February 24, 1977
15° W
Legend
Sample Location


BUZZARDS BAY, MASSACHUSETTS
DAILY SAMPLE ACTIVITIES CHART
'BOUCHARD 65' OIL SPILL
March 2, 1977
15° W
Legend
Sample Location
103
104
102
101
100
99
WAREHAM
ONSET
Pt. Independence
Buzzards Bay
Great Neck
Monument Beach
Tobys Island
Great Hill
Butler Pt.
Bassetts I.
SCRAGGY NECK
Silver Beach
46'
44'
42'
41° - 40'
70° - 40'
39'

APPENDIX IV

HYDROLOGY

Table IV.1(a). Current measurements taken in Phinneys Harbor (master station 10), February 2,3,4, 1977.

Station 10 February 2, 1977
Location: Phinney's Harbor Entrance

Time of Measurement	Depth in ft. (m)	Velocity in Kn (km/hr.)	Direction in Degrees from Magnetic North
1000	1 (0.3)	.15 (.28)	195
	12 (3.6)	.15 (.28)	165
	27 (8.2)	.15 (.28)	173
1100	1 (0.3)	.15 (.28)	200
	12 (3.6)	.15 (.28)	180
	27 (8.2)	.15 (.28)	193
1300	1 (0.3)	.15 (.28)	240
	12 (3.6)	.10 (.19)	202
	27 (8.2)	.15 (.28)	148
1500	1 (0.3)	.15 (.28)	265
	12 (3.6)	.15 (.28)	307
	27 (8.2)	.15 (.28)	355
1600	1 (0.3)	.20 (.37)	325
	12 (3.6)	.27 (.50)	355
	27 (8.2)	.20 (.37)	350
1700	1 (0.3)	.30 (.55)	350
	12 (3.6)	.35 (.65)	345
	27 (8.2)	.10 (.19)	270

Table IV.1(b)

Station 10
Location: Phinney's Harbor Entrance

February 3, 1977

Time of Measurement	Depth in ft. (m)	Velocity in Kn (km/hr.)	Direction in Degrees from Magnetic North
1000	1 (0.3)	.20 (.37)	215
	12 (3.6)	.17 (.31)	190
	27 (8.2)	.25 (.46)	197
1100	1 (0.3)	.15 (.28)	172
	12 (3.6)	.20 (.37)	147
	27 (8.2)	.20 (.37)	200
1200	1 (0.3)	.10 (.19)	137
	12 (3.6)	.10 (.19)	130
	27 (8.2)	.15 (.28)	195
1400	1 (0.3)	.15 (.28)	30
	12 (3.6)	.15 (.28)	290
	27 (8.2)	.15 (.28)	127
1500	1 (0.3)	.10 (.19)	35
	12 (3.6)	.10 (.19)	15
	27 (8.2)	.10 (.19)	122
1600	1 (0.3)	.15 (.28)	315
	12 (3.6)	.20 (.37)	355
	27 (8.2)	.20 (.37)	15
1700	1 (0.3)	.30 (.55)	355
	12 (3.6)	.35 (.65)	5
	27 (8.2)	.20 (.37)	357

Table IV.1(c)

Station 10
Location: Phinney's Harbor Entrance

February 4, 1977

Time of Measurement	Depth in ft. (m)	Velocity in Kn (km/hr.)	Direction in Degrees from Magnetic North
1100	4 (1.2)	.17 (.31)	195
	12 (3.6)	.17 (.31)	165
	23 (7.0)	.22 (.41)	200
1200	1 (0.3)	.15 (.28)	194
	12 (3.6)	.17 (.31)	155
	24 (7.3)	.15 (.28)	197
1300	1 (0.3)	.15 (.28)	213
	12 (3.6)	.15 (.28)	191
	22 (6.7)	.17 (.31)	190
1400	1 (0.3)		235
	12 (3.6)		160
	24 (7.3)		127
1500	1 (0.3)	.07 (.13)	250
	12 (3.6)	.07 (.13)	155
	22 (6.7)	.07 (.13)	158

Table IV.2. Tide tables for Northern Buzzards Bay and Cape Cod Canal entrance
January 28 - March 2

JANUARY 1977		HIGH & LOW WATER							
		BUZZARDS BAY				B.BAY R.R.BRIDGE (CAPE COD CANAL ENTRANCE)			
		HIGH		LOW		HIGH		LOW	
		A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
Friday	28	2:23	2:46	7:54	7:58	3:58	4:03	11:08	11:23
Saturday	29	3:19	3:42	9:08	9:01	5:02	5:07	11:56	--
Sunday	30	4:13	4:35	10:20	10:05	5:57	6:02	0:05	12:42
Monday	31	5:02	5:25	11:11	11:00	6:42	6:47	0:45	1:24
FEBRUARY									
Tuesday	1	5:49	6:11	11:54	11:49	7:19	7:24	1:22	2:03
Wednesday	2	6:34	6:54	--	12:31	7:54	8:01	1:54	2:42
Thursday	3	7:15	7:36	0:33	1:08	8:25	8:35	2:26	3:22
Friday	4	7:57	8:19	1:15	1:45	8:57	9:12	3:01	4:01
Saturday	5	8:39	9:01	1:59	2:26	9:33	9:51	3:42	4:39
Sunday	6	9:22	9:46	2:41	3:04	10:14	10:33	4:33	5:22
Monday	7	10:07	10:34	3:26	3:46	10:56	11:22	5:43	6:07
Tuesday	8	10:57	11:24	4:14	4:32	11:43	--	6:52	7:12
Wednesday	9	11:48	--	5:04	5:22	0:12	12:33	7:59	8:16
Thursday	10	0:20	12:49	6:02	6:18	1:05	1:27	9:02	9:20
Friday	11	1:23	1:52	7:08	7:22	2:05	2:28	10:03	10:24
Saturday	12	2:28	2:57	8:28	8:39	3:12	3:34	11:04	11:23
Sunday	13	3:31	4:00	9:52	9:59	4:24	4:46	--	12:03
Monday	14	4:32	4:59	11:05	11:09	5:33	5:55	0:21	12:58
Tuesday	15	5:28	5:52	11:59	--	6:35	6:55	1:17	1:52
Wednesday	16	6:19	6:42	0:06	12:46	7:29	7:46	2:11	2:44
Thursday	17	7:07	7:29	0:57	1:28	8:18	8:36	3:04	3:34
Friday	18	7:53	8:13	1:41	2:04	9:03	9:23	3:53	4:24
Saturday	19	8:35	8:56	2:21	2:37	9:47	10:06	4:42	5:10
Sunday	20	9:17	9:38	2:55	3:09	10:29	10:52	5:30	5:56
Monday	21	9:59	10:21	3:30	3:40	11:11	11:35	6:20	6:44
Tuesday	22	10:42	11:05	4:40	4:12	11:52	--	7:07	7:30

Table IV.2. Tide tables for Northern Buzzards Bay and Cape Cod Canal entrance January 28 - March 2 (continued)

FEBRUARY 1977		HIGH AND LOW WATER							
		BUZZARDS BAY				R.BAY R.R.BRIDGE (CAPE COD CANAL ENTRANCE)			
		HIGH		LOW		HIGH		LOW	
		A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
Wednesday	23	11:26	11:53	4:38	4:46	0:22	12:34	7:58	8:19
Thursday	24	--	12:14	5:15	5:23	1:08	1:20	8:48	9:07
Friday	25	0:43	1:07	6:00	6:10	2:00	2:07	9:39	9:58
Saturday	26	1:39	2:05	6:52	7:05	3:00	3:03	10:28	10:46
Sunday	27	2:38	3:05	7:57	8:10	4:09	4:09	11:17	11:29
Monday	28	3:34	4:00	9:10	9:20	5:09	5:12	--	12:02
MARCH									
Tuesday	1	4:29	4:53	10:16	10:26	6:00	6:03	0:11	12:45
Wednesday	2	5:18	5:41	11:11	11:21	6:37	6:45	0:50	1:24

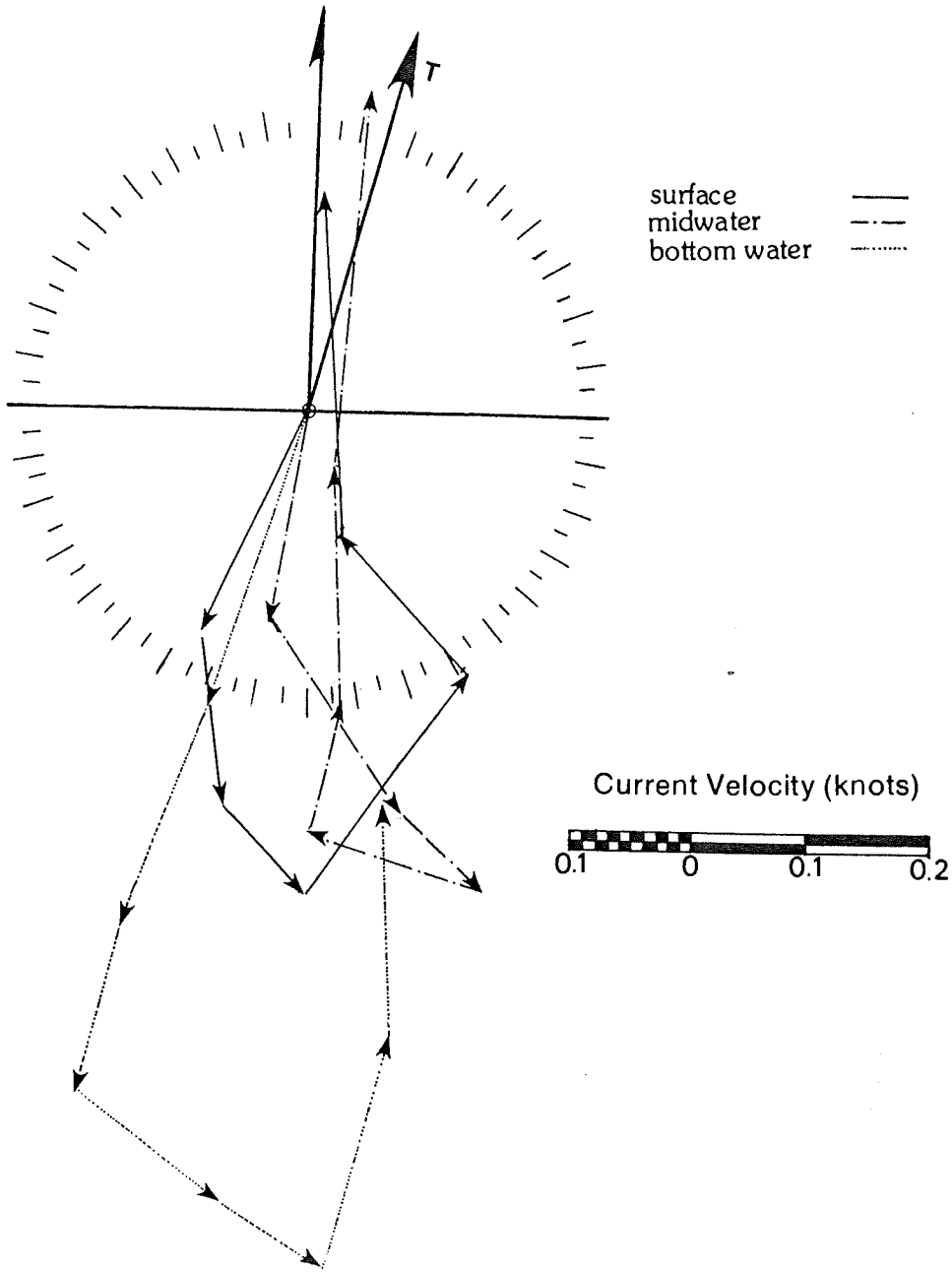


Figure . Progressive vector diagram of current velocity at surface, mid and bottom water for ENDECO station 3, Phinneys Harbor, 2 February, 1977, 1000-1700 hrs. (measurements hourly)

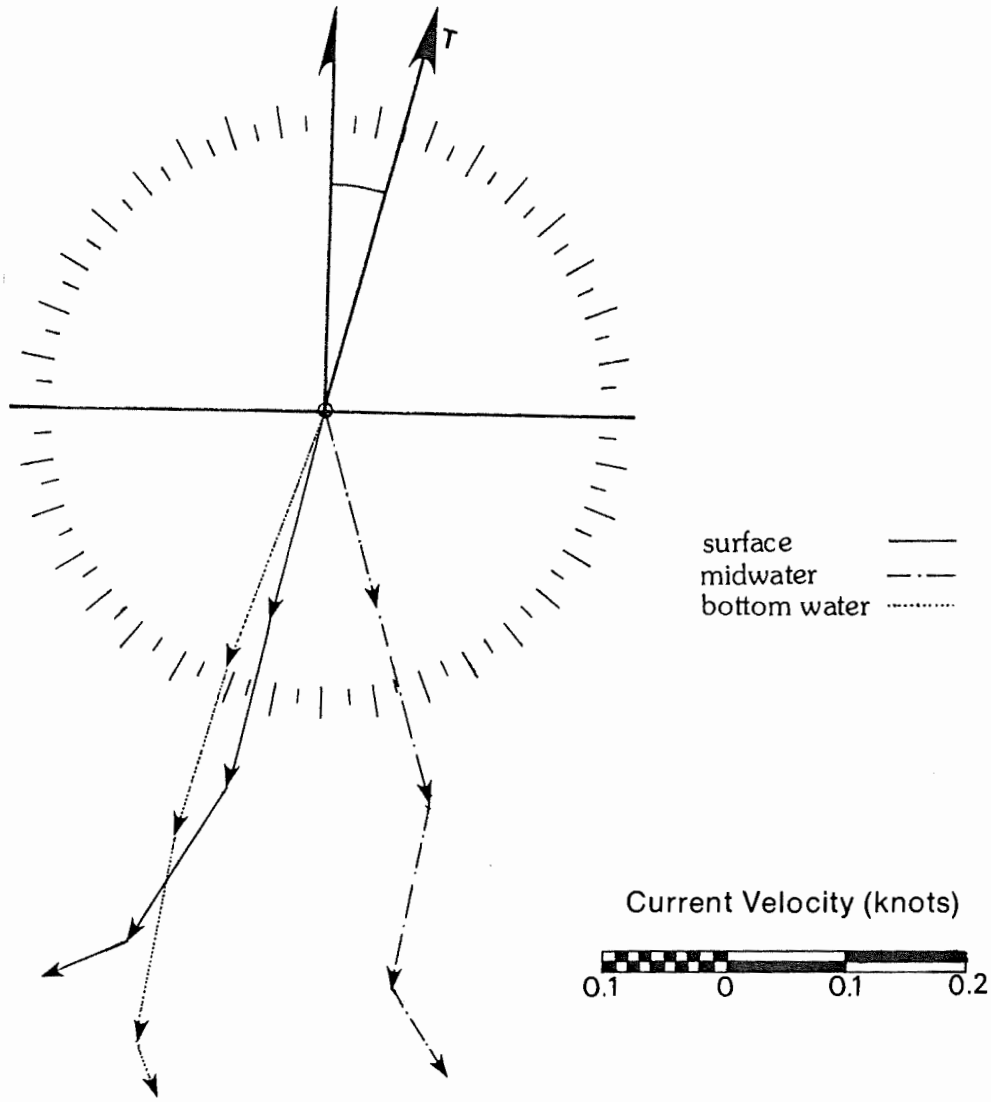


Figure . Progressive vector diagram of current velocity at surface, mid and bottom water for ENDECO station 3, Phinneys Harbor, 4 February, 1977, 1100-1500 hrs. (measurements hourly)

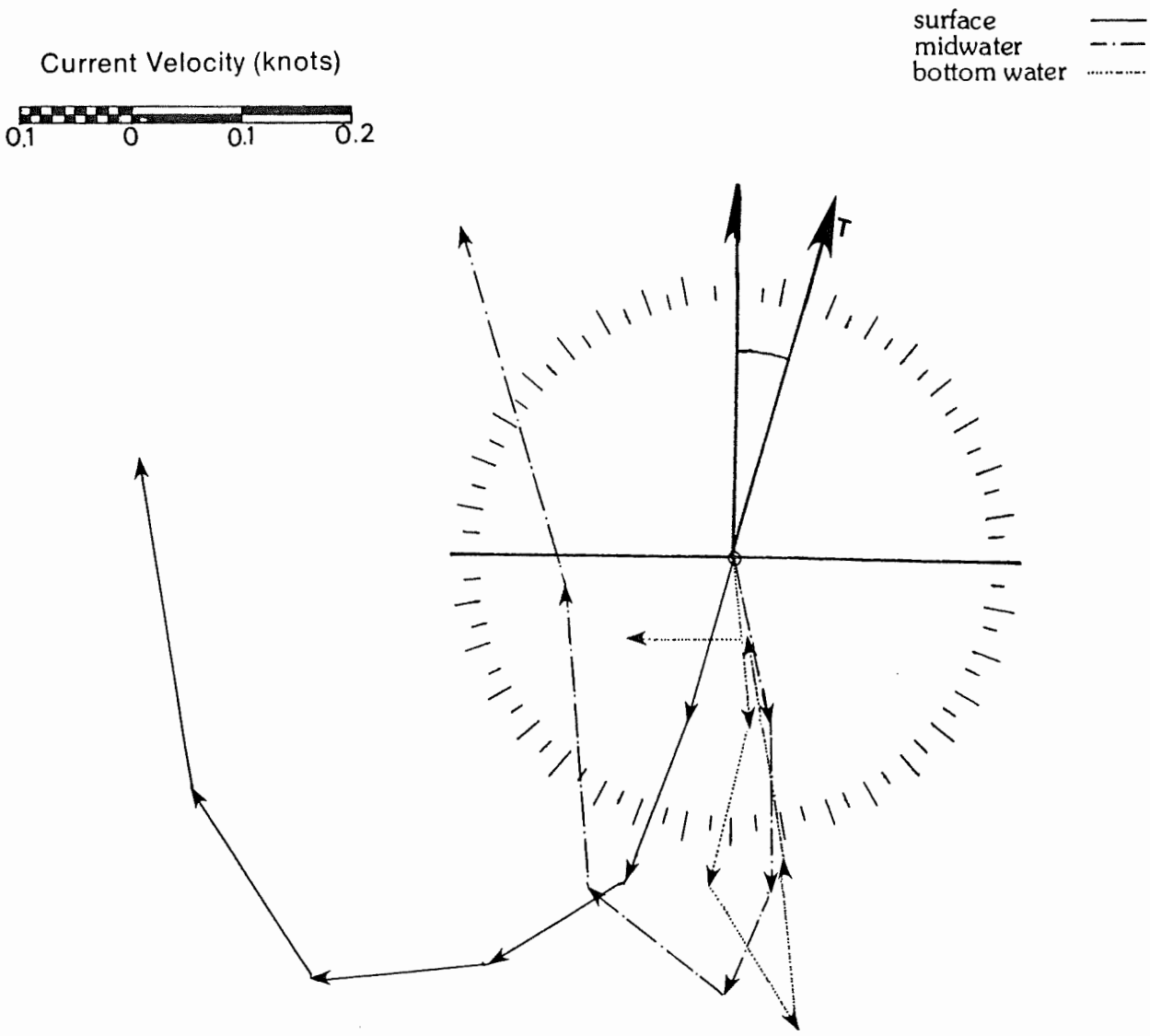


Figure . Progressive vector diagram of current velocity at surface, mid and bottom water for ENDECO station 3, Phinneys Harbor, 3 February, 1977, 1000-1700 hrs. (measurements hourly)

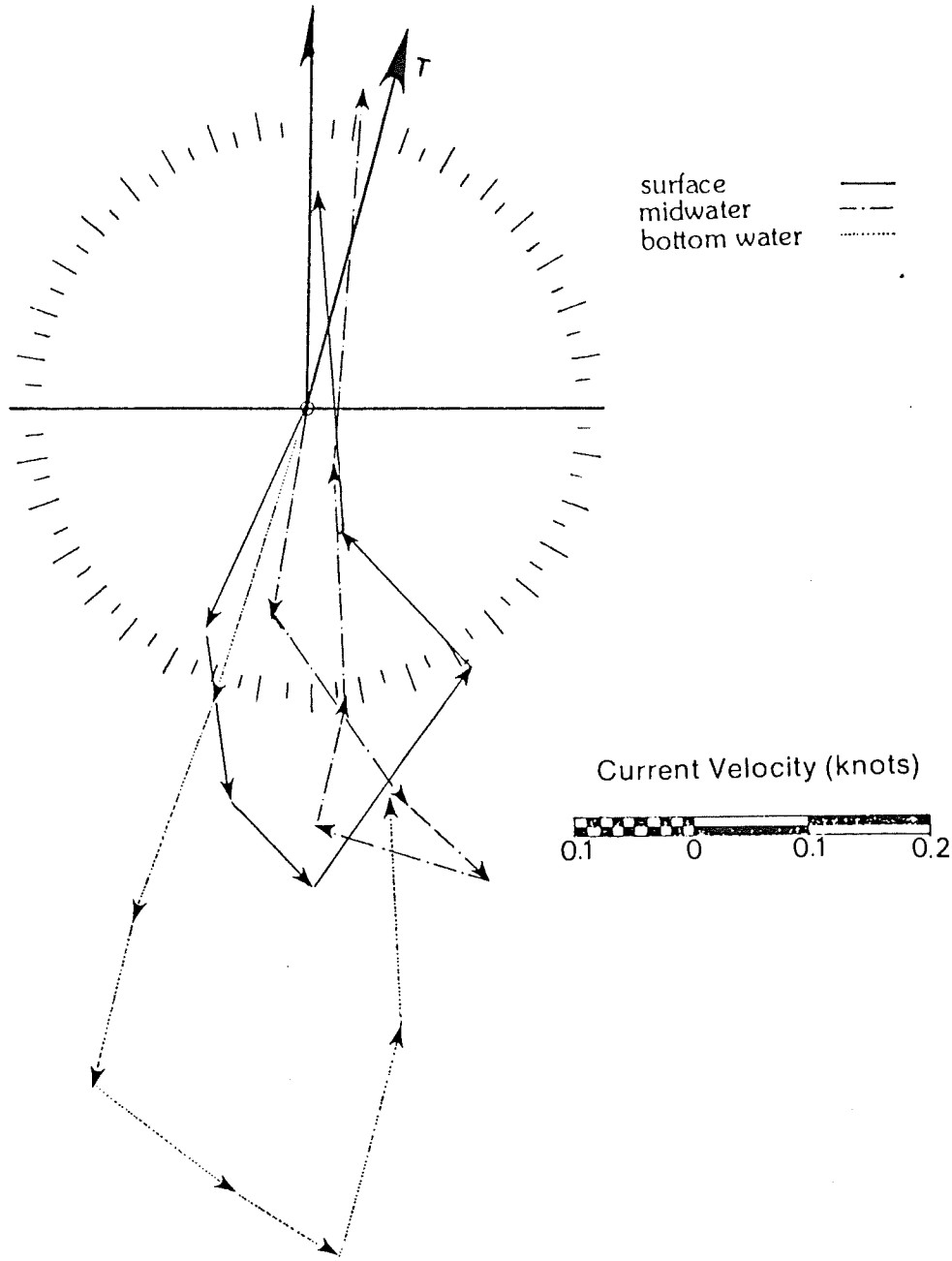


Figure 1. Progressive vector diagram of current velocity at surface, mid and bottom water for ENDECO station 3, Phinneys Harbor, 2 February, 1977, 1000-1700 hrs. (measurements hourly)

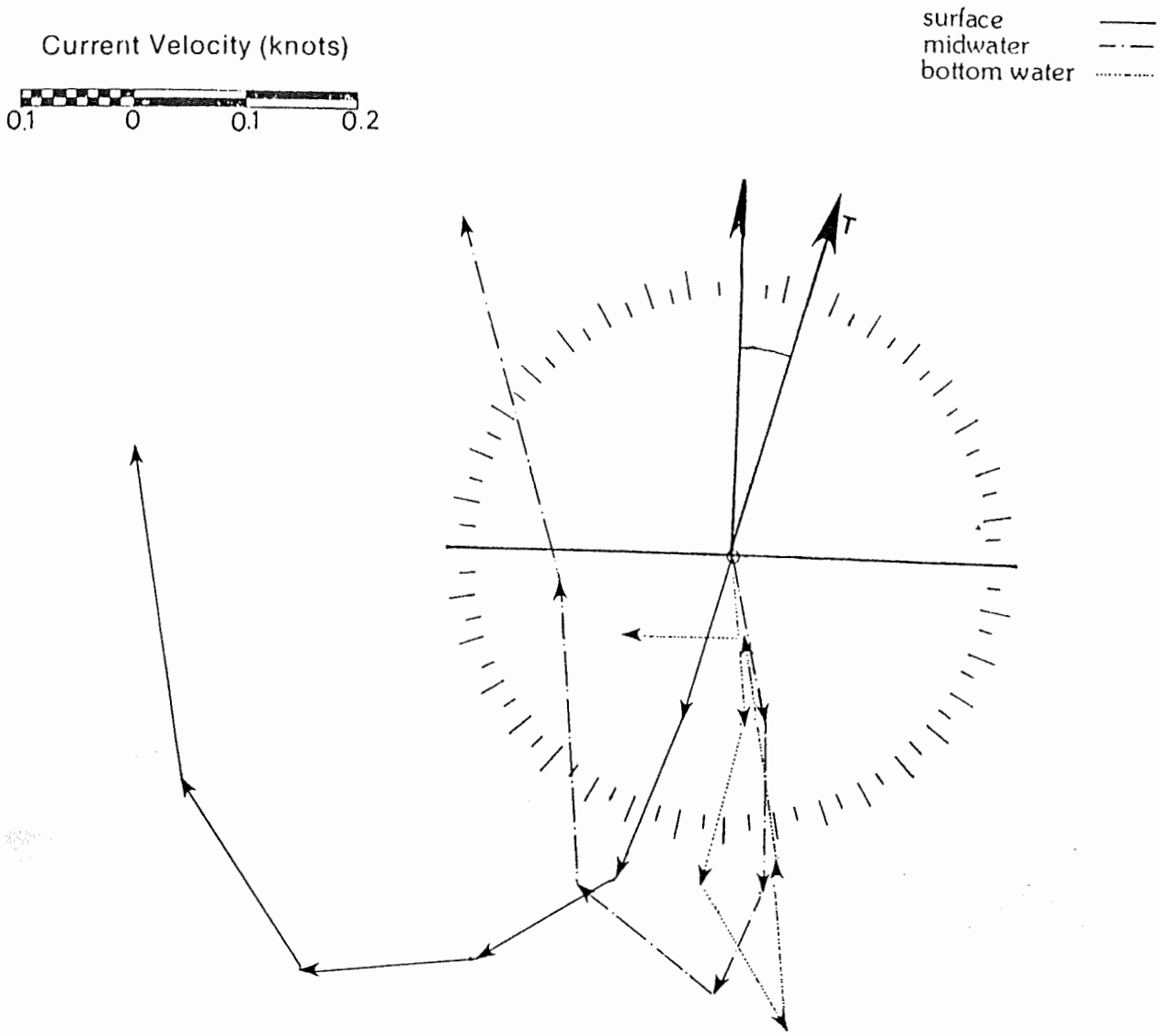


Figure 2. Progressive vector diagram of current velocity at surface, mid and bottom water for ENDECO station 3, Phinneys Harbor, 3 February, 1977, 1000-1700 hrs. (measurements hourly)

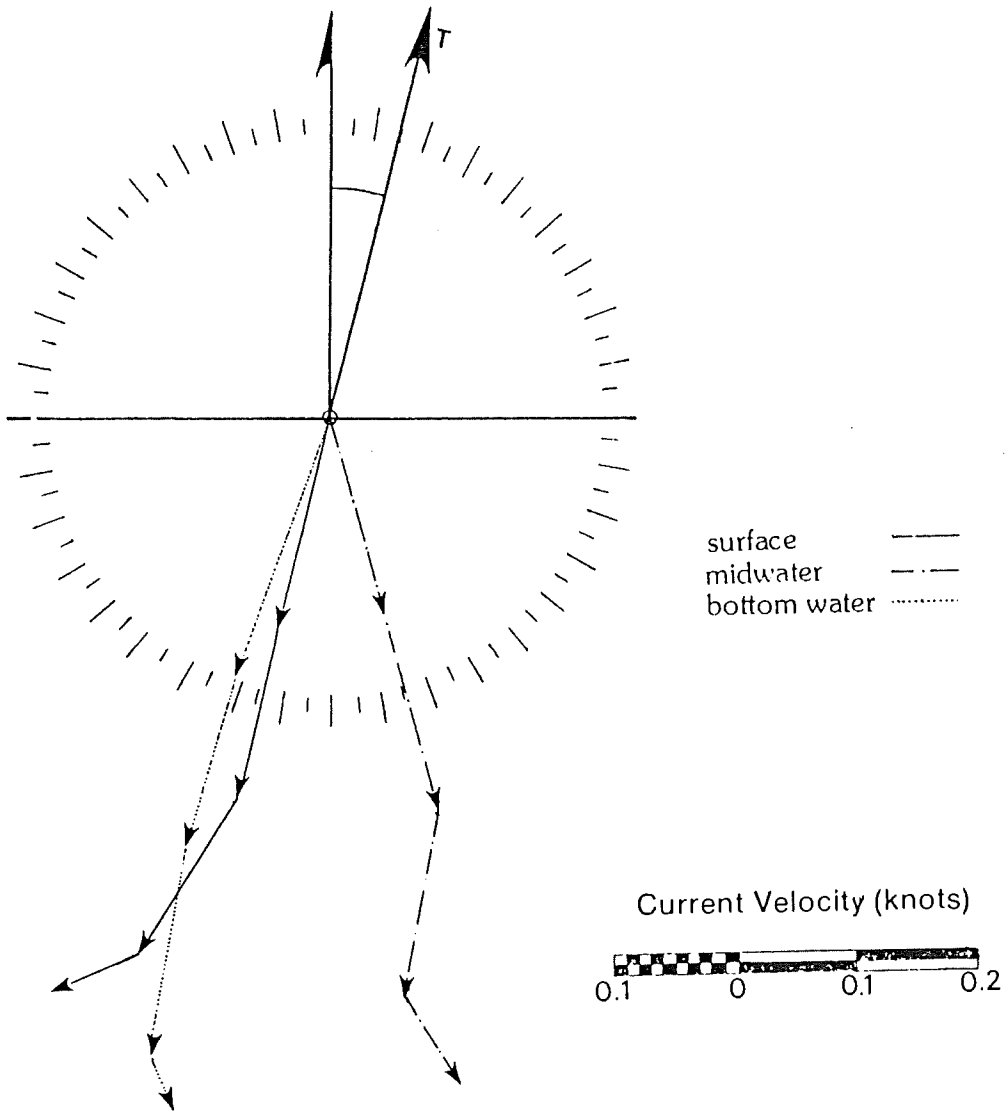


Figure 3. Progressive vector diagram of current velocity at surface, mid and bottom water for ENDECO station 3, Phinneys Harbor, 4 February, 1977, 1100-1500 hrs. (measurements hourly)

APPENDIX V

OIL AND ICE CHRONOLOGY

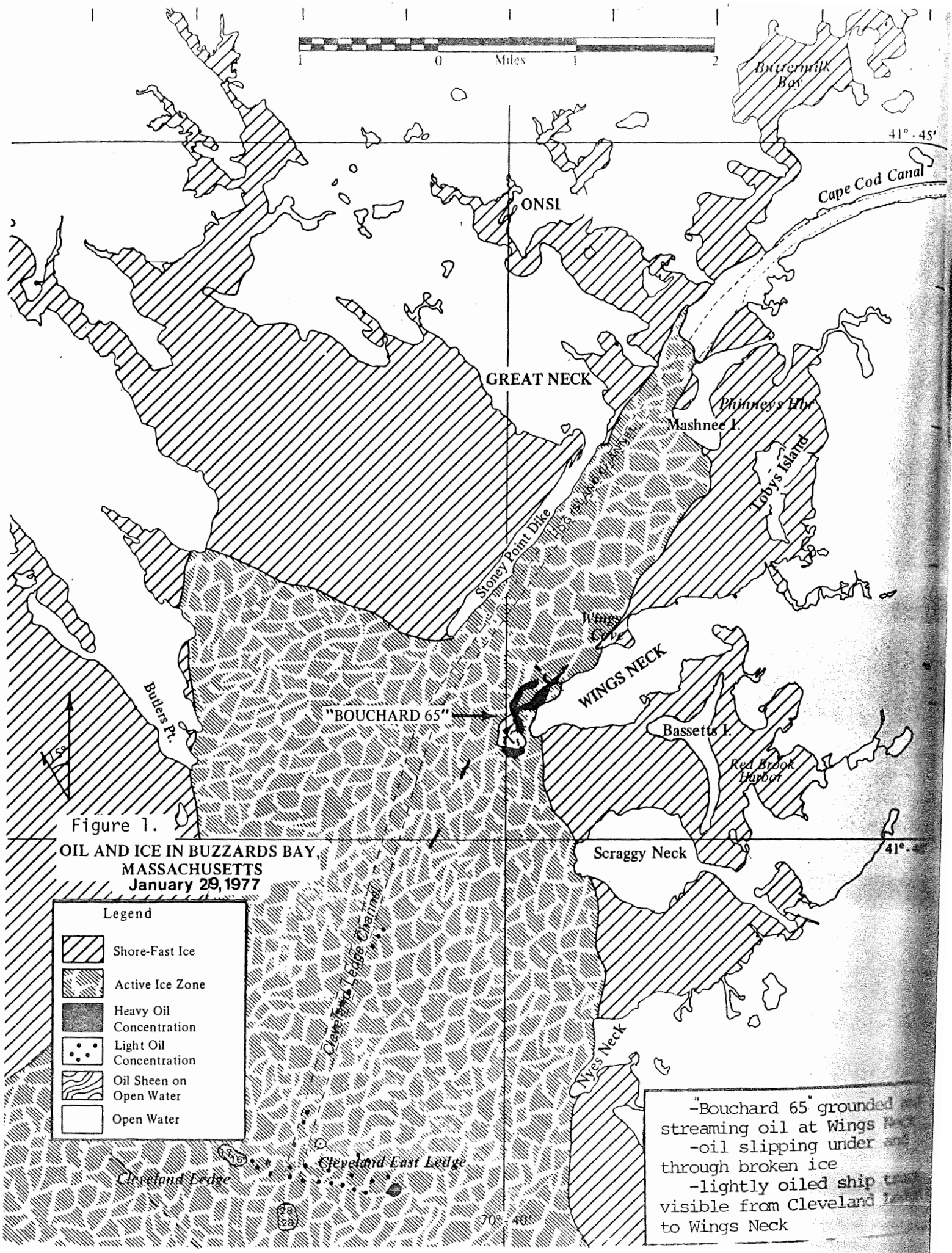


Figure 1.
OIL AND ICE IN BUZZARDS BAY
MASSACHUSETTS
January 29, 1977

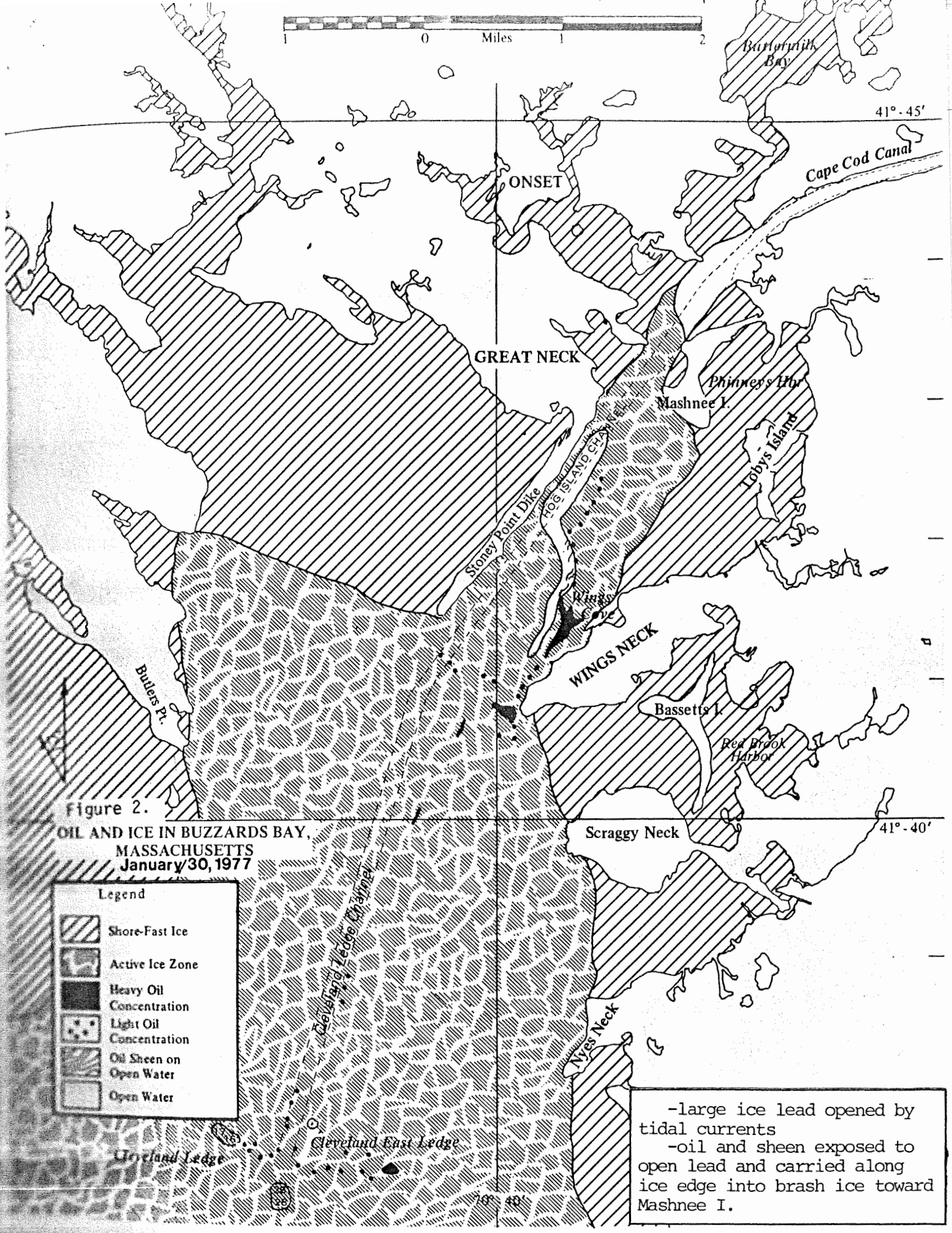


Figure 2.
OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
January 30, 1977

-large ice lead opened by tidal currents
-oil and sheen exposed to open lead and carried along ice edge into brash ice toward Mashnee I.

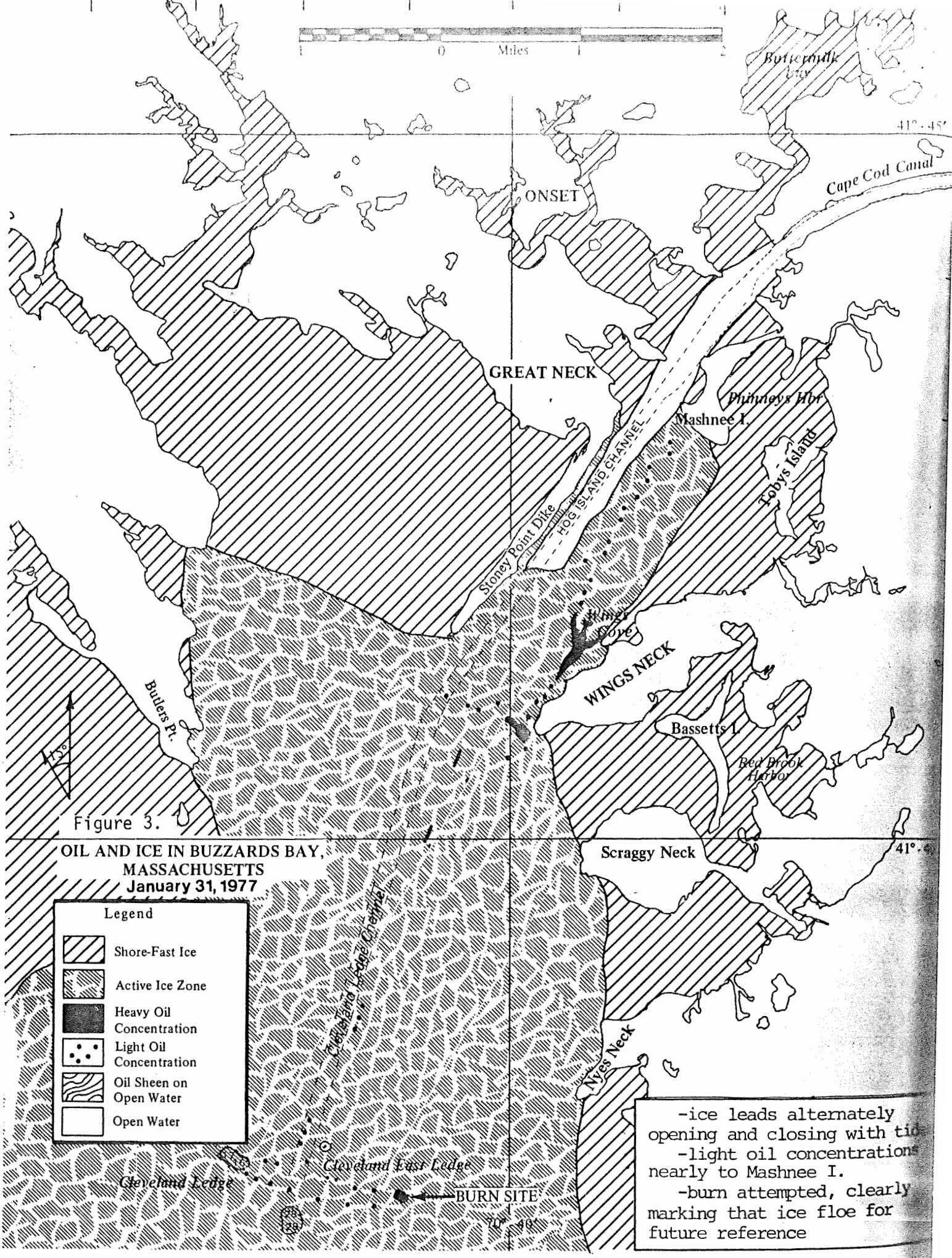


Figure 3.

OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
January 31, 1977

-ice leads alternately opening and closing with tid
-light oil concentrations nearly to Mashnee I.
-burn attempted, clearly marking that ice floe for future reference

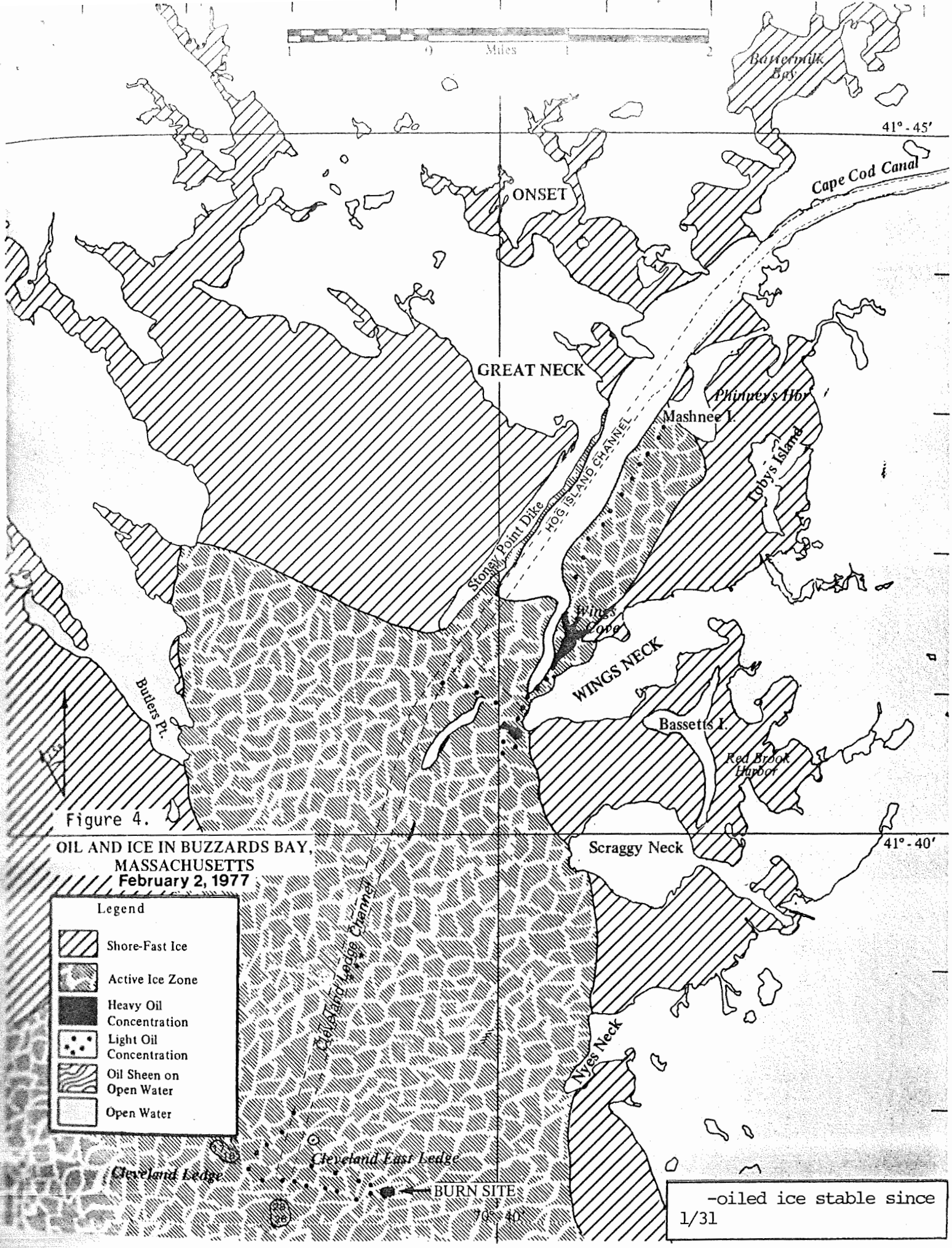


Figure 4.

OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
February 2, 1977

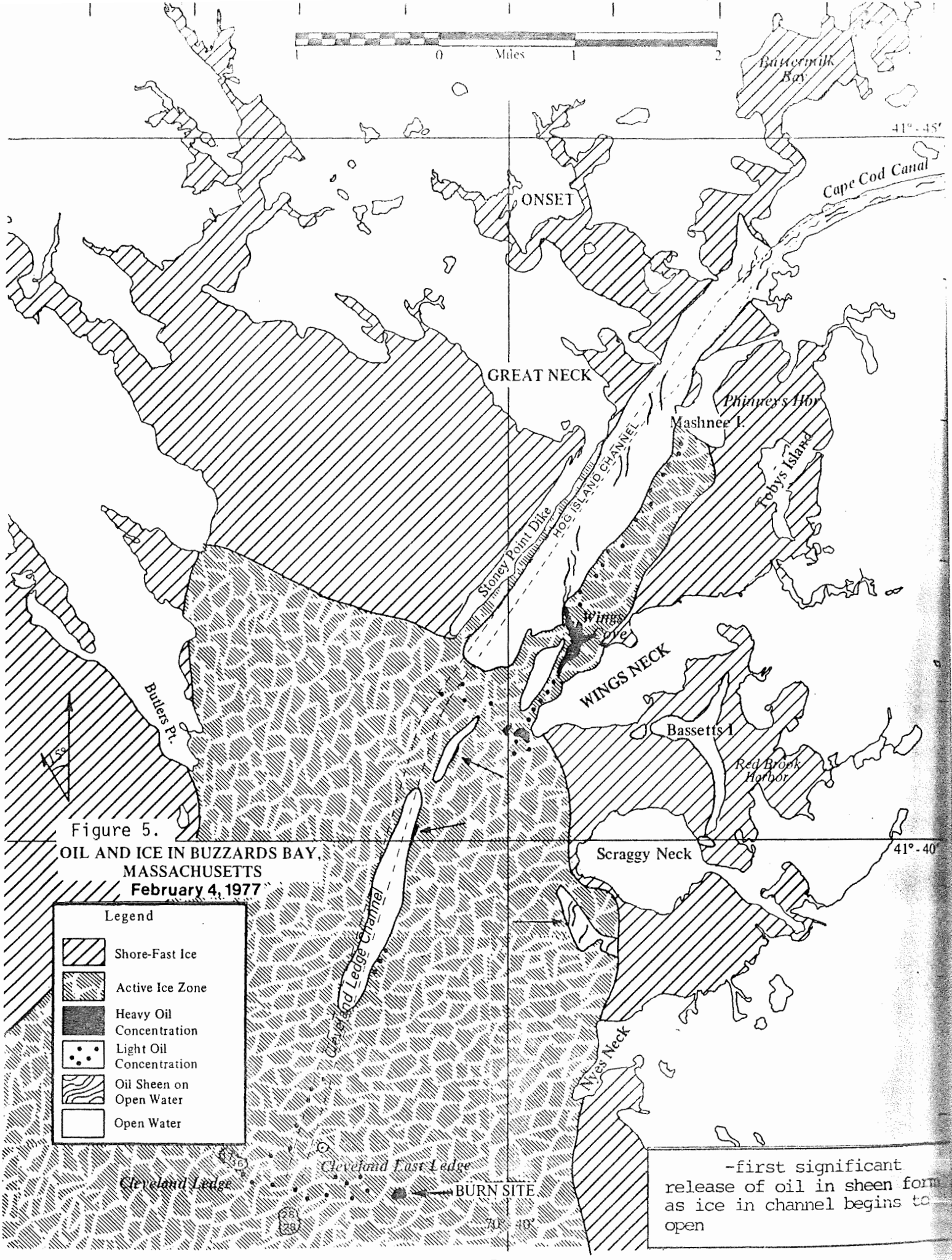


Figure 5.
OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
February 4, 1977

-first significant release of oil in sheen form as ice in channel begins to open

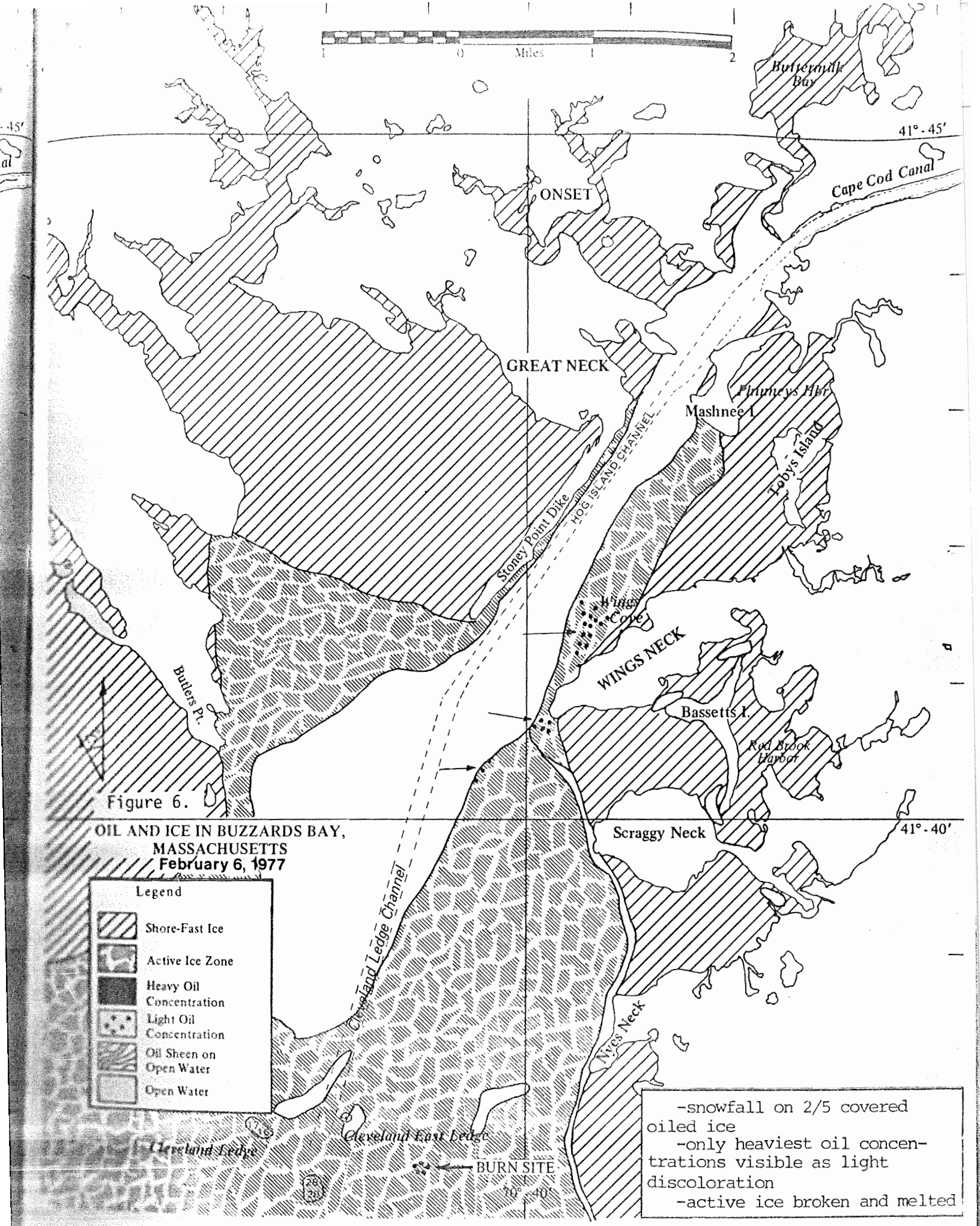


Figure 6.

OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
February 6, 1977

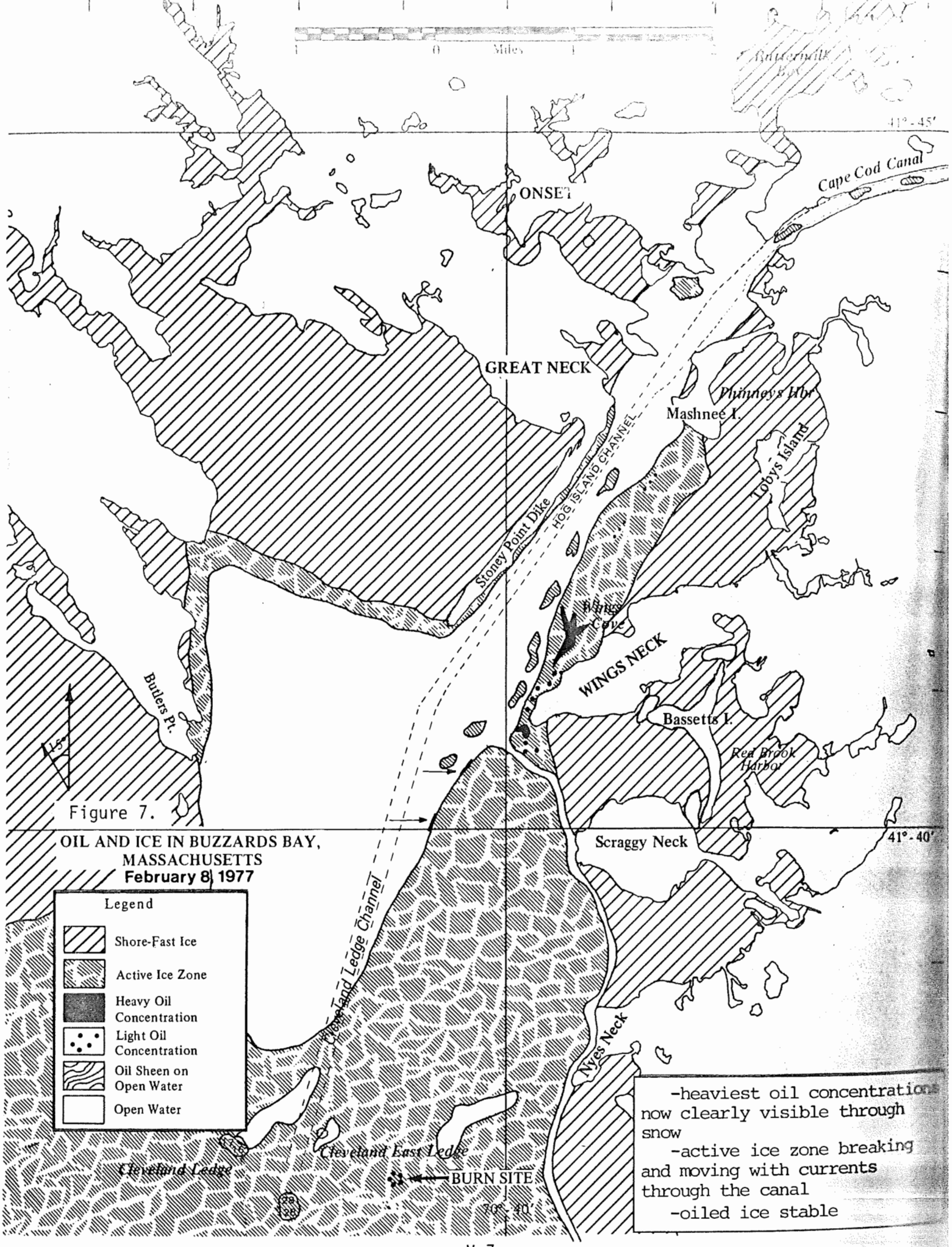


Figure 7.

-heaviest oil concentrations now clearly visible through snow

-active ice zone breaking and moving with currents through the canal

-oiled ice stable

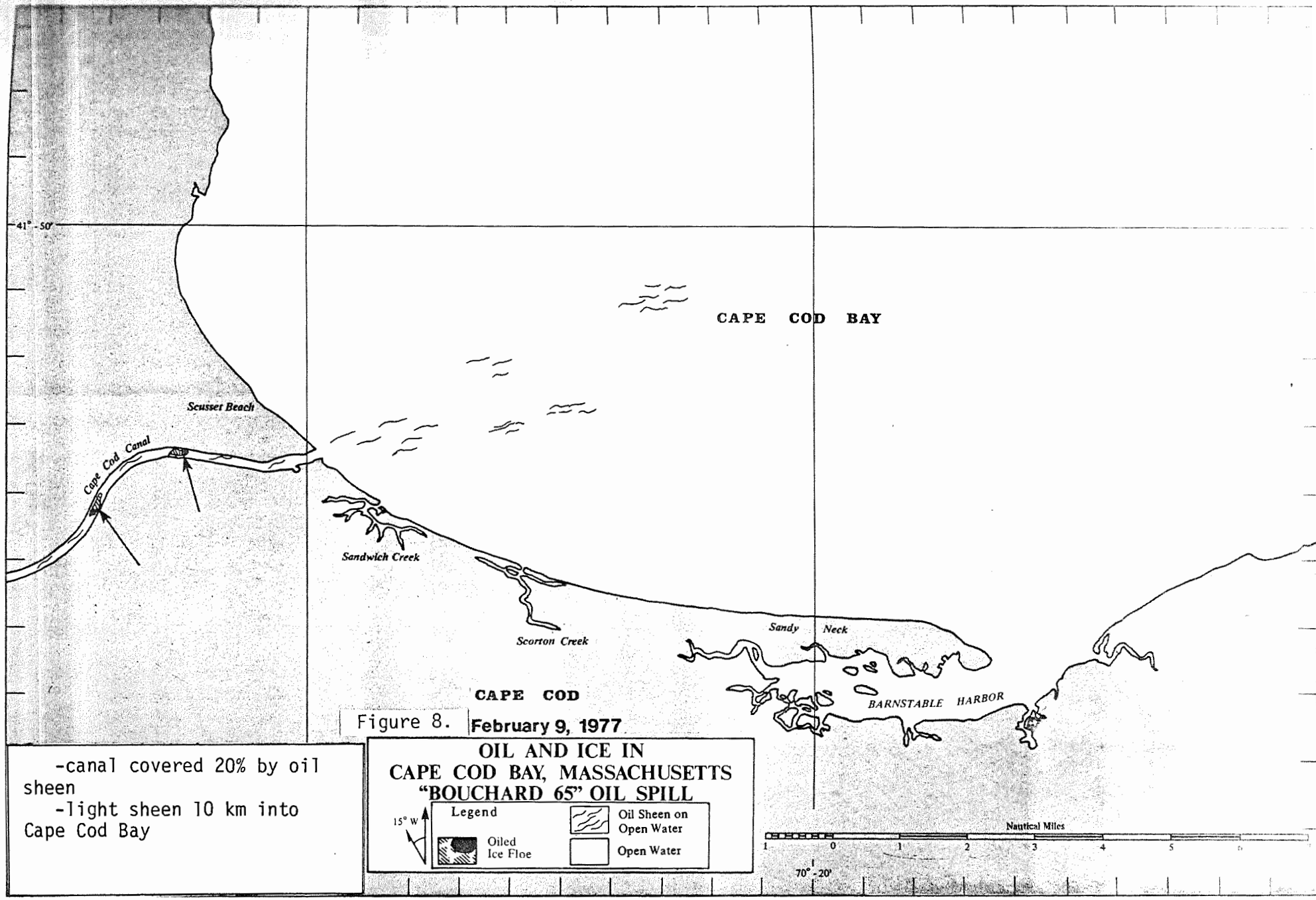


Figure 8. February 9, 1977

-canal covered 20% by oil sheen
-light sheen 10 km into Cape Cod Bay

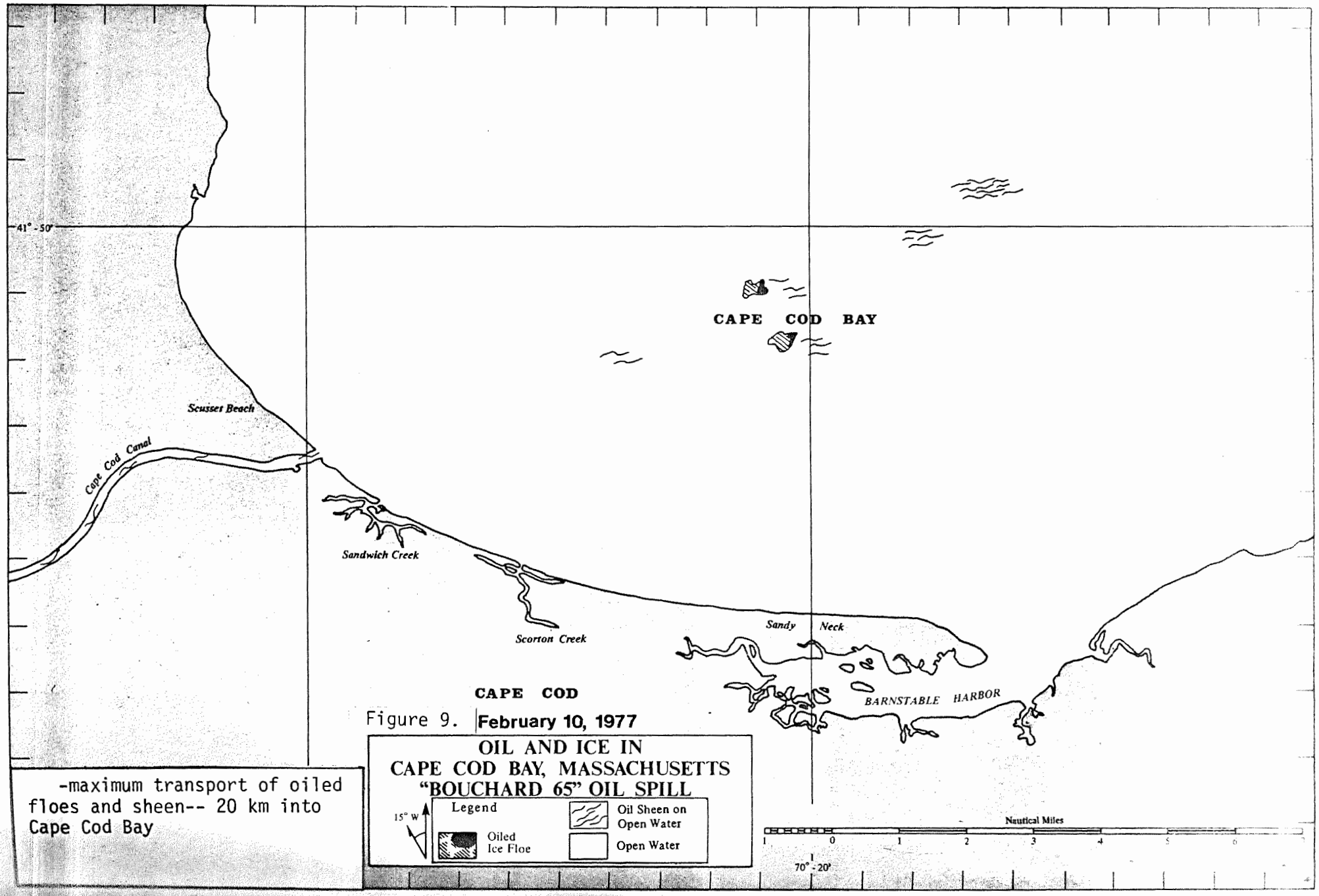


Figure 9. February 10, 1977

OIL AND ICE IN
CAPE COD BAY, MASSACHUSETTS
"BOUCHARD 65" OIL SPILL

-maximum transport of oiled floes and sheen-- 20 km into Cape Cod Bay

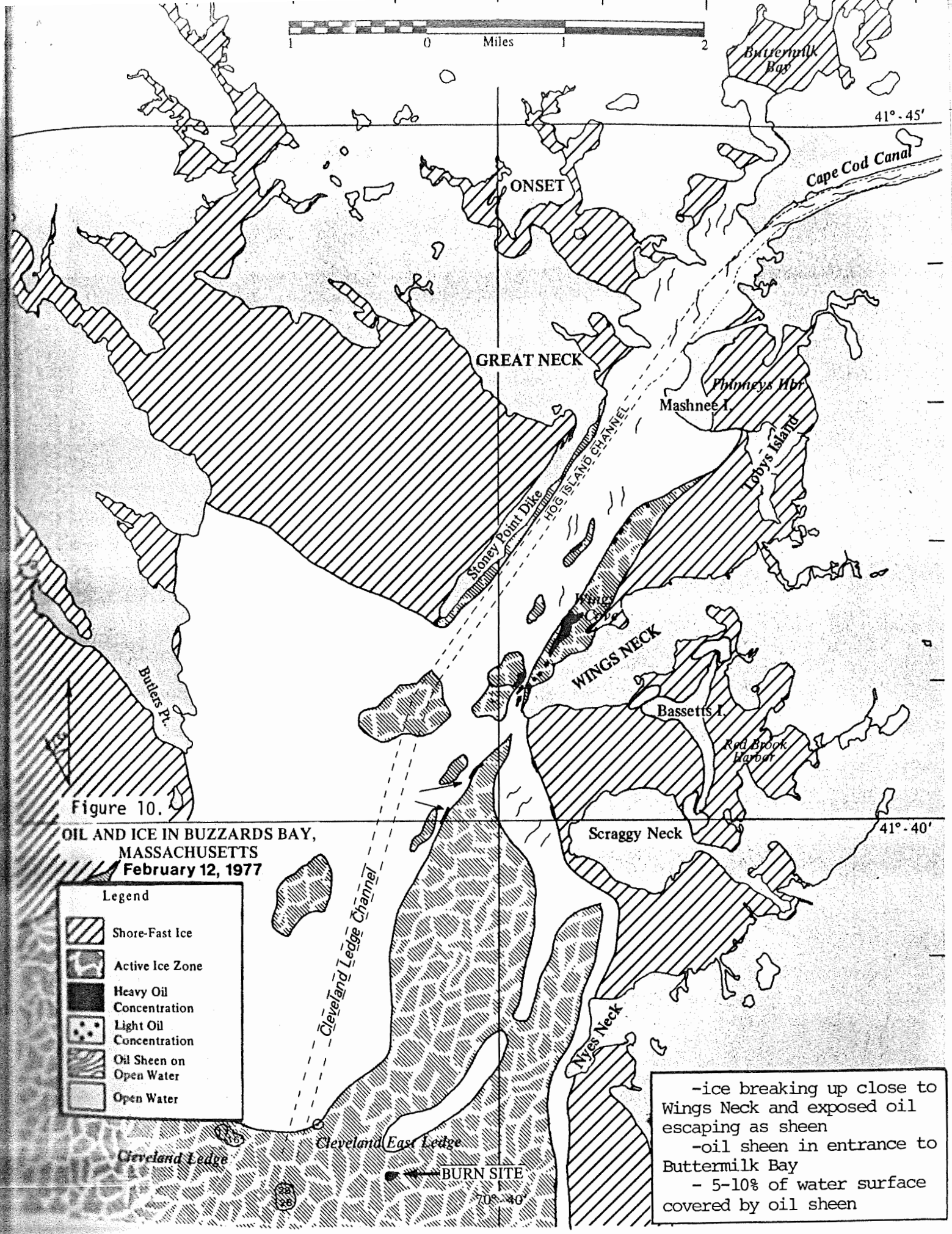


Figure 10.
OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
February 12, 1977

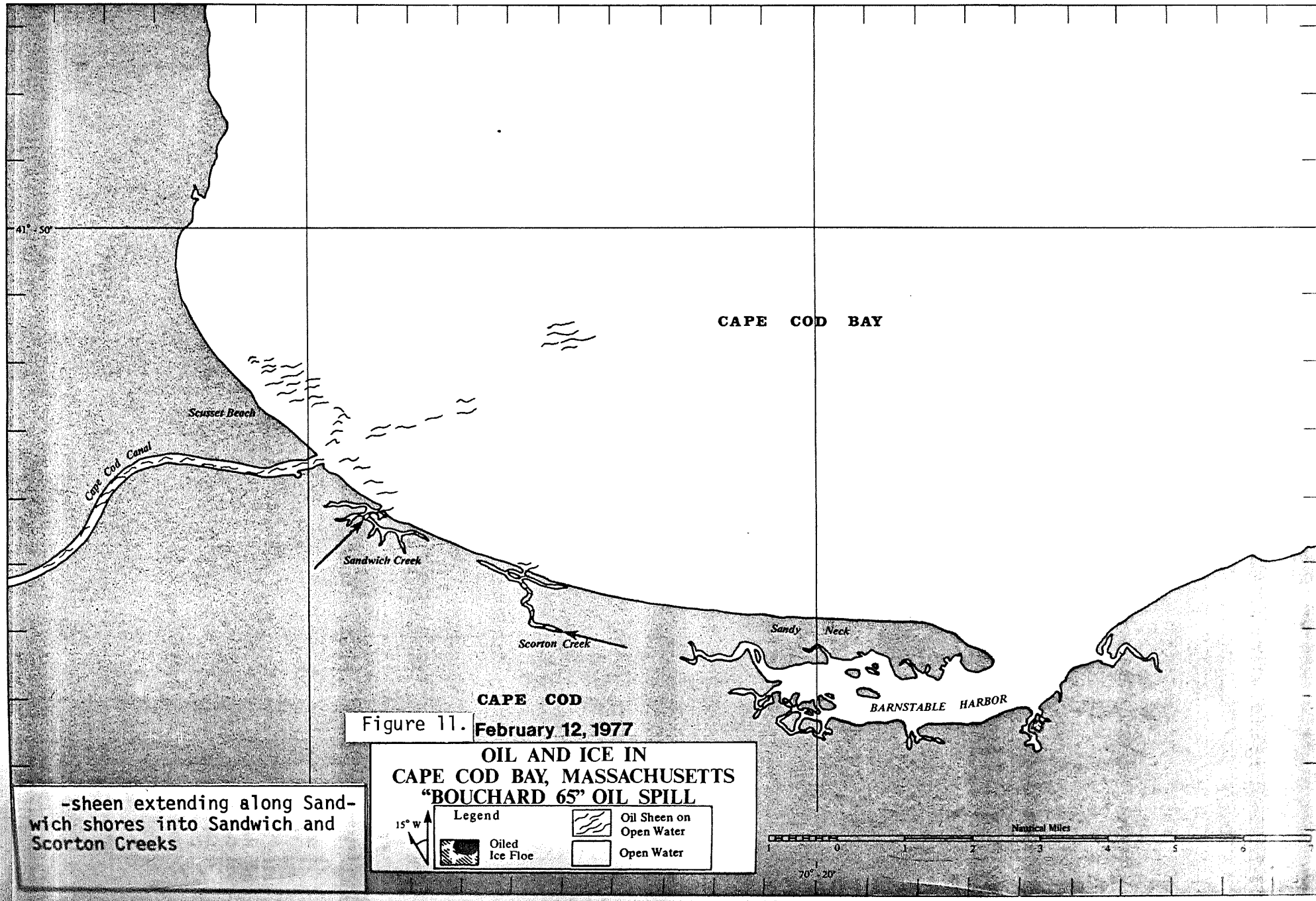


Figure 11. February 12, 1977

OIL AND ICE IN
CAPE COD BAY, MASSACHUSETTS
"BOUCHARD 65" OIL SPILL

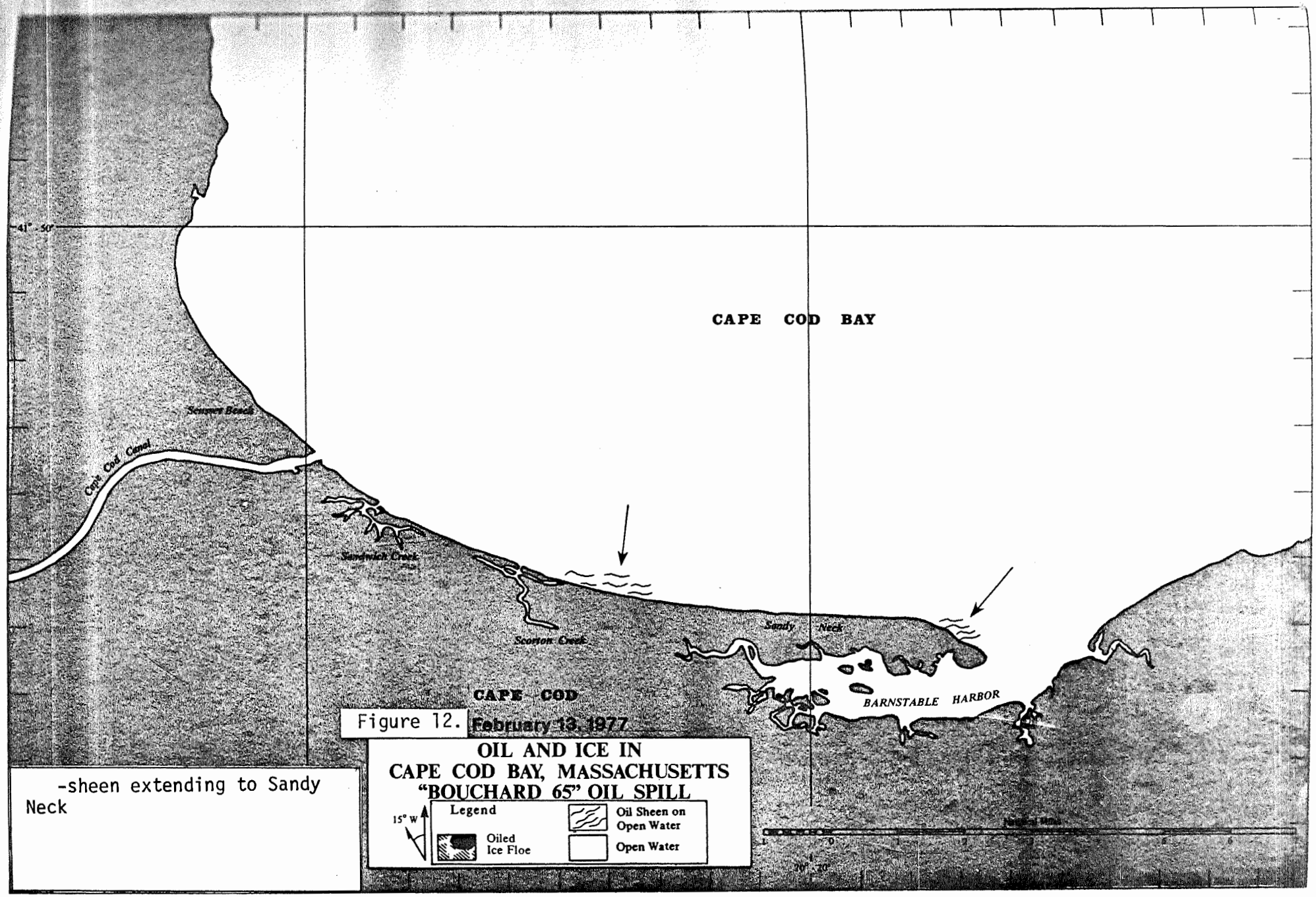


Figure 12.

-sheen extending to Sandy Neck

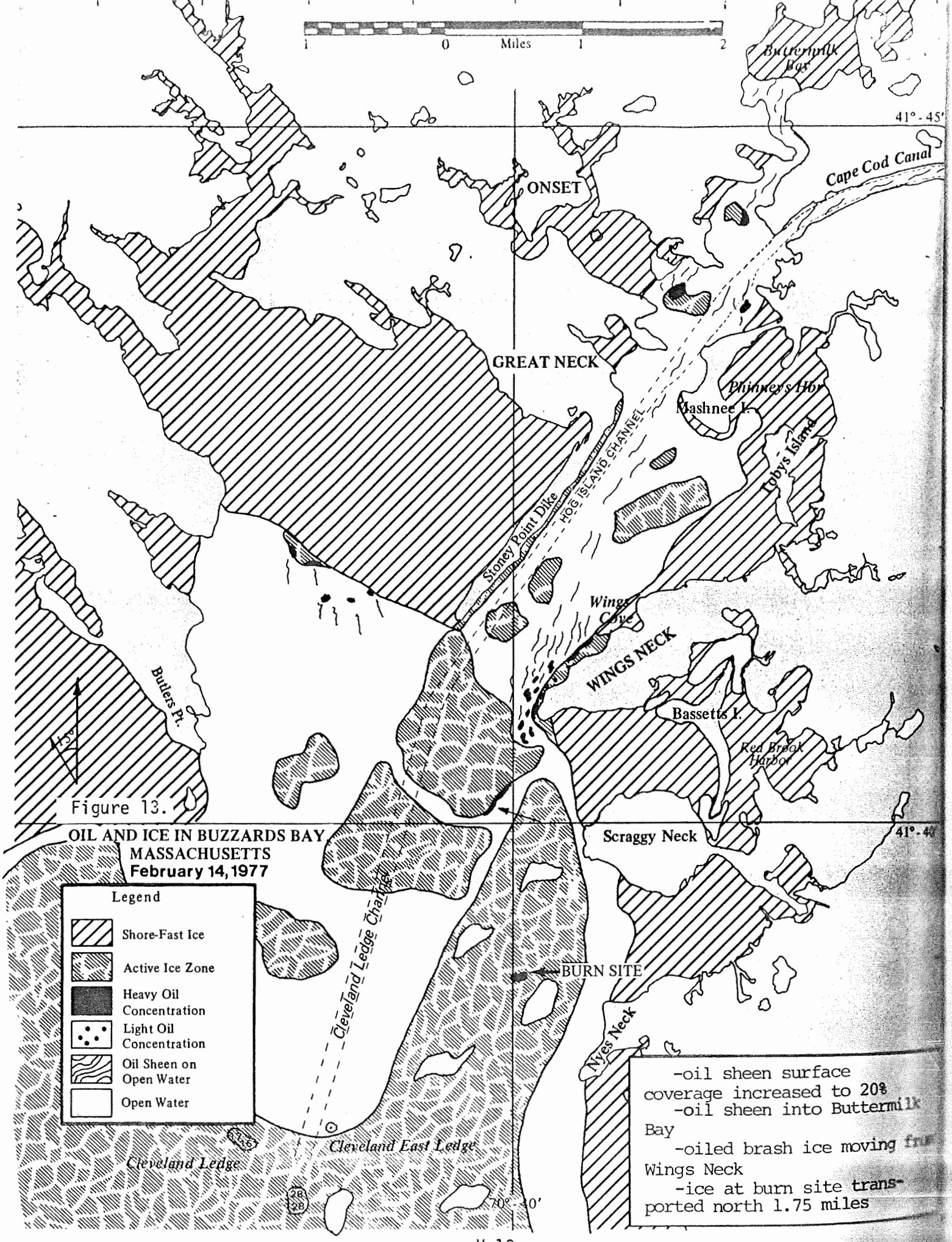


Figure 13.
OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
February 14, 1977

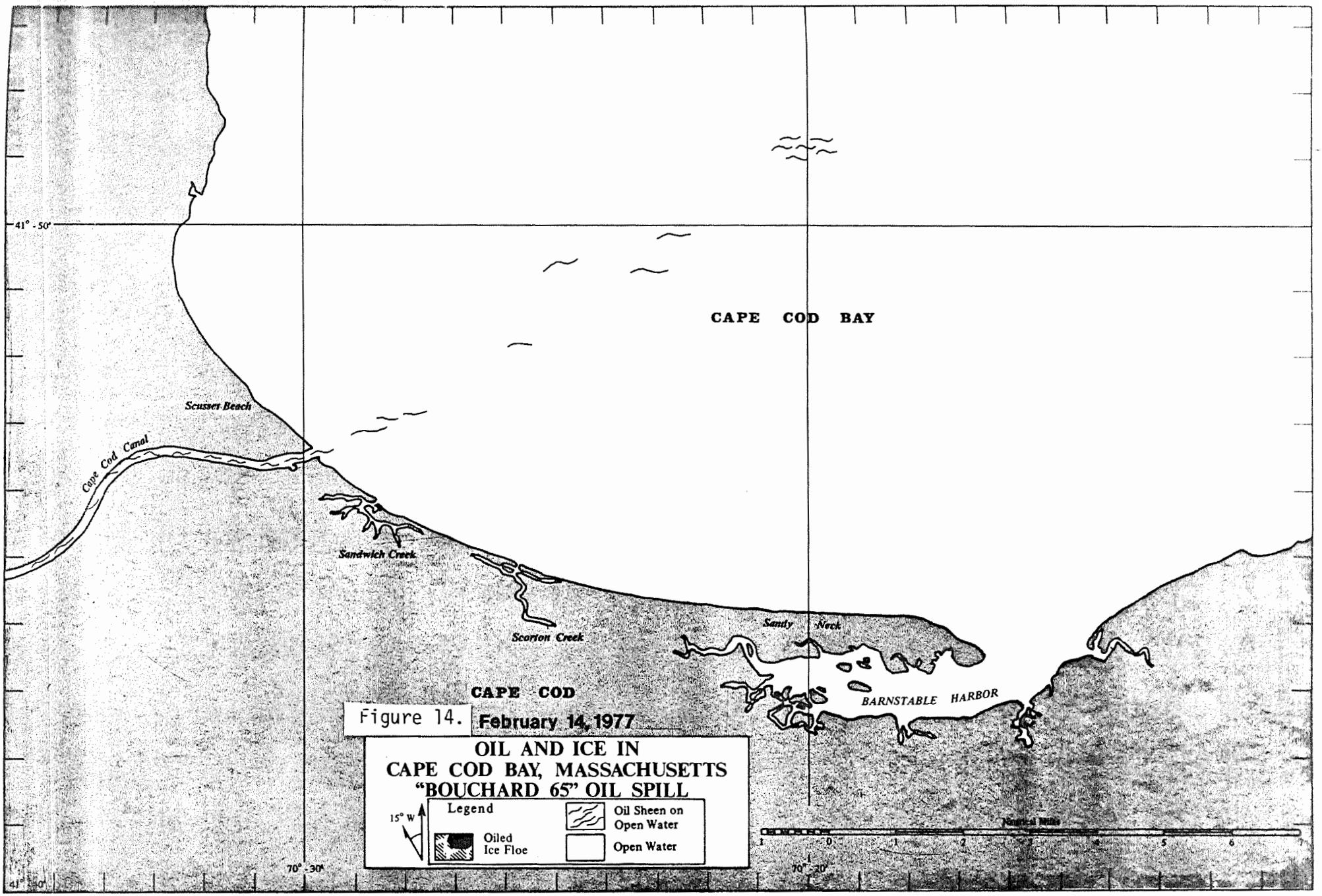

CAPE COD BAY
Scusset Beach
Cape Cod Canal
Sandwich Creek
Scorton Creek
Sandy Neck
BARNSTABLE HARBOR
CAPE COD
February 14, 1977
OIL AND ICE IN
CAPE COD BAY, MASSACHUSETTS
"BOUCHARD 65" OIL SPILL
Legend
Oiled Ice Floe
Oil Sheen on Open Water
Open Water
15° W
41° - 50'
70° - 30'
70° - 20'
Nautical Miles

Figure 14.

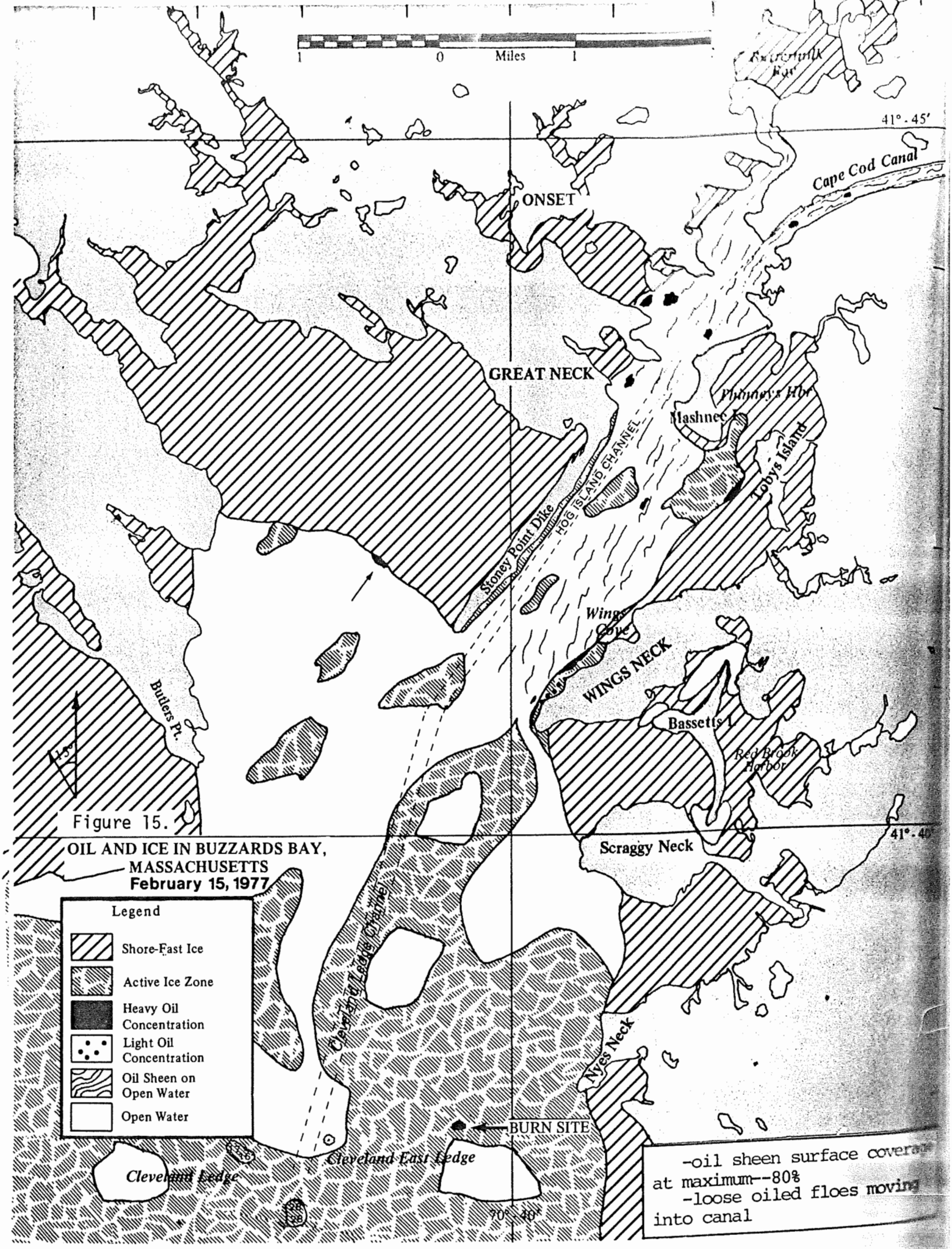


Figure 15.
OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
February 15, 1977

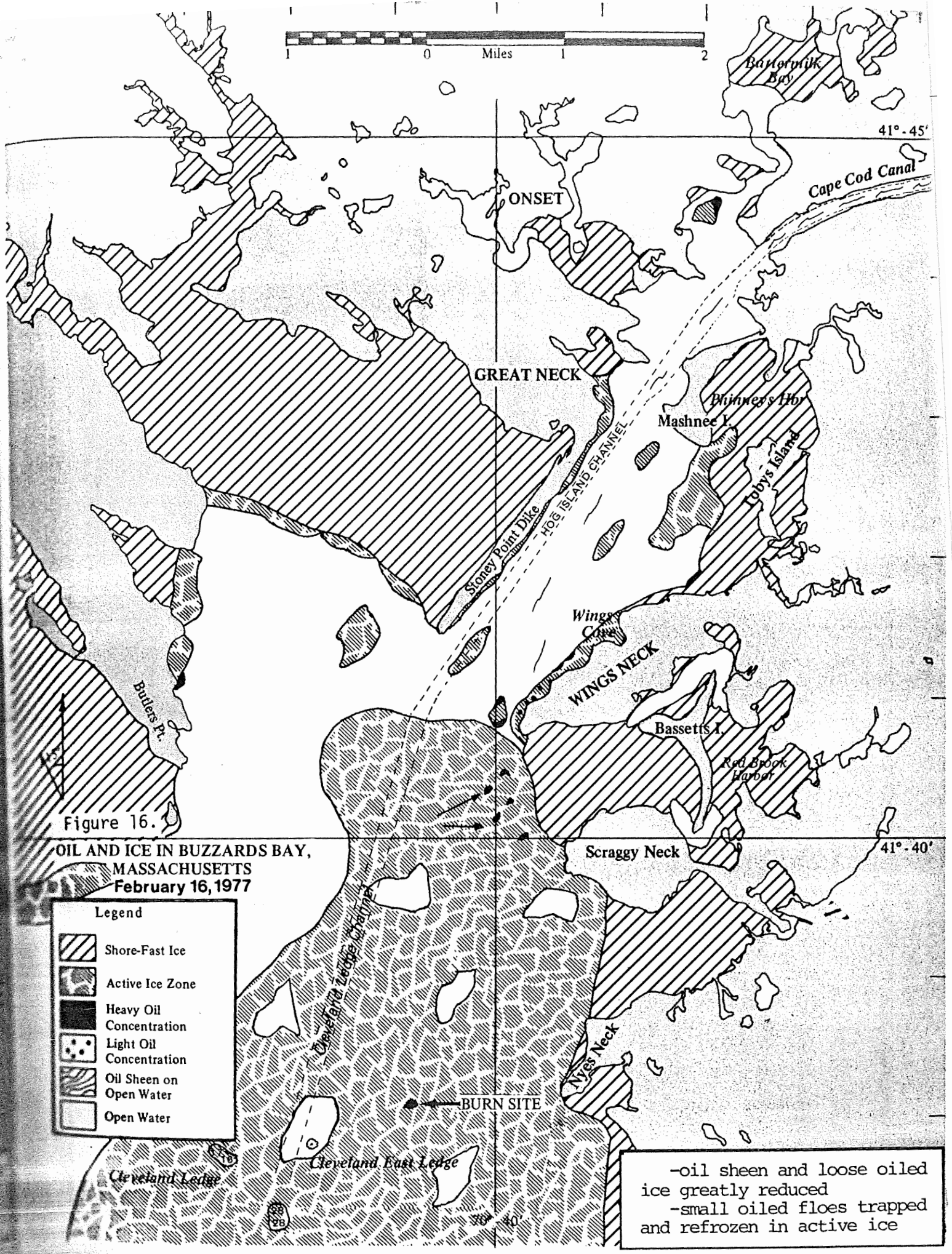


Figure 16.
OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
February 16, 1977

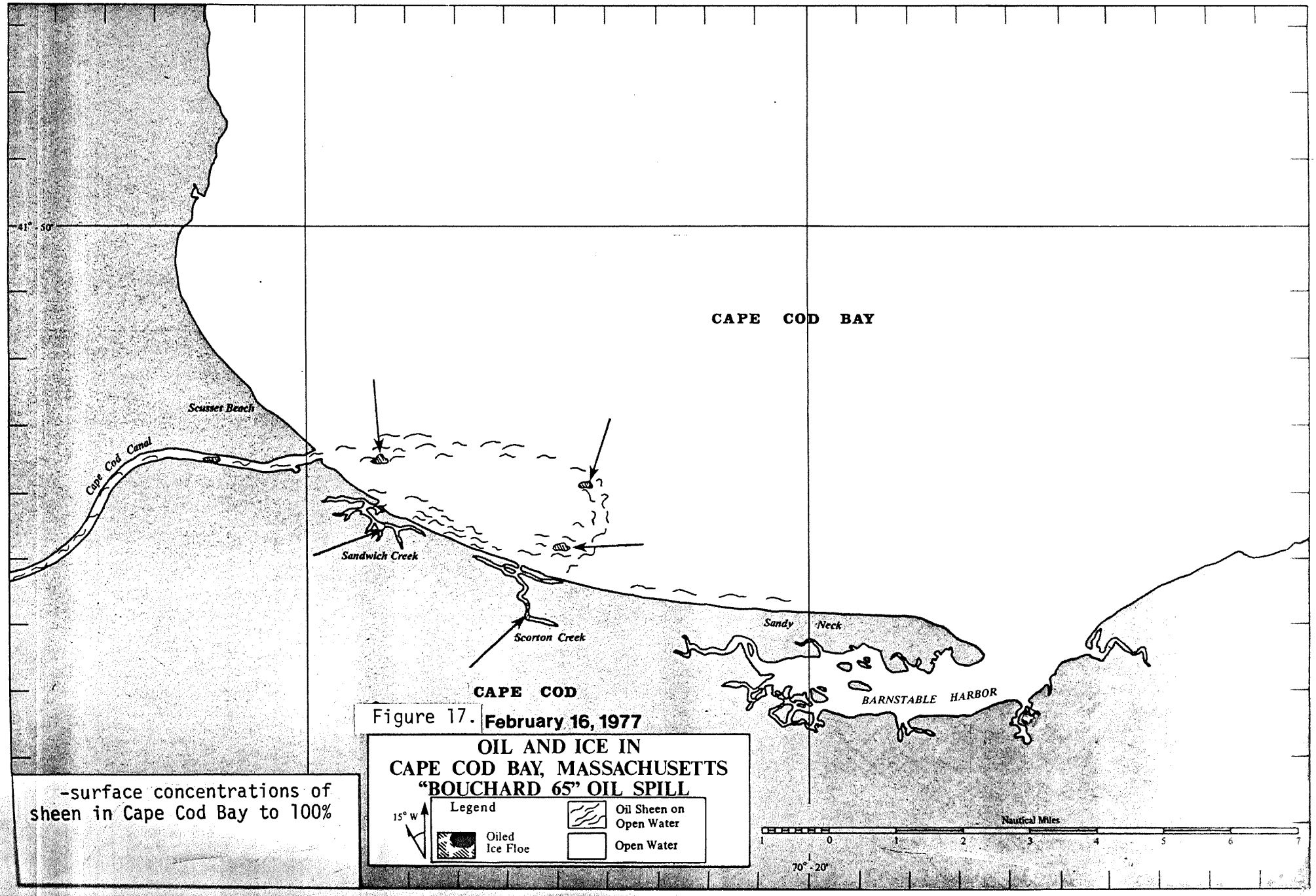


Figure 17. February 16, 1977

OIL AND ICE IN
CAPE COD BAY, MASSACHUSETTS
"BOUCHARD 65" OIL SPILL

-surface concentrations of sheen in Cape Cod Bay to 100%

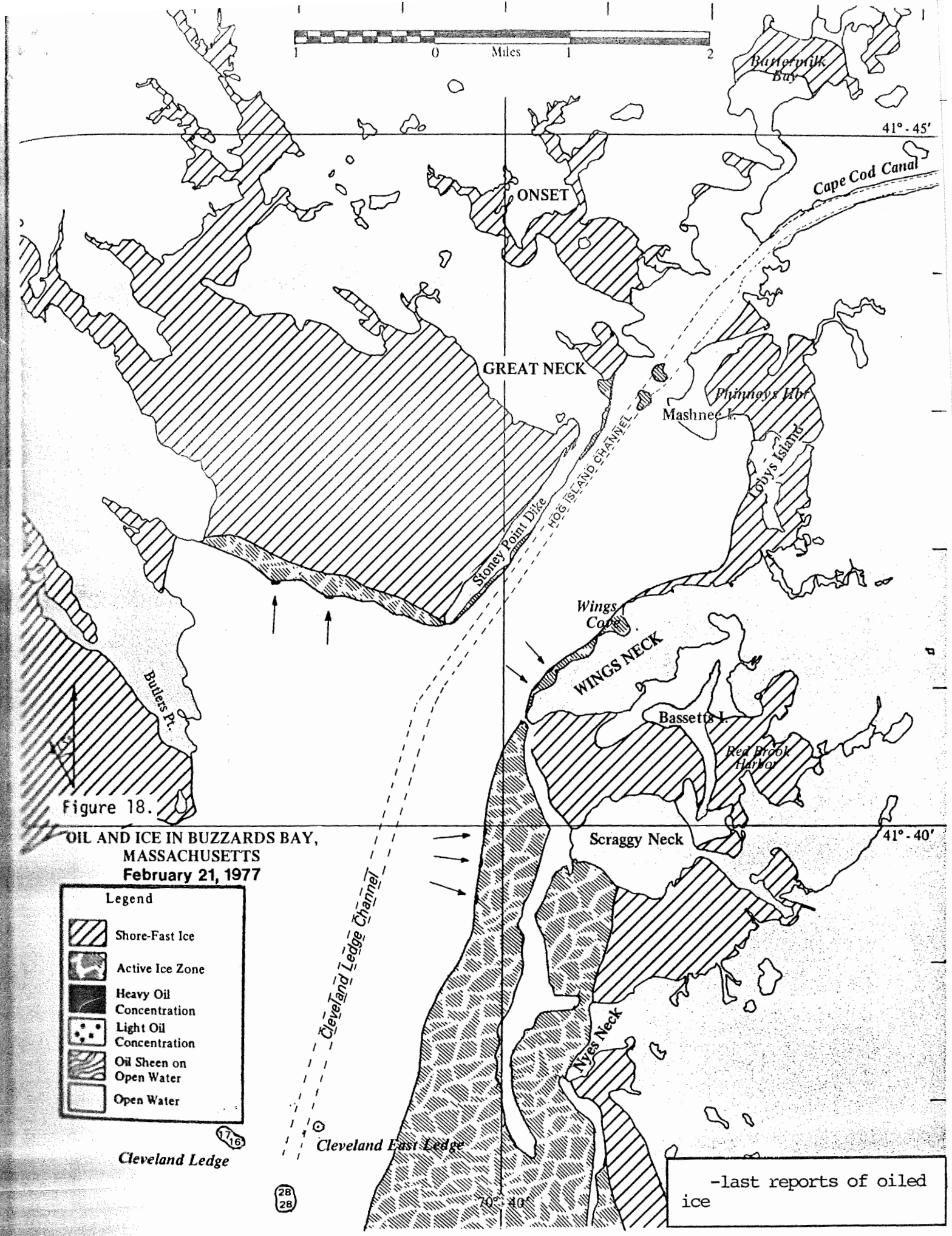


Figure 18.

OIL AND ICE IN BUZZARDS BAY, MASSACHUSETTS
February 21, 1977

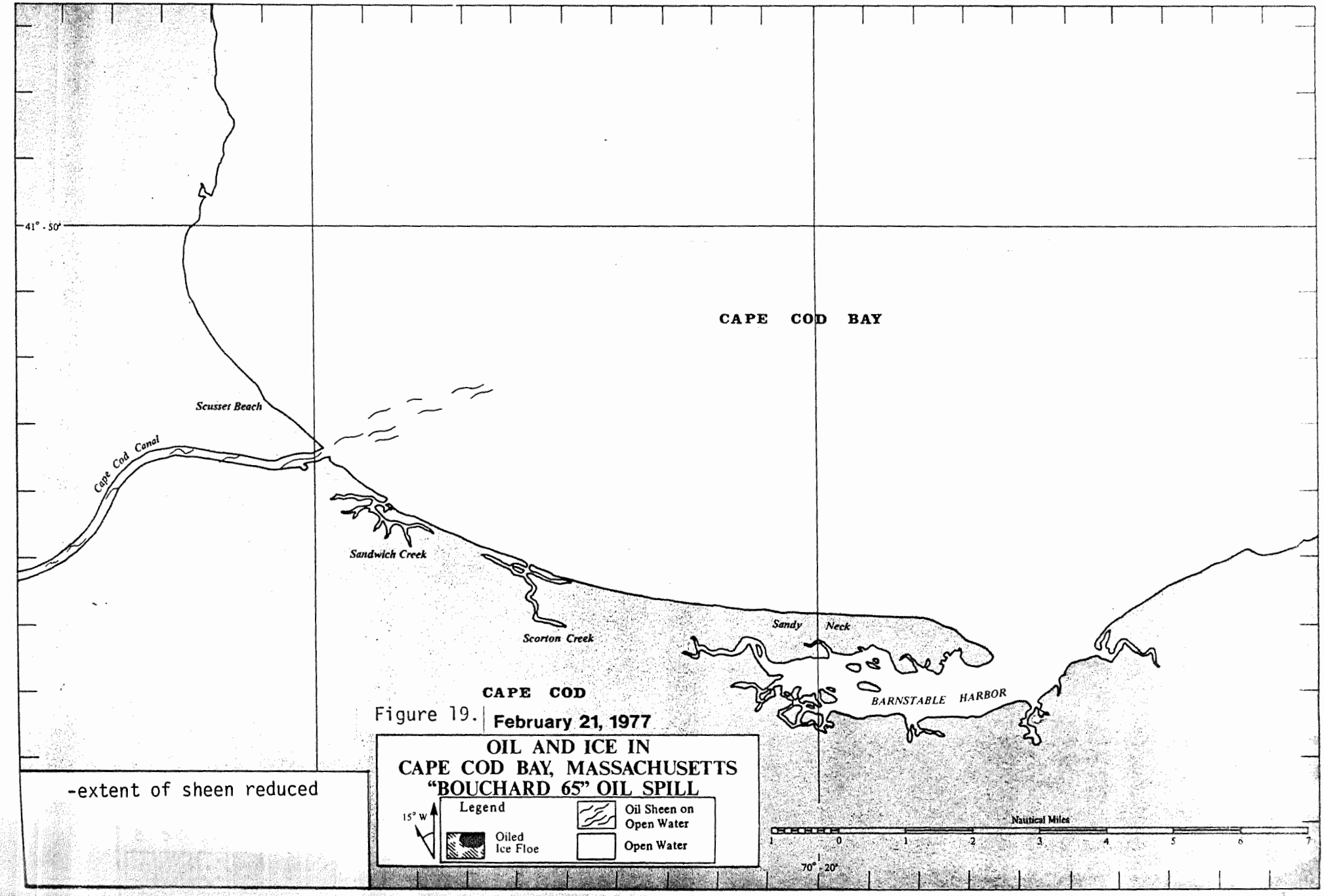

41° - 50'
CAPE COD BAY
Scusset Beach
Cape Cod Canal
Sandwich Creek
Scorton Creek
Sandy Neck
BARNSTABLE HARBOR
CAPE COD
OIL AND ICE IN
CAPE COD BAY, MASSACHUSETTS
"BOUCHARD 65" OIL SPILL
February 21, 1977
Legend
15° W
Oiled Ice Floe
Oil Sheen on Open Water
Open Water
Nautical Miles
1 0 1 2 3 4 5 6 7
70° - 20'
-extent of sheen reduced

Figure 19.

APPENDIX VI

REPORTS FROM FIELD OPERATIONS

REPORT ON FIELD OPERATIONS AT BUZZARDS BAY, 4 FEBRUARY 1977, PROVIDED BY JOSEPH ROSETTA, GEOPHYSICAL SURVEY SYSTEMS, INC.

On 28 January 1977 the Bouchard Barge #65 grounded on Cleveland Ledge in Buzzards Bay, Massachusetts and reportedly spilled 100,000 gallons of #2 oil. Later that weekend GSSI learned thru the news media of the spill and that some oil had possibly been entrapped under the ice in the Bay area.

GSSI established contact on 2 February 1977 with Mr. James Mattson of the National Oceanic and Atmospheric Administration Environmental Research Laboratory, who was on site at Falmouth, Massachusetts. During a telephone conversation between Rexford Morey of GSSI and Jim Mattson, NOAA, GSSI was invited to send its Subsurface Interface Radar Equipment with a crew to the spill site for a one day period on a no charge basis.

A survey was scheduled to be conducted on 4 February 1977 for the purpose of providing an opportunity for GSSI to operate it's Radar System from the ice surface in areas where oil had been possibly entrapped under the ice and to acquire recorded data that might provide information indicating locations of oil under ice. Data was also to be used to contribute further information to a current research project being conducted by GSSI related to the detection of oil under ice.

A survey transect was made from Scraggy Neck to Wings Neck following the path of an EPA crew already working on the site (see Appendix V-A, 4 February sampling map). All the data during the survey was recorded on Magnetic Tape to allow further computer analysis. This data reduction is now in progress for the purpose of correlating the different ice conditions encountered with the acquired Radar data.

The thinnest ice was found in refrozen leads and was approximately 6" thick. Ice thickness varied from 8 to 12" where there were no leads. Real-Time Radar Graphic Records clearly showed different characteristics of bottom reflections from thin and thick ice. It was easy to observe a higher frequency signal content in the bottom reflections from the thin ice. This fact was later correlated in the laboratory when the data was processed on the GSSI Computer using a Fast-Fourier-Transform Program. Further analysis and interpretation of the acquired data will be continued on an available time basis. No evidence of a measureable amount of oil under ice along the route surveyed was detected either by observation through the holes cut along the route or from the radar data (see map).

GSSI has a proven operational capability for thickness profiling of sea and fresh water ice from the surface or from a helicopter using its impulse radar equipment. The company has provided thousands of kilometers of continuous ice thickness profiles and has sold many systems for ice profiling.

One application for a GSSI Radar Ice Profiling Survey is to determine the topography of the bottom of the ice in order to be able to drill holes in areas where it is the thinnest in the event of an offshore oil or gas well blowout. Oil or gas being lighter than water will collect in the highest area and holes can be drilled to provide access for the oil or gas removal equipment. This type of a survey is performed in areas of possible spillage by laying out an X-Y Grid pattern of lines and scanning each line with the Radar. Data is recorded and kept for possible future use. This procedure could be performed at any spill site where oil has been trapped under the ice.

GSSI has also conducted laboratory research to detect oil and gas under ice using Impulse Radar Technology. Because it is impossible to deliberately spill oil under ice in the field for research purposes, no data on oil under ice in a field situation has been acquired using Impulse Radar.