Light Intensity and Primary Productivity Under Sea Ice Containing Oil

W.A. ADAMS

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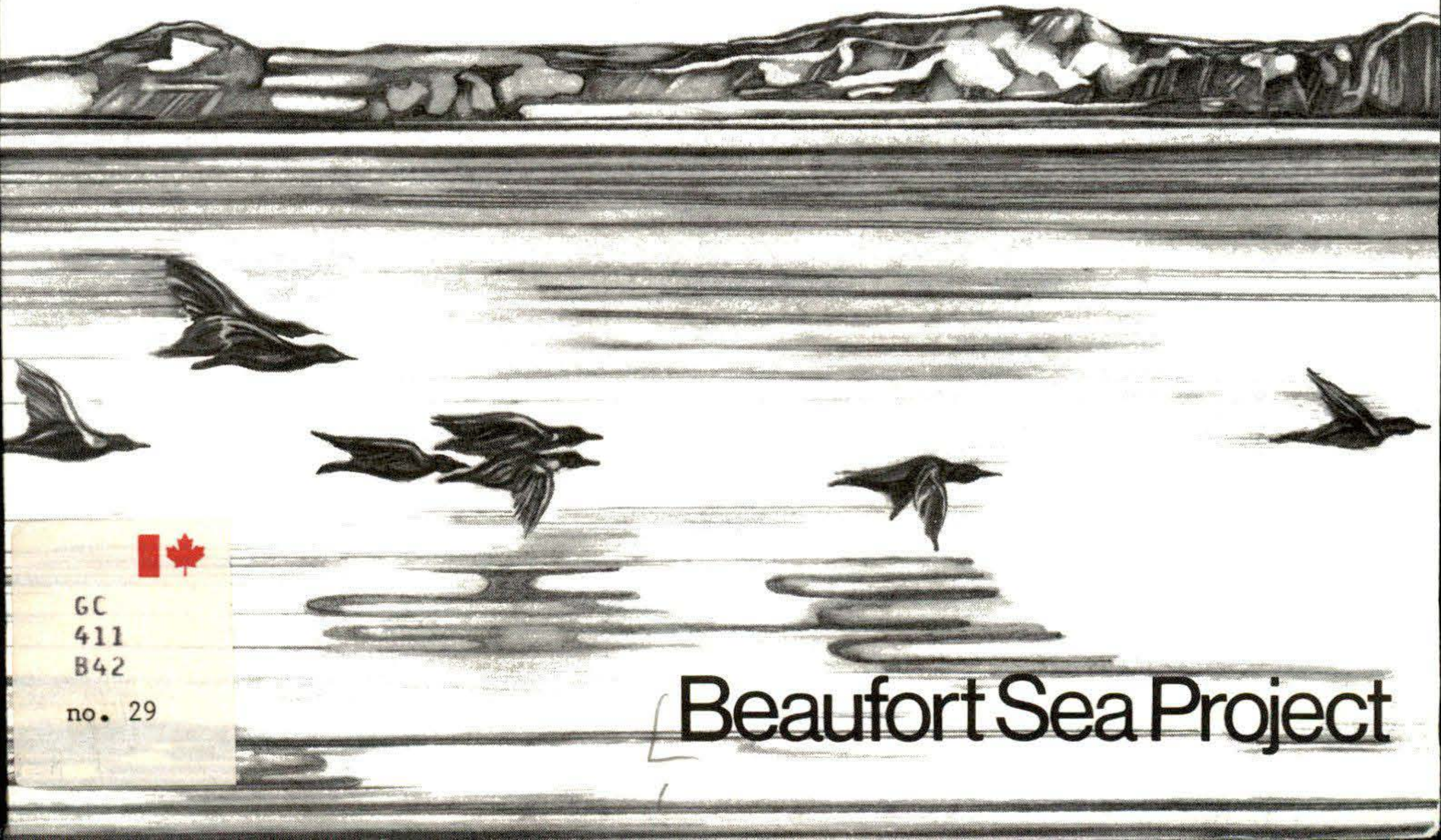

Beaufort Sea Project

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1. SUMMARY

Field and laboratory work undertaken between July, 1974 and November, 1975 is presented. Field work was associated with an experimental discharge of 64 m^3 of crude oil under sea ice in Balaena Bay near the tip of Cape Parry (N70° 02', W124° 54'). The penetration of solar radiation through the water column was measured prior to freeze up in 1974 and below the ice cover during the spring melt period until open water in 1975. Water quality parameters, primary productivity, and microbiological abundance and identification studies were made on part of the bay exposed to the oil and compared to a control area. The open water in the bay was found to be stratified into a warm salty bottom water layer and a cold fresh upper water layer about 4 m thick in September, 1974. During the spring melt, the stratification was even more pronounced with a cold water mass having a salinity of 30-32 p.p.t. lying below a 2-3 m warmer fresh melt-water ice layer. The high transparency of the water mass in this bay as observed in September 1974, was again found during May and June, 1975, but lower light levels (approximately 50%) were found below the ice containing the entrapped oil. The diffuse attenuation coefficients (400-700 nm) of ice and water were found to be greater in close proximity to the oil discharge. However, despite the lower light levels, the primary productivity, as measured by ^{14}C uptake, was found to be slightly enhanced for stations close to the oil. The abundance and number of genera of phytoplankton (approximately 40) support the ^{14}C uptake results, indicating a slight enhancement of total abundance and a greater variety of genera present in the oil contaminated samples. Minor differences were observed in temperature, salinity and in the chemical analysis of the water below the oil discharge. The oil contaminated area was subjected to a clean-up procedure which involved igniting the oil when it formed pools on the ice surface. The airborne combustion products were observed to contaminate a wide area surrounding the spill. Melt ponds in this large area were found to contain a dense mixed algal population including some blue-green and several macrophytic algae, the latter which are normally attached benthic species. The oil contaminated area was free of ice about ten days prior to the remainder of the bay.

2. INTRODUCTION

2.1 General nature of study

The physical, chemical and biological consequences of oil spills on open water in a temperate climate have been the subject of considerable study because of the frequency and serious consequences of major spills in both the marine and fresh water environments. A review of the literature on these spills has been given by Brunskill et al. (1973). In the Arctic, the effects of an oil spill on the environment are much less well understood, with lower temperatures decreasing the rate of biodegradation and the fate of oil spilled in ice covered waters being uncertain (for reviews see Gantcheff, 1971, and Eedy, 1974). The scope of the present impact study is limited to assessment of some physical and chemical parameters of the ice covered Arctic sea subjected to under-ice crude oil discharges, especially those parameters which strongly influence marine plant growth such as light intensity. These have been correlated with algal activity, diversity, and abundance.

It is important to emphasize that these results have been obtained from a controlled winter oil discharge experiment carried out on a relatively large scale compared to previous field oil discharge experiments, at least two orders of magnitude larger. In addition, the biological effects observed are a result of a realistic low level of insult from a crude oil discharge on a natural aquatic ecosystem. By this, it is meant that the effects have not been produced under controlled laboratory or field conditions designed to exaggerate the impact of oil by enhancing the concentration of oil relative to water or by reducing the biological diversity. More detailed information on the biochemical and physiological mechanisms by which oil interacts with a given organism can of course be obtained by isolating it and conducting carefully controlled laboratory experiments, but in situ investigations provide an opportunity to observe the effects when the impact of oil is on the total complex interacting ecosystem in its natural environment.

2.2 Specific Objectives

2.2.1 Irradiance

Underwater irradiance was to be measured at stations throughout Balaena Bay (see Figure 1(a)) in September, 1974, prior to the winter under-ice oil discharge tests and again in the spring following the tests. Diffuse attenuation coefficients and reflectance functions over the range 400 nm to 700 nm were to be calculated from the data. Spectral information in two regions of photosynthetic importance were to be monitored. Diurnal and seasonal time dependence, as well as depth and horizontal distribution of solar radiation were to be considered for correlation with ice conditions, presence of entrapped oil, and primary production.

2.2.2 Water quality

A survey of water quality parameters as a function of depth throughout Balaena Bay, including temperature, conductivity (salinity), dissolved oxygen, pH, oxidation-reduction potential and chemical analysis for major ions was to be made prior to and following the oil spills.

2.2.3 Biological

Biological studies of the rate of carbon fixation by phytoplankton using the ^{14}C method were to be conducted during the spring by in situ incubation at the stations shown in Figure 1 (b) in Balaena Bay. Water and ice samples from these stations were to be examined for variety and numbers of phytoplankton. The primary productivity data obtained was to be assessed to determine whether there would be significant effects resulting from the oil discharge during the winter.

2.3 Relation to offshore exploratory drilling

The drilling activities associated with exploration for petroleum in the Beaufort Sea are planned for the ice-free season likely to be two months long and ending in early October. The results of such activity on the water quality and primary productivity, should there be an accidental blowout, depend on the location of drilling and the timing. The waters of the Mackenzie River are extremely rich in nutrient, but because of the heavy load of suspended material, light of sufficient intensity to support photosynthesis is restricted to the upper 0.5 m of the water column (Grainger, 1976). This turbid fresh water extends out into the Beaufort Sea overlying the more dense oceanic water mass. Therefore to assess the nature of disruptions to the ecosystem from drilling activity, it must be determined whether the site is in relatively clear marine waters or in the turbid outflow of the Mackenzie River. Within this turbid region, the productivity during the open water period is very low due to light limitations, so that further reduced light levels due to an oil slick are unlikely to produce any significant effects on productivity. A blowout or accidental release of oil would be unlikely to significantly affect phytoplankton production due to modification of the light regime under open water conditions in any case, because the oil would be rapidly dispersed by wind and wave action. Should the drilling activity be in an area free of suspended material with water transparency such as that found under the permanent pack ice or in the shore zone, away from regions of high turbidity caused by river borne sediment, the result of an oil discharge could be quite different. In this situation, the system could well be nutrient limited and the crude oil itself (or by-products of its bacterial degradation or residues from clean-up procedures involving dispersants or burning) could bring about profound changes in the level of primary productivity and in the distribution of microorganisms. This situation would be likely to occur in May and June in sea ice or in leads exposed to a continuous discharge of oil where the season and water clarity are such to ensure that light is not a limiting factor in photosynthesis. During the ice covered period, there is less of a difference in the light regime between the Mackenzie River turbid zone and the zone of clearer marine waters. It has been reported by Grainger (1976) that under-ice water turbidity is reduced due to a reduction of river flow during winter months and a settling out of suspended sediment. This fact would reduce the differences in submarine light between these two zones. However, differences in temperature, salinity, and nutrient availability would be present, so that even if light levels were reduced by an equivalent amount, the presence of oil from a blowout in and under the ice would not have a similar ecological consequence in the two zones.

3. CURRENT STATE OF KNOWLEDGE

3.1 Light penetration through sea ice

The units traditionally used to express the intensity of light passing through ice or the water column have been based on energy. This system has worked well since many older instruments measured energy directly and often results were applied to considerations of the flow of energy in food chains. As suggested by Lewis (1975), however, a more appropriate measurement system is based on the number of photons in a given spectral range. The rate of photosynthesis, or of photochemical reactions in general, depends on the number of quanta of the appropriate energy, not the total light energy. There is no distinction between an energy or quantum unit system if the spectral composition of the light does not vary, but in natural waters there is a considerable spectral shift to lower wavelengths with increasing depth. Most of the measurements in the present work have been made with quantum meters in units of microeinsteins $m^{-2}s^{-1}$($\mu Em^{-2}s^{-1}$) for a specified wavelength. The einstein unit is an Avogadro number of photons (6.023×10^{23}) of a specified wavelength. Where the radiation has been measured in energy units, as in the case of the solarimeter data, the common radiometric unit, watt m^{-2}(or mW cm^{-2}), or the langley (15° gram-calorie cm^{-2}) have been used. Units for light measurement have been reviewed by Strickland (1958) and Maguire (1974).

The theoretical and practical aspects of underwater light measurements have been discussed in three recent monographs, Williams (1970), Tyler and Smith (1970), and Jerlov (1968). The complexity of the interaction of light as it passes through a natural water body is a result of the non-homogeneous nature of the medium. Natural water, optically speaking, consists of pure water containing dissolved material which absorbs light in spectral regions characteristic of the dissolved species and suspended particles of varied size and shape which both absorb and scatter light. The temperature and pressure gradients in the water column and the surface conditions of the water also influence its optical properties.

The radiation field of ice-covered water is modified by the changes produced in the solar radiation as it encounters the snow and ice layer prior to entering the water column. The optical properties of snow and ice have been studied from two perspectives. In the laboratory, physicists and chemists have prepared pure samples and studied the optical properties with a view to achieving a basic understanding of ice as a material. Ice exhibits many unusual features due to the directional nature of hydrogen bonding and the complexity that this engenders in a molecular solid. Early work has been reviewed by Dorsey (1940) and there are recent reviews by Glen (1974) and by Eisenberg and Kauzmann (1969). Pure ice absorbs radiation strongly only in the infrared region, being transparent in the visible and radio frequency regions. Water molecules absorb in the far U.V. (Herzberg (1967), Dorsey (1940), and Onaka et al. (1968)) near 125 nm and 200 nm. The penetration of light through an ice or snow medium, however, depends to a great extent on the light scattering properties of the bulk medium as well as on the individual crystal properties. These radiation transfer processes are a property of the physical nature of the snow or ice. The density (presence of air or bubbles in ice) the distributions of bubble size, the crystal grain size, the free water content, and presence of contamination, biological or otherwise, are important factors (Weller (1969), Maykut et al. (1975), Carras et al. (1975), and Thomas (1963)). Maguire (1974) has compiled an extensive literature survey on factors influencing the attenuation of solar radiation by the snow and ice cover over lakes. It is pointed out that light levels sufficient for most photosynthetic activity are not present in water below ice if snow is deeper than 20 cm on clear ice or even less than 20 cm on cloudy ice. The measurement of under-ice light levels in the field has generally been carried out by biologists concerned with photosynthesis. The measurements are usually of photosynthetically active radiation (P.A.R.) from 400 to 700 nm or in general of radiation in the visible region and the attenuation is expressed by a diffuse attenuation coefficient which combines the effect of snow, ice and water. Welch et al. (1975) has described light measurements in Resolute Bay, N.W.T., which were used in primary productivity estimates. In fresh water, the I.B.P. Char Lake project has resulted in a series of publications on studies of the role of light levels in primary production in polar lakes (Schindler et al. (1974), Welch et al. (1974), and Kalff et al. (1974)). The importance of the role of snow cover in light attenuation in the water below an ice cover is greatly emphasized by these investigators and also by Ostrofsky et al. (1975) and Duthie et al. (1974) working on lakes in western Labrador. Grainger (1971) has given irradiance values at various depths for water in Frobisher Bay, N.W.T., measured during biological studies. In almost all of the work reported there has been a lack of spectral information. The Arctic Sea-Air Interaction Group at University of Washington have recently developed a portable submersible spectrophotometer (Roulet et al., 1974) which has been used to study first-year sea ice near Point Barrow, Alaska in June, 1972 (Maykut et al., 1975). The effect of various surface ice conditions on the irradiance over the range 400-1000 nm was evaluated. The spectral signature of marine algae was observed. Light attenuation also depends on the salt content of the ice (Davis et al., 1973). The radiation absorption of clear ice in the region 0.3 to 3.0μm has been reviewed by Goodrich (1970).

3.2 Albedo of sea ice after an oil spill

The surface of sea ice is highly variable, especially in the spring during the melt period. There are four main optical categories of ice which have been recognized by Maykut et al. (1975): snow covered ice, white ice, which is drained melting ice above the local water table, blue ice which is melting ice saturated with water at the local water table, and ice covered by melt ponds. In order to predict under-ice light levels the albedo of these various surface types, the ice thickness, and the attenuation coefficients of the water, snow and ice must be known. In addition, the horizontal distribution of the ice thickness and surface types have to be measured. At the moment this kind of complete description is not available, although there have been studies of some of the parameters. The albedo of the natural unperturbed Arctic ice cover has been discussed by Kukla and Kukla (1974), Campbell and Martin (1973), Ayers et al. (1974), Campbell and Martin (1974), Maykut and Untersteiner (1971), Langelben (1971), and Hanson (1961). A series of five publications by the Arctic Meteorology Research Group at McGill University (see Larson and Orvig (1962)) reports on radiation studies related to the heat balance in the Arctic.

There is a large reduction in the albedo of an ice, snow or water surface when covered by crude oil. This has been discussed by Ayers et al. (1974) and Martin and Campbell (1973, 1974) with respect to the increased absorption of solar energy due to the effects of oil on either water in leads or on ice surfaces in the Arctic ice pack. In a literature survey on the behaviour of oil under ice, Keevil (1974) has collected 15 references, all dating between 1970 and the present, with one exception. To indicate the paucity of radiation studies on the sea-ice-oil system in this survey only the discussion by Campbell and Martin (1973) referred to above, concerns the effect of oil on the albedo of sea ice. Correlations have been made between solar radiation (clear sky and cloudy sky) and the surface oil temperature and ice temperature in artificial ponds subjected to winter oil spills at Shirley's Bay in Ottawa, reported by Scott (1974) and by Scott, Adams and Chen (1974). Work by Glaciology Division and the Ottawa Detachment of CCIW is continuing at Shirley's Bay. The effect of oil on the surface of water has received some attention. Smith (1973) has commented on experimental difficulties experienced from very thin oil slicks on the water surface in ice holes during attempts to make very precise measurements of diffuse light attenuation by the water column through ice holes from Fletcher's Ice Island, T-3 in the Arctic Ocean. The appearance of an oil film on a natural water body, based on considerations of the oil film thickness and viewing angle, has been discussed by Millard and Arvesen (1973). Oil on the surface of water increases light reflectance in the visible region by 2 to 3% depending on the refractive index of the oil on the water surface, the viewing angle, and the possible contribution of fluorescent return for the benzoid components in the oil. The visual appearance of oil slicks on water have been related to oil thickness empirically by Allen (1970). A report has been made on microwave radiometry which indicates that this technique permits quantitative estimates of the extent and thickness of sea surface oil slicks (Hollinger and Mennella, 1973). There is a comment by Straughan (1971) that solar radiation (visible) penetration through the sea surface measured during a plankton survey was reduced to 2.0 percent of the normal level by oil released in the Santa Barbara Channel blow-out in 1969. This was a rather massive spill estimated to have had a volume of from 500 to 5000 bbl/day (8×10 to $8 \times 10^2 m^3$ (Straughan and Abbott (1971) and Holmes (1969)) and the light measurements were made in the vicinity of the oil rig where the slick would likely be thickest. Measurements of light intensity effects produced by a thin Norman Wells' Crude oil film are reported by Adams, Scott and Snow (1974) based on a field experiment conducted on a shallow lake in the Mackenzie Delta in 1973. Sensors placed below the water were used to record the solar radiation passing through the slick at wavelengths of 450 nm and 680 nm with a 20 nm band-pass. Results indicated that as the slick was blown over the sensors the relative irradiance at 450 nm was reduced by the slick to 25% of the pre-spill value while the effect at 680 nm was to reduce the irradiance to about 50% of the pre-spill value. The slick thickness responsible for these results is estimated to be less than 0.1 cm, but greater than a monolayer, based on visual appearance of the slick at the time and later estimated from coloured 16 mm motion pictures of the slick as it formed a film on the water over the sensors.

In summary, the available data in the literature on the movement of oil entrapped in sea ice and its effects on the albedo or on the radiation regime is not sufficient to enable a satisfactory prediction of the thermal effects expected either locally or on a larger scale where climatic phenomena might be affected. The major reason for this lack of predictive ability is that unperturbed ice and snow covered water has not yet been fully investigated in the case of either fresh or marine waters. Radiation penetration throughout an ice cover and the thermal and biological consequences of this light field must be better understood before an adequate theory of the effects of oil on the system can be developed.

3.3 Effect of oil on primary productivity associated with sea ice

Photosynthesis by marine plants depends on a sufficient supply of available nutrients, light levels of P.A.R. sufficient for the species in question, appropriate temperature and salinity conditions, and in some cases a suitable substrate for attachment. An oil spill introduces an enormous variety of chemicals into the water which can produce modifications to the biochemistry of the plant as well as direct physical damage due to clogging and coating of plant surfaces. These first order effects, some of which may be long term, are accompanied by second order effects when the environment of the plant is modified by the presence of the oil. Furthermore, any perturbation of the primary producers in the food chain will have unpredictable consequences throughout the whole ecosystem.

Since it has been reported that a substantial proportion of the primary productivity by phytoplankton in Arctic and Antarctic waters occurs within the sea ice structure (Bunt and Wood (1963), Bunt (1963), Meguro *et al.* (1966), Bunt and Lee (1972), Matheke and Horner (1974), Horner (1973), Horner and Alexander (1972), Apollonio (1961), Clasby, Horner and Alexander (1973), and Welch and Kalff (1975)) or attached to the undersurface of the ice (Maykut and Grenfell (1974)), oil present in and below sea ice could seriously affect primary productivity. Mechanical effects produced on such growth by oil penetrating into the brine channels and coating ice surfaces could be very damaging. As well, the effects on photosynthesis that reduced light intensity due to absorption of solar radiation by the oil could be substantial. There is no literature on the effect of oil on this algal community. In fact, the relative importance of this bloom to the total Arctic marine ecosystem has yet to be established. It is clear, however, that substantial algal blooms occur in the spring before the ice cover melts after the intensity of solar radiation has become sufficient to melt the accumulated snow cover on the ice. Modifications to the thermal and salinity structure of the water-ice system could have significant effects on this algal community, but since little is known about the distribution of primary productivity throughout the water column during the annual melt process, the magnitude of the effects can not be predicted.

4. DESCRIPTION OF STUDY AREA

A site for the oil discharge experiments was chosen in a protected bay shown on Figure 1 (N70° 02', W124° 54') which is about 15 km south of a DEW line station (PIN MAIN). The oil was released in a small cove on the north side of this bay (see insert No. 2 of Figure 1 (a) or (b).

The Parry peninsula is for the most part low-lying and dotted with small land-locked lakes. In the region surrounding the oil spill cove (70° 01'N, 124° 55'W), elevations greater than 61 m above sea level are uncommon. The large bay on which this cove is located is the east arm of Balaena Bay located 16 km south of the north tip of Cape Parry. The terrain has been extensively altered by glaciation which ended 10,000 years ago (Pearl (1969)). This was the Laurentide (pre-Wisconsin) glacial stage, during which the direction of glacial flow was approximately east to west (Craig 1960), as can be seen by the orientation of roches moutonnes. The crests of hills are extremely rounded and the slopes have been smoothed. Large boulders scattered randomly over the hills (erratics) are very noticeable. Most of the ground consists of a medium-sized clastic till which is relatively well consolidated. The surface is fairly rough although it appears smooth in outline. The till is composed mainly of weathered dolomite. Freshly exposed surfaces have a very coarse crystalline appearance. The underlying bedrock is brown limestone, of Ordivician-Siluran age (approximately 425 million years old). Where outcrops occur, exfoliation is evident, forming screes of angular particles. This is due to the action of frost and is especially obvious along the steeper parts of the shoreline of the bay. There the screes will eventually form a beach. Considerable wind erosion also occurs as the annual average wind speed is 19 km per hour. Wind borne soil material was visible on the snow and ice on the bay in May and June, 1975. The intertidal zone of the small cove on which the NORCOR camp was established is made up of blackened rocks underlain by a layer of heavy mud. These rocks have been rounded by wave and ice action. Beyond a depth of about two metres the bay bottom becomes fairly smooth due to a heavy accumulation of organic detritus and wind borne silt. This was noticed in deeper water (six to seven metres) by W.A. Adams during a SCUBA diving reconnaissance of the oil spill cove. However, this muddy bottom cover was not present in all parts of the bay. A bottom of small, light-coloured stones was observed at the current-swept mouth at the western end and the shallow areas toward the eastern end of the bay. Tidal currents up to 0.45 m sec^{-1} were measured with a current meter at the mouth of the bay, but were extremely small in the rest of the bay. Maximum tidal currents would be slightly higher than this as indicated by the tide tables and the time that the current was measured.

5. METHODS

5.1 Irradiance field program

5.1.1 Sea ice

The measurements of solar irradiance under shorefast sea ice were made during the period May 11 to June 23, 1975, at locations indicated in Figure 1 (a). The Norman Wells (NW) or Swan Hill (SH) crude oil discharges were made throughout the winter from below the ice into the circular areas enclosed by plastic skirts hanging below the ice sheet. These are shown on the map in Figures 1 (a) and (b) and can be seen in the aerial photographs in Figure 2. Observations using underwater video equipment and by a diver indicated that the oil was contained within the skirted areas (NORCOR, 1976). However, some finely dispersed oil was found to have entered the water column since the diver found his gear to be contaminated by a film of crude oil (NORCOR, 1976). A quantum meter (Model LI-185, Lambda Instruments Corp., Lincoln, Nebraska) was used with two underwater quantum sensors (Lambda model LI-192S) mounted on the ends of a black metal bar 1 metre in length, one up-facing to record downwelling irradiance and one down-facing to record upwelling irradiance. Lewis (1975) suggests using a quantum instrument since it is more suited to the study of photochemical processes such as photosynthesis than an instrument measuring light in energy units. The sensors were silicon photodiodes mounted as shown in Figure 3 (a) with a response between 400 and 700 nm as shown in Figure 3 (b). The time of the readings and the cloud conditions were recorded to enable correlations to be made with angle of solar incidence and variations of solar spectrum. The housings are designed to limit cosine error to less than 2% for angles less than 82% from the normal axis to the plane of the sensor. Irradiance is measured to an accuracy of 5%. The readings taken in water have to be corrected for an immersion effect by multiplying the values by 1.4 as outlined by Smith (1969). The absolute calibrations are traceable to N.B.S. (Lambda, 1974). The two sensors had a difference in response of 0.5% which was not considered significant. Holes through the ice were cut with a 25 cm diameter power auger making as little disturbance of the ice and snow surface around the hole as possible. The general changes in surface conditions on Balaena Bay were documented with photographs taken over the site from a helicopter (see Figures 2(a)-(d). Some of the irradiance profiles were made with and without the holes being covered by pieces of 3 cm thick, green foam rubber to test for the "hole effect" mentioned by Schindler *et al.* (1974). Surface albedo measurements were made at the time of the under-ice readings by manually orienting the sensor support 30 ± 10 cm horizontally above the ice surface facing the direction of sun. The sensor support and associated surface electronics and cabling is shown in the photograph in Figure 4. Ice and snow depths were recorded for some of the profiles in order to estimate attenuation coefficients of the ice and snow cover independently of the water column. Temperature errors of sensors were ± 0.15% maximum.

5.1.2 Open water

In addition to the measurements in the spring of 1975 described above, a survey was conducted of the same bay in the open water period, September 5 - 10, 1974, from a small inflatable boat. The stations surveyed are shown on Figure 1 (a). Floating ice was observed at this time only at the west end of the bay near the outlet. Four of the same type of underwater sensors as described above were used for these measurements. Three sensors were attached to a water quality sonde by means of P.V.C. collars fitted to the ends of aluminum support arms bolted to the sonde, two to record downwelling irradiance and one to record upwelling irradiance while a fourth sensor unit was attached to the deck of the boat to record incident radiation as shown in Figure 5 and in the photograph in Figure 6. The sonde was rotated during light readings to avoid putting underwater sensors in the boat's shadow.

5.1.3 Monitor system

Two underwater irradiance systems, each consisting of five light sensors on a tubular support, were placed at 6.1 m depth in the bay in September 1974 close to the site of the proposed winter oil discharges (see Figure 1 (b) stations IS1 and IS2). The support platforms positioned the sensors at depths between 3.4 m and 6 m. These sensors were photodiode interference filter combinations equipped with operational amplifiers (United Detector Technology, type UDT-500) mounted in cosine corrected aluminum housings connected by cables to a power supply, readout, timing, and recording system in an instrument housing on shore. Details of this system have been described previously (Adams <u>et al.</u> (1974) and Adams (1974). Fortunately the output of the sensors was <u>manually</u> recorded at intervals throughout the experiment since a fault developed in the digital-tape cassette data-loggers which invalidated some of the taped data.

The two light-sensor supports were deployed by means of an inflated boat. A SCUBA diver ensured that the supports provided a horizontal platform when settled on the bottom. (Figure 7 (a) is a photograph of the support prior to its placement on the bottom of the cove). Some of the light sensors were equipped with neutral-density filters to provide information on the downwelling irradiance over the whole-visible and part of the UV and IR regions while others were equipped with 450 and 680 nm filters having a 20 nm band-pass. The construction details of these sensors built at the Carleton University Science Workshops, Ottawa, are given in Figure 8. The sensor support design and details of their placement in the bay can be seen in Figure 9. The temperature profile of the water below the ice cover was measured by means of a thermistor chain strung on each support and recorded on a second data logger in the equipment shelter on shore.

5.2 <u>Water quality parameters</u>

5.2.1 Multiparameter survey

5.2.1.1 September, 1974

A Hydrolab Surveyor Model 6D in situ water quality system (Hydrolab Corp., Austin, Texas) was used from an inflatable boat to measure five parameters as a function of depth at the stations shown in Figure 1 (a). The arrangement of the sonde containing the sensors, light sensor attachments and top deck units is shown in Figure 5. A diaphragm type strain-gauge pressure sensor, providing a full-scale response for 20 m depth, was used to measure the distance in metres between the sonde and the water surface. Accuracy of ± 0.2 m was found by checking cable length. Temperature of the water drawn through the sonde by the circulation pump on the underwater unit was measured by thermistor probes. The accuracy of the temperature readings was ± 0.1°C, the reproducibility ± 0.05°C. A four-electrode system that eliminates errors due to cable resistance and electrode polarization and helps reduce fouling effects on electrodes was used to measure conductivity in m mhos cm^{-1} (m siemens cm^{-1}) corrected to 25°C with an accuracy of ± 0.2 m mhos cm^{-1}. A membrane type gold-silver passive, polarographic cell was used in conjunction with a motor driven circulator on the underwater unit to measure dissolved oxygen concentration in p.p.m. to a precision of ± 0.05 p.p.m. The concentration was automatically corrected for the temperature coefficient of the membrane permeability, but not for salinity effects. The probe was calibrated against the oxygen in air and checked by means of Winkler analyses (see Strickland and Parsons (1968)). A glass electrode and silver-silver chloride solid state reference probe were used to measure pH on a scale of 2 to 12 with an accuracy of ± 0.05 pH units. The oxidation reduction (redox) potential (O.R.P.) of the water was measured with a platinum O.R.P. probe which shared the solid state reference probe of the pH system. Corrections for the probe response dependence on temperature were applied instrumentally. Results are reported in mV units on a 0 to ± 1000 mV scale. Probe response was checked by testing with a standard solution prepared according to Light (1972). The precision of these measurements was ± 1 mV. Sensor calibrations were stable over the period of measurements.

5.2.1.2 May - June, 1975

The sonde, calibrated as described in 5.2.1.1, was lowered through 25 cm holes cut through the ice at several stations in Balaena Bay during May and June, 1975, and water quality parameters recorded manually. In addition, a data logging system using a digital tape cassette unit similar to that described for the irradiance and temperature monitors, was interfaced to the Hydrolab Surveyor and to a Lambda LI-185 quantum meter multiplexed to four Lambda model LI-192S underwater quantum sensors. The meters and data logger were placed next to the ice hole in an aluminum box containing a 15 cm lining of polyurethane foam insulation. The water quality sonde and the quantum sensors were lowered to a fixed depth and the system left to record the data on an hourly (or on a one minute) basis. Power was provided by a 12 V battery and conserved by having the sensor systems shut down except just prior to the measurement cycle once each hour.

5.2.2 Conductivity - temperature survey

A Hydrolab model TC-2 conductivity meter with type 503 H temperature compensated four-electrode a.c. conductivity probe was used to obtain temperature and conductivity profiles through the ice in Balaena Bay in May and June, 1975, at the stations shown in Figure 1 (b). The temperature sensor, a thermistor, was calibrated against a platinum resistance thermometer standard in Ottawa to obtain an accuracy of ± 0.05°C. The conductivity readings, temperature compensated to 25°C, were checked against standard KCl solutions at various temperatures between 0° and 25°C and the overall accuracy in the conductivity estimated to be ± 0.5% of the range. Ice cores obtained with a 3-inch SIPRE corer were sectioned and the conductivity of the melted sections determined in the laboratory in Ottawa.

5.2.3 Water analysis for major ions

Water samples were recovered through holes drilled in the ice at the stations shown in Figure 1 (b) with an opaque 2ℓ P.V.C. Van Dorn sampler. Thirty-one one-litre samples stored and shipped in polyethylene bottles were analyzed for fourteen parameters by the Water Quality Branch, Analytical Laboratory at Canada Centre for Inland Waters, Burlington.

5.2.4 Field analysis for total alkalinity and pH

Water samples obtained during May and June, 1975, through holes in the ice at the stations shown in Figure 1 (b) at the time of in situ productivity measurements were taken the same day in 300 ml stoppered glass B.O.D. bottles to a work tent at the field camp where pH was determined to ± 0.05 pH units with a glass electrode using the Fisher Scientific Accumet Portable pH meter, model 150. Total alkalinity was determined by titration with standard hydrochloric acid solution using methyl orange indicator as described in Standard Methods (1971).

5.2.5 Chlorophyll analysis and ice core absorption coefficients

A section (from 88 cm to 113 cm) of an ice core obtained with a 3 inch SIPRE corer west of station BH6 in Balaena Bay, well away from the oil spills, on May 25, 1975, was analyzed for chlorophyll 'a' using the method outlined in Standard Methods (1971).

Sections of the above core (No. 3 at about 90 cm depth), sections of a core taken in NW2 on May 24, 1975, (No. 4 and No. 7 at 50 cm and 110 cm) and a section of a core taken in SH2 on May 11, 1975, (No. 3 at 40 cm) were shaped with a lathe in a cold room at -10°C into cylinders about 3.2 cm in diameter. The ice samples were placed in a cylindrical holder, temperature controlled to -4°C, and the absorption coefficients determined from the spectra obtained using a Cary 14 spectrophotometer in the Glaciology Division Laboratory in Ottawa.

5.3 Biological sampling

5.3.1 Field procedure

Water samples for plankton identification and abundance analysis were taken at the time, depth, and location of primary productivity experiments and stored in 120 ml polyethylene bottles with formalin to give a 5% preservative solution. Some 1 litre polyethylene bottles were used to store

6. RESULTS

6.1 Irradiance

The downwelling and upwelling irradiance data are presented in Table 2. It is possible to classify the station profiles according to the relative magnitudes of the upwelling to the downwelling irradiance ratios or reflectance functions at a given depth: most station profiles show ratios of 2% or less while a few stations show higher ratios. Six profiles are plotted for station DH1 in Figure 10, two of which indicate extremely high upwelling to downwelling ratios. It is possible that these higher ratios are due to the sensor support not hanging horizontally. However, the frequent observation of these higher ratios found in June suggests that they are not an artifact of the measurement technique. The zero depth results reported in Table 2 were obtained above the ice surface and have been used to calculate the albedos shown in Table 3. As expected, the highest albedos are recorded over fresh snow, 0.7 to 0.9, wet snow or ice giving about half of these values, and the presence of oil on the surface reducing the albedo to values of 0.1 to 0.3. The equation relating attenuation coefficient, k, to the intensity of light, I, penetrating to a depth, d where I_o is the incident light intensity is given by the formula:

$$\ell n \left(\frac{I}{I_o}\right) = -k\ d \qquad (1)$$

The attenuation coefficients of the downwelling irradiance were obtained from least-mean-square fits of the logarithm of the downwelling irradiance at a given depth divided by surface irradiance plotted as a function of depth. An example of one of these plots is shown in Figure 11 for station CH1. The irradiance readings for this profile, made for the two cases, with the hole covered and uncovered, were each fitted by a linear least-mean-square (l.m.s.) procedure and gave the same attenuation coefficients (slopes) and intercepts for each case within the estimated experimental error of the measurements. In some profiles a definite "hole effect" was noted i.e. the curve turned up or down at the shallow end which led us to reject the data close to the ice and obtain attenuation coefficients from the deeper linear part of the curve. The under-ice attenuation coefficients contained in Table 4 which average $0.215 \pm 0.097\ m^{-1}$, have been grouped into twenty-three stations close to the oil having a mean of $0.237 \pm 0.107\ m^{-1}$, and twelve control stations having a mean of $0.173 \pm 0.080\ m^{-1}$, where the uncertainty quoted is the standard deviation of the l.m.s. fit. It can be seen from the histogram in Figure 24, that there is a greater spread in the values of the attenuation coefficients for the oil group than the control group and that the mean is higher than for the control group. The attenuation coefficients from the open water irradiance data of September, 1974, are given in Table 5. The irradiance results from September, 1974, from which these coefficients are derived, are plotted in Figures 12, 14, 16, 18, 20 and 22. The mean attenuation coefficient is $0.290 \pm 0.062\ m^{-1}$ (based on 26 profiles) which is higher than the mean under ice attenuation coefficient. By making use of the measured ice depth, the albedo data to calculate the radiation entering the ice, and the radiation at the bottom of the ice sheet based on the fitted irradiance profiles, the attenuation coefficients of the ice cover have been calculated for June 17th and June 23rd. The results are presented in Table 6. The mean control station attenuation coefficient is 0.013 ± 0.003 cm^{-1} compared to 0.018 ± 0.004 cm^{-1} for the mean of the oil stations.

To give an indication of the effect of the oil on irradiance at the depths being used for in situ productivity measurements undertaken during the period of these studies, the mean of oil and control station irradiance data at 2.5, and 5.0 m depths has been plotted as a function of day number in Figure 25. There is a gradual increase in irradiance as the ice sheet melts, but a considerable fluctuation due to variation in ice surface conditions, movement of oil entrapped in the sea ice, and variation in light attenuation of the ice cover itself with water content on different days. The effect of the oil in reducing the light intensity is shown in Figure 26, which is a direct plot of intensity ratios rather than a logarithmic ratio for the period during which both control and oil areas were investigated. On only one occasion did the oil-station mean ratio exceed the control-station mean ratio and that was on June 2nd when it rained heavily and numbers of melt ponds developed on the ice resulting in oil moving throughout the spill area. The oil can be seen as it appeared June 7th in the photograph, Figure 2 (b). The reduced light intensity was more pronounced at 5.0 m than at 2.5 m with an average reduction of 43% at 2.5 m and 55% at 5.0 m over the period late May until the end of June.

The variation of irradiance ratios, in $\ell n\ (I/I_0)$, with day number at 2.5 m and 5.0 m depths for four stations (BH7, CH1, DH2 and DH1) are given in Figure 28. The variation with time observed is not a regular increase in $\ell n\ (I/I_0)$ as the ice depth decreases as might have been expected, but reflects the variability of surface conditions. There is a greater difference between the 2.5 m and 5.0 m $\ell n\ (I/I_0)$ values in the oil stations CH1, DH1, and DH2 than in the BH7 control station. Greater attenuation in the water column due to a greater abundance of planktonic scatterers and suspended oil droplets near the oil could account for this effect.

The light sensor output voltages from the under ice irradiance monitors are directly proportional to light intensity. These voltages indicated qualitatively that for the month of June: (1) the rate of daily increase in irradiance was greatest as detected by the 450 nm and 680 nm filter-equipped sensors as compared to the neutral-density filter-equipped sensors; (2) the rate of increase in the observed intensity with time was not significantly different between the 680 nm and 450 nm light; (3) the rate of increase was least for the sensors at a depth of 5.95 m and greatest for the sensors just below the ice at 3.35 m; (4) there was no visible biological growth on the diffusers of the light detectors when the monitors were recovered from the bay indicating that the above observations must be attributed to effects of light attenuation in the water column and ice sheet above the sensors and not to epiphytic growth on the diffusers.

6.2 Water quality

6.2.1 Multiparameter survey

6.2.1.1 September, 1974

The data from the stations shown in Figure 1 (a) have been plotted as a set of six sets of profiles, each set corresponding to a series of stations in Balaena Bay. These are shown in Figures 12 to 23. The dissolved oxygen (D.O.) has not been corrected for salinity e.g. at 32 p.p.t. and 0°C, the D.O. correction factor is 0.8.

6.2.1.2 May-June, 1975

The temperature, D.O., conductivity, pH and O.R.P. results are given in Table 7 for several stations on different dates. The high D.O. values are indicative of saturated or supersaturated conditions. At 0°C and 0 p.p.t. salinity, oxygen saturated water contains 14.6 p.p.m., and at 0°C and 30 p.p.t. salinity, oxygen saturated water contains 11.8 p.p.m. The results obtained from the data logging experiment were invalidated by a malfunction in the recorder.

6.2.2 Conductivity-temperature

The conductivities have been converted to salinities at 25°C which are given for all stations and dates during May and June, 1975, in Table 8. The water temperatures obtained at the same time are given in Table 9. To indicate the trends of these temperature and salinity vs depth profiles with time, and the relation between the two parameters, the temperature and salinity data has been plotted together against depth for control station BH7 between May 24 and June 25th in Figure 27. The development of a distinct halocline is evident and its role in determining the thermal structure of the water can be seen especially through mid to late June. The temperature and salinity at 2.5 m and 5.0 m depths for four stations (CH1, BH7, DH1, and DH2) have been plotted against time in Figure 28. These plots show a steady increase in the temperature difference between the warmer 2.5 m water compared to the 5.0 m water which develops a few days earlier at the stations DH1, DH2 and CH1 which are close to the entrapped oil. The difference which develops in the salinity between the 2.5 m and 5.0 m depths, corresponds roughly in time with the development of the temperature difference. However the salinity time dependence does not seem to show a distinct difference between BH7 and the other stations.

The stations have been grouped into those close to the entrapped oil, and hence possibly influenced by it, and those separated from the oil spill area (the BH series of stations and others in Balaena Bay away from the cove, see Figure 1 (b))-called control stations. Mean values of temperature and salinity have been calculated for the two groups for each day measurements were made. These results are plotted in Figure 29 for 2.5 m and 5.0 m depths. A difference develops between the mean oil and control water temperatures especially at 2.5 m of about 0.5°C. The oil group of stations warms more quickly with time than the control group. There appears to be approximately 1 p.p.t. higher salinities in the oil group.

Ice cores from control and oil areas of Balaena Bay were sectioned as follows: NW2 (core No. 1), May 24, 1975, 7 sections; N (core No. 2), May 20, 1975, 5 sections; SH2, May 11, 1975, 9 sections; and a control core taken west of BH6 between the island and the mainland, May 25, 1975, 3 sections. The cores were shipped frozen to Ottawa where they were kept in a freezer until analysis in July, 1975. The sections were melted in the dark to eliminate photosynthesis during melting and oil when present was removed with a separatory funnel. Conductances measured at 20 kH_2 have been converted to salinities both of which are reported for the measurement temperature, 22°C. The results are presented in Table 10. There is a higher average salinity in the cores containing oil than in the control core. There are also sections of higher salinity above the oil lenses which represent oil trapped in the ice when the ice sheet was forming.

6.2.3 Water analysis

The results of water sample analyses are given in Table 11 in two sections corresponding to 5.0 m and 2.5 m depths.

6.2.4 Alkalinity and pH

The results obtained from these analyses have not been given explicitly in the report, however they were used in the calculations to convert carbon uptake count ratios to total carbon fixed for each sample as described in Section 5.4.

6.2.5 Chlorophyll analysis and ice core optical properties

The section of the control core analyzed for chlorophyll contained 1.76 μgl^{-1} chlorophyll 'a'. This indicates that there was a significant population of photosynthetic organisms present in the ice at about 1 metre depth on May 25, 1975.

The results of the spectra run on ten samples cut from the ice cores are given in terms of absorbance in Table 12 (a). The attenuation coefficients, K_λ, are given in Table 12 (b). There does not seem to be a difference between control and oil K_λ values. However, the values of K_λ, except for NW2 (7) which averages about 0.8 cm^{-1}, have a mean of about 0.5 cm^{-1} which is about a factor of ten higher than the diffuse attenuation coefficients measured in the field. The samples were quite bubbly and porous in appearance while in the field the ice would have been saturated with water i.e. less scattering from bubbles and a lower K_λ. There is greater attenuation of the blue end of the visible spectrum which is expected since the ice reflects more of the blue light i.e. appears blue-green to the observer. Only one sample appeared to have oil entrapped in it and this sample, No. 8, gave much higher attenuation coefficients as expected from studies of the absorbance of crude oil.

An absorbance spectrum from 800 to 300 nm of Norman Wells' crude was run diluted in n-heptane (5.3% crude by weight) in 1 mm cuvettes v.s. heptane. The transmittance of pure crude oil for a 1 cm path length was calculated from the spectral data. Below 600 nm less than 0.3% of light is transmitted. Other percent transmittances are: at 650 nm, 18%, at 700 nm, 83%, at 750 nm and 800 nm, 100%. These results are not highly accurate, but do give some indication of the effect oil will produce on the spectral distribution of solar radiation below an oil slick in ice or water.

6.3 Biological identification results

6.3.1 Field observations

During the May-June, 1975 period at Balaena Bay ice cores were examined visually when possible for evidence of the epontic ice algae community described earlier in Section 3.3. No obvious discolouration of the underside of cores was observed. General observations on conditions in Balaena Bay in May-June, 1975, are reported in point form in Table 13. On June 4, 1975, dark areas of a few centimetres in diameter were noted just below ice surfaces which were free of snow close to CH1 (see Figure 1 (b)). This location was exposed to fallout from a burn of crude oil in early May which resulted in the snow melting from the area prior to melting from the rest of the cove and bay (see Figure 2 (a), bottom). Within a few days these dark areas developed into water filled melt ponds on the surface having diameters from 3 or 4 cm to holes 0.5 m wide and 0.5 m deep. The temperature and conductivity of a series of these holes, which were called algal melt ponds, because they contained an abundant mixed algal community, were measured and appear in Table 8D and Table 9D. There are generally low salinities 1 to 5 p.p.t. and temperatures well above 0°C and in some melt ponds as high as +4°C at the bottom of the holes close to the algae. The appearance of some of these melt ponds and the algae within them can be seen in the photographs in Figure 30. The microbiota in water sampled and fixed from these ponds has been identified (see C.O.I.C., 1975, for a detailed breakdown into genera present in four melt ponds close to CH1). The melt ponds contained plankton populations well in excess of those of the under-ice water column or of the ice itself (see Table 14). There was also present in these melt ponds a variety of macrophytic algae some of which have been identified according to station location in Table 15. The relative percent abundance of the plankton in the algal melt ponds is given in Table 16. The identification number code is given in Table 17. Some of the plankton are shown in photographs in Figure 31. There are considerable concentrations of green and blue-green algae present in these melt ponds. During the remainder of June after the clean-up procedure began on the afternoon of June 7, 1975, when the crude oil was ignited (see Figure 32 (a)-(d)), the surface of the ice surrounding the oil spill cove gradually became pockmarked by algal melt ponds. A survey was conducted June 18, 1975 in which it was estimated that from 0.1 to 0.5% of the ice surface was covered by algal material (see Table 18). The survey began 25 m from shore on the west side of the oil spill cove and went 182 m south with a width of 10 m. This was typical of surface conditions within a radius of about 0.5 km of the oil spill cove in late June. An absence of these characteristic surface melt ponds containing algae over the rest of Balaena Bay, was confirmed by walking surveys during mid to late June. The ice surface between Balaena Bay and the DEW line station PIN MAIN was surveyed on June 19 and June 21 on a walk out from the camp at Balaena Bay to the DEW line station and back. There were no melt ponds which resembled the algal melt ponds in Balaena Bay near the oil spills seen over the 13 km distance covered on the sea ice.

6.3.2 Quantitative results of identification study

The biota abundance information from the C.O.I.C., 1975, has been summarized in Figures 33 and 34. The upper code marked area of each bar represents the more abundant group of stations (i.e. oil or control) while the lower code marked area of less abundant stations is to be considered superimposed over the former groups. The five most abundant genera shown in Figure 33 are all diatoms and are more abundant in the oil group of stations. *Gyrosigma* (450) is shown again in Figure 34 to indicate the relative magnitude of the less abundant biota. The abundances of all the taxa shown in the histogram for the control station samples are arranged in order of decreasing relative cell counts (not applicable to some of the coded biota such as 100-annelidea of course) until code number 110 after which there are eight taxa present only in the oil station samples. Of those taxa present in both oil and control stations only two diatoms, *Chaetoceros* and *Cocconeis* and a dinoflagellate, *Gonyaulax*, are present in significantly higher abundance in the oil than in the control.

The distributions of organisms with depth has been determined in the water column for three stations (BH7, DH1, and II) and in an ice core taken in shore-fast sea ice 29 km north of Cape Parry. Plankton abundance has been plotted against depth in Figure 35. There is an indication of a peak in cell count close to the halocline, 2.5 ± 0.5 m, and also of a gradual increase in cell count with depth. The ice counts are lower than the water counts, but of the same order of magnitude as in water close to the underside of the ice sheet.

Figures 36, 37, and 38 indicate the variation in cell counts of *Nitzschia* and *Navicula* for the mean abundances of the oil and control stations at 2.5 m and 5.0 m depths. There does not seem to be a consistent pattern of cell count with time between oil and control stations evident from these plots. There is some evidence of a gradual increase in both oil and control daily means for the 5.0 m depth abundances of *Nitzschia* with time while the 2.5 m means decrease with time. This is however, not evident in the time course of the abundance of *Navicula*. The significance in the daily variation of differences between depth or between oil vs control station results is questionable according to the statistics of the sample abundances. The abundance increase apparent close to day number 155 could be a result of nutrient additions to the surface waters in the bay from runoff due to heavy rains June 2nd and 3rd.

A statistical summary of the abundance data making a division of stations into control and oil groups is given in Table 19. There is an increase of 12.3% in the number of genera present in the oil group over the number present in the control group of stations. This arises as follows: 55% of the increase comes from an increase at the 5% level, 32% comes from an increase at the 1% level (new genera), 12% comes from the 25% level, and 1% from the 50% level.

To investigate not only the change in total number of genera, but at the same time the distribution of abundances over the genera present, the use of a diversity index, H, has been recommended by Haedrich (1975). It is calculated from the equation

$$H = \Sigma\ p_i\ \ln(p_i) \qquad (2)$$

where p_i is the number of individuals of the ith species (or genera in this case) divided by the total number of individuals. Using the mean distributions for oil and control, H is 1.35 for the control stations and 1.45 for the oil stations. To assess the degree of specific change between these samples, an index of overlap called the percentage similarity (PS) can be defined as follows:

$$PS = 100(1.0 - 0.5\Sigma|p_{ia}-p_{ib}|) \qquad (3)$$

where p_{ia} is the number of individuals of the ith species (or genera) in sample 'a' divided by the total number of individuals in sample 'a'; p_{ib} is defined the same for sample 'b'. This function has been discussed by Haedrich (1975) and can be calculated from the same data required to calculate H. For the oil and control groups of stations it is 92.9%.

6.4 Primary productivity

The gross carbon fixed (m mol C), per volume (m^3), per hour for the light and dark bottles is given in Table 1B. The stations have been grouped into four categories; control, "influenced by oil", "in oil", and surface melt ponds. The "influenced by oil" and "in oil" categories are somewhat arbitrary and have been combined for most of the treatment into an "oil" category. The dark-bottle values are high relative to the light-bottle values. The implications of these results will be discussed in Section 7. The data has been combined into two groups depending on the approximate incubation times in Table 20. The mean of the light-bottle results, dark-bottle results, and the differences in these means, shows that there is an increase in the net primary productivity in the combined "oil" stations over the control stations of 55% for the four-hour incubations and of 15% for the twenty-four hour incubations.

In order to combine the 24-hour and 4-hour incubation data, the total radiation received at the in situ incubation locations during the incubation times was calculated for every experiment. In order to calculate these values, we made use of the solarimeter data recorded at Balaena Bay by NORCOR (1976) until June 7, 1975. This data provided an hourly value of radiation measured above the ice surface in langley units (cal. cm^{-2}). To extend the hourly solarimeter data until the end of June when the productivity experiments were terminated, the solar radiation unattenuated by the atmosphere received at latitude N70°, was combined with the weather records (hourly cloud opacity and cloud amount) of the Atmospheric Environment Service, PIN MAIN, Cape Parry, weather station, to obtain values equivalent to the solarimeter record. Then using the diffuse attenuation coefficients for the snow, ice, and water obtained from the irradiance measurements at each of the ice stations, the solar radiation received at each under-ice incubation location over the period of incubation was estimated. The average productivity per langley was then calculated and the daily net productivity calculated by multiplying this average production by the total radiation received at that incubation site during that day. The daily rate of production per unit surface (m^{-2}) was calculated from the 2.5 m and 5.0 m results according to the method outlined by Vollenweider (1969). The final results of this calculation are presented in a histogram in Figure 39. There are 17 stations in the control group with a mean of 6.7 m mol C m^{-2} d^{-1} and 38 stations in the oil group with a mean of 8.4 m mol C m^{-2} d^{-1} which is a 25% enhancement of oil above control. The variation of mean net primary production with time is given in Figure 40 for the oil stations and the control stations. There are two spikes in the oil station points, a large one around June 2 when there was heavy rain and a smaller one June 9 following the beginning of clean-up burns of surface oil pools June 7. The oil points lie above the control points except in late June when there does not appear to be a significant difference between the oil and the control stations. It should be pointed out that the spread of values in the net productivity in the histogram curves in Figure 39 result in large measure from the variation in net productivity with time as seen in Figure 40.

7. DISCUSSION

7.1 Irradiance

The optical properties of natural waters or those of ice are generally more sensitive to the presence of suspended light-scattering material than to variation in the salinity or to the concentration of other dissolved material. In general, the attenuation of visible radiation is due more to scattering processes than to absorption of radiation (Lewis, 1969). In the present study, the under-ice water had a diffuse attenuation coefficient of 0.215 m^{-1} compared to 0.0444 m^{-1} as found by Smith (1973) for Arctic ocean water. However, the measurements of Smith (1973) were made off-shore below the permanent Arctic ice pack in early May before the disappearance of the snow cover and onset of planktonic growth. Results reported by Grainger (1971) on light intensities in Frobisher Bay close to land, as in the present work, for both open water and ice-covered conditions, have been analyzed to obtain the following mean water diffuse attenuations coefficients: under an ice cover, 0.31 ± 0.17 m^{-1}; open water, 0.20 ± 0.03 m^{-1}; mean of ice covered and open water 0.21 ± 0.08 m^{-1}. The mean diffuse attenuation coefficient is close to the value obtained, 0.15 m^{-1}, in the present work. The higher under-ice coefficient is not significantly greater than the open-water value due to the few variable data reported from ice stations. However, the higher attenuation found in open water in the present study (see Figure 24) is significant, and results from sediment suspended through wave action in the shallow water of the bay and the summer plankton bloom. It is also noticeable in the open water data of Table 5, that the attenuation coefficients were generally greater in the shallower stations as a result of suspension of scattering material by tide and wave action.

The reflectance function, or upwelling to downwelling irradiance ratio, was reported by Smith (1973), to be 0.0189 ± 0.0006 between 40 and 120 metres below the off-shore pack-ice. Most of the ratios found in Balaena Bay were of this magnitude, however, they varied with depth to a much greater extent as would be expected in a shallow bay. Also, it is possible that due to the presence of a sharply defined halocline, found both in September, 1974 and in May and June, 1975, scattering material including oil emulsified by water percolating through the porous sea ice in the spring, could have been trapped in the density gradient of the halocline. The higher ratios found later in June as the oil began to move through the brine channels to the surface, suggest that oil and/or planktonic scattering layers were present. The variation in this ratio shown on Figure 10 for an oil station DH1, between 2 and 3 metres, supports such an explanation. In addition, the mean attenuation coefficient of oil stations is 40% greater than that of the mean of under-ice control stations. Although the range of attenuation coefficients of both oil and control stations is large, as can be seen in the histogram of the results in Figure 24, the larger range of values for the oil stations, suggests the presence of a higher concentration of plankton under the oil in some of the oil stations. This is supported by the primary productivity studies. Also the presence of scattering layers of emulsified oil droplets in the water column would give rise to greater attenuation by scattering and absorption in the oil stations.

The average attenuation of the ice and snow cover June 17th and 23rd was 0.015 cm^{-1} which compares to values of 0.1 cm^{-1} and 0.5 cm^{-1} for soft new snow or hard powder snow respectively and 0.02 cm^{-1} for clear Ottawa River ice reported by Maguire (1975). The lower mean attenuation observed in the ice cover at Balaena Bay is due to the high melt-water content of the decaying sea ice in late June. However, ice samples returned to Ottawa gave K_λ values close to 0.5 cm^{-1} (see Section 6.2.5) close to the snow values of Maguire (1975). The mean attenuation of the ice in the oil stations is 40% greater than that of the mean of control station results, which indicates that oil trapped in the ice and ponding on the surface as well as biological activity in the ice produces a similar effect in the ice itself as in the water column below the ice. Due to the high absorbance of crude oil, very little oil in an ice sheet could greatly reduce the transmitted radiation (see Section 6.2.5).

The observation of a reduction of irradiance at 2.5 m and 5.0 m depths presented graphically as a function of time in Figure 26, shows that by the end of June, when the oil discharge area was ice-free and the bulk of the oil burned off, mechanically removed, or blown to the edges of the open area, the control and oil areas have very little difference in subsurface irradiance.

The observations of the intensity of filtered light is only interpretable qualitatively. Since the bandwidths chosen for the blue-green and red filters are those absorbed by photosynthetic pigments in algae, variation of the response of these sensors should be directly related to the concentration of phytoplankton in the water and ice above the sensors. Light in the blue-green (450 nm) region would be attenuated by crude oil much more than in the red (680 nm) (see Section 6.2.5). Since both red and blue-green responded similarly, it can be concluded that phytoplankton was probably responsible for the variations observed over the period of observations in the filtered sensor responses. The neutral density equipped sensors were not as sensitive as the filter equipped sensors and would not give a significant response for selective absorption in the red and blue-green by phytoplankton. This lack of variation relative to the filtered sensors was observed. The greater variation observed for the sensors just below the ice probably reflects the downward movement of the dark adapted spring phytoplankton bloom in response to the higher under ice light levels as the snow cover was melted and the ice became more transparent. There seems to be no evidence of a difference in response between the sensors placed close to the oil discharge and those placed further away from it.

7.2 Water quality

Throughout the Arctic Ocean there is a surface layer (100 to 150 m deep) of low salinity water (30 to 32 p.p.t.) of low temperature, below which lies a second layer, where there is sufficient depth, of higher salinity water (34 - 35 p.p.t.) which is somewhat warmer. The surface layer of low salinity in the Arctic Ocean, which constitutes most of the Beaufort Sea water mass, results from run-off from rivers such as the Mackenzie which has been studied by Cameron (1952, 1953) and as part of the Beaufort Sea Project by Herlinveaux and de Lange Boom (1976) and from the surplus precipitation over evaporation as discussed by Zenkevitch (1963). However, in the part of Balaena Bay studied in the present project the maximum depth is about 18 m. The mouth of the bay is quite shallow having a sill at only 2 or 3 m depth somewhat isolating the bay from water masses in the Beaufort Sea. The stratification of salinity and temperature observed in September, 1974, indicated that the lower water mass in the bay was warmer and more saline than the upper few metres. When holes were drilled in May it was found that a uniform high salinity (32 p.p.t.) and low temperature (-1.6°C) persisted throughout the water column.

Some evidence of a heliothermal effect in the bay can be seen in the profiles which show a rise in temperature close to the dark solar radiation absorbing bottom (Hudec and Sonnenfeld, 1974). The presence of the very extreme halocline during late May and June, 1975, in which the density gradient of the salt prevents convection and mixing between the upper few metres of fresh water above the halocline and the denser waters below, tends to stabilize the water column and greatly influences the nature of biological and thermal processes in this upper layer containing the melting ice sheet. The extent to which the development of this temperature-salinity gradient in Arctic waters influences the formation of the polar ice by modifying the heat flux from the underlying warmer water masses has been discussed by Aagaard and Coachman (1975). They conclude that the destruction of the halocline and the release of heat from the warmer deep water mass could restrict the formation of winter ice. It appears from the results obtained in the present study that the oil entrapped in the ice has not brought about a significant change in the development of thermal and salinity stratification. The slightly higher salinities close to the oil are probably a result of dissolved ionic components from the crude oil. A marked temperature inversion which developed in the upper layer of fresh water above the halocline during late June is indicative of the extent to which the water masses are separated by the halocline at 1.5 to 2.5 m depth. The behaviour of the temperature and salinity profiles correlate well with ambient air temperatures and precipitation records at the site.

Some of the temperatures that were recorded in the water under the ice seemed to be lower than would be predicted on the basis of the salinities. To investigate the possibility of supercooling, the temperature-salinity probe calibration was carefully checked in Ottawa. It did not deviate from the specifications given in Section 5.2.2. In addition, thin plates of ice were seen on the cable and rising through the water column from below the bottom of the ice sheet while measurements were in progress. It is suggested in agreement with the interpretation of similar phenomena observed by Keys *et al.* (1969) in Disraeli Fiord, that low salinity water was being frozen at the interface of the colder more saline water at the halocline and that there could have been some supercooling associated with this freezing process.

The chemical composition of water and ice is of importance in determining the level of primary productivity possible in the ice-water system. The fixation of a mole of carbon by photosynthesis is accompanied by the uptake of nitrogen and phosphorus in the ratio C:N:P: = 106:16:1 (Fleming, 1940) and the release of a mole of oxygen gas. It is therefore possible to relate the primary production to one or to several of these chemical parameters if the system is closed (i.e. gases are not lost to the atmosphere and currents do not alter concentrations), and if respiration and decomposition processes are small in comparison to photosynthesis (Richards, 1965). When an ice cover forms over a water body the rate of exchange of gases with the atmosphere is greatly reduced. The high concentrations of dissolved oxygen reported in

Section 5.2.1 represent concentrations sometimes equivalent to saturation or supersaturation conditions in agreement with a level of oxygen production that would be expected in May and June in a shallow bay sealed by ice or in a bloom condition in open water, (September 1974). Unfortunately, there are no primary productivity results to confirm that a bloom condition existed in September, 1974. The low salinity of sea ice (see Section 6.2.2) compared to sea water from which it forms has been observed by others and the underlying mechanisms discussed in great detail (Lake and Lewis, 1970). The formation of sea ice does not proceed by a uniform mechanism but in at least three stages which results in three recognizable forms of sea ice. These have been discussed by Oradovskiy (1974) for Antarctic sea ice. Initially, the ice forms on open water accompanied by snow falling and mixing with the water, then sea ice begins to form from below the new ice sheet from sea water, and finally toward the end of winter underwater ice, rather less dense than the second form of ice, grows down from the ice sheet. These processes are accompanied by a complex zone refining effect by which pockets of nutrients are concentrated in the ice and below the ice. Since a lens of oil would prevent salt from diffusing down from the solid-liquid boundary, the observations in ice core sections of higher salinities (see Section 6.2.2) associated with oil pockets is expected. Our sampling methods using the 2 litre Van Dorn sampler were not on a microscale which would have been necessary to show up the details of this phenomenom in the water column just below the ice. In the ice core salinity results, there were indications of the complex nature of the nutrient distribution since salinities (hence nutrient concentrations) were quite variable down the length of the cores. The variation in ice type (density, crystal orientation, salinity, presence and size distribution of gas bubbles) with position in the core is accompanied by a wide variation in the optical properties of the ice (see Section 6.2.5). If these phenomena were greatly affected by the presence of the entrapped oil, there might have been expected to have been some changes in water chemistry in the water column below the ice containing the oil. The results do not show any consistent variation that can be attributed to oil.

7.3 Primary productivity

The results in Figures 39 and 40 indicate that there was a level of primary productivity typical of Arctic marine waters at 70°N latitude in Balaena Bay during the months of May and June, 1975. The productivity values obtained by Petersen (1964) in 1959 and 1960 for Godhavn harbour, West Greenland also at about 70°N latitude, have been sketched on Figure 40. Our productivities are of the same order of magnitude as those of Petersen. If it is assumed that the sea ice, light and nutrient conditions are similar in Godhavn, the total annual phytoplankton production in Balaena Bay might be similar to that reported by Petersen, 3 mol Cm^{-2} yr^{-1}. In fact taking a yearly average of 10 m mol $Cm^{-2}d^{-1}$ for Balaena Bay from Figure 40, allowing for higher summer productivities to balance lower winter productivities, a value very close to 3 mol Cm^{-2} yr^{-1} is obtained for Balaena Bay. To establish the relative level of primary productivity in Balaena Bay compared to marine waters throughout northern latitudes and in temperate latitudes, Table 21 has been compiled. It would appear that 3 mol Cm^{-2} yr^{-1} represents a moderately productive marine system for the Canadian Arctic e.g. Welch and Kalff (1975) report 2.7 mol Cm^{-2} yr^{-1} for Resolute Bay, Grainger (1976) reports 4.2-8.3 mol Cm^{-2} yr^{-1} for Frobisher Bay, and there are a series of lower values. By comparison, in temperate marine waters, values often reach 10-20 mol Cm^{-2} yr^{-1}. The maximum possible in situ primary productivity in the natural environment is estimated to be from 150-300 mol Cm^{-2} yr^{-1} (Parsons and Takahashi, 1973).

The planktonic primary productivity reported is only one of three sources of production in the estuarine and inshore ecosystem. Benthic production and ice algae can account for a large proportion of the total productivity in these environments (Welch and Kalff, 1975; Metheke and Horner, 1974). However methods to measure the productivity of sea ice algae are quite elaborate and require the use of a diver (Clasby, et al., 1973) and were not attempted as part of this project. As indicated in Section 6.2.5, 1.76 μg ℓ^{-1} chlorophyll 'a' was found in the ice core analysis for a core taken May 25, 1975. This is lower than values given by Clasby, et al. (1973) which ranged from a high of 3 x 10^3 μg Chl. 'a' ℓ^{-1} in late May to a low of 300 μg Chl. 'a' ℓ^{-1} June 8 in the bottom surface of sea ice at Barrow, Alaska in 1972. Because the core section we analyzed was not from the ice bottom, where ice algal activity would have been maximum, it is reasonable to conclude that Balaena Bay probably did have an epontic ice algae bloom, perhaps as great as that in the Barrow study (Matheke and Horner, 1974) which gave productivities of the order 12 m mol $Cm^{-2}d^{-1}$. The productivity observed in melt ponds on the ice surface in Balaena Bay will be discussed separately in Section 7.4. In a shallow (average depth, 8 m) non-turbid in-shore area such as Balaena Bay, annual benthic productivity would likely be about a factor of ten greater than the combined epontic and planktonic production as was found by Clasby et al. (1973) near Barrow, Alaska, at in-shore sites about 5 m in depth. Welch and Kalff (1975) have calculated the opposite relative magnitudes of the benthic and planktonic production in Resolute Bay which has an average depth slightly greater than Balaena Bay (average depth, 11.3 m). They estimate that 33% photosynthesis is benthic and 67% is planktonic, and that due to snow cover, the epontic contribution is negligible. It would seem that all that can be concluded from the literature is that benthic and epontic production is probably of nearly equal magnitude to planktonic production.

The harmful chemical effects of crude oil on aquatic plants is generally considered to be due to the lighter fractions of the crude oil (see Baker, 1971; and Snow and Scott, 1975). These light fractions have been found to remain trapped in the ice for the remainder of the winter when crude oil is discharged under an unbroken ice sheet (NORCOR, 1976) since the weathered crude appearing on the ice surface of Balaena Bay in June was essentially unchanged in its initial properties. Despite the presence of high concentrations of these toxic compounds that must therefore have been present in the water in the cove near the discharged oil when the oil began moving through the ice, the abundance and species composition of the phytoplankton does not seem to have been greatly perturbed when compared to the nearby phytoplankton community outside of the cove. This result is in agreement with the effects observed on phytoplankton by Hellebust et al. (1975) when Norman Wells' crude was applied to open water in a small subarctic lake near Norman Wells, N.W.T. By contrast, it has been reported by Shindler et al (1975) that the abundance of bacteria is enhanced, but initial diversity is reduced by crude oil in winter tests in small fresh water ponds near Ottawa. Roeder et al. (1975) have reported that the diatom community in fresh waters in northern Canada are not grossly affected by the presence of crude oil. Our results also indicate a slight enhancement in phytoplankton abundance and a greater diversity index for the oil stations than for the control stations.

The high dark-bottle gross productivities found in our study are of interest because high dark counts have been reported by other investigators using the ^{14}C uptake method. This phenomenon seems to occur in waters containing high organic loads. Petersen (1964) reported that in one experiment he found high carbon uptake in both light and dark bottles in Godhavn harbour after a factory ship had spent about one month preparing fish fillet which polluted the harbour with fish offal and in addition a sperm whale had been taken into the harbour for flensing. He suggests that unusually high bacterial activity could have accounted for the high ^{14}C uptake. The presence of high concentrations of organic components dissolved in the water from the crude oil could have produced high dark bottle results from a similar bacterial mechanism, but they were often high in the control stations well away from the oil. Considerable experimental effort has been applied to studying the dark survival of phytoplankton and heterotrophic carbon uptake by phytoplankton (Bunt and Lee, 1972; Horner and Alexander, 1972; Smayda and Mitchell-Inness, 1974). There is no agreement on whether phytoplankton survive the dark of the polar winter with its extended period low-light levels and intense cold under snow-covered ice, by heterotrophic uptake of suitable dissolved organic compounds or remain essentially dormant. Experiments in the laboratory with isolated cultures have not been conclusive in settling this question since the situation in the natural environment is undoubtedly more complex with a mixed population of bacteria and microalgae. (Smayda and Mitchell-Innes, 1974). In any event, the observation of many high dark-uptake values in Balaena Bay is not inconsistent with either hypothesis i.e. bacterial activity or phytoplankton heterotrophy.

Although the availability of a sufficient supply of essential nutrients is a necessary condition for photosynthesis by phytoplankton, the spring marine bloom is seldom limited by nutrients and in fact there is considerable evidence that nutrients such as nitrogen concentrate because ammonia is absorbed and accumulated in the ice (see Oradovskiy, 1974). The levels of nitrogen, 0.36-1.07 μg at l^{-1}, and phosphorus, 0.14-0.97 μg at l^{-1}, in the sea water below the ice in spring in Balaena Bay are as high or higher than the values found in Frobisher Bay by Grainger (1971) or at Igloolik by Grainger (1959). It therefore appears that in Balaena Bay, except in surface melt ponds where nitrogen concentration was found to be lower, <0.36 μg at l^{-1}, light is the growth limiting factor. The intense algal activity in surface melt ponds which received extremely high light levels, suggests that the under ice plankton is a shade adapted flora. When there is considerable vertical stabilization of the water column throughout the euphotic zone, as is found in Balaena Bay, plankton adapt physiologically to the widely varying light intensities even though the occurrence of species may be nearly identical at different depths as was found in the present study (Steemann Nielsen and Hansen, 1959). It therefore appears that even though light levels were lower under the ice close to the oil area in Balaena Bay, the higher plankton abundance, perhaps due to reduced zooplankton grazing as a result of chemical inhibition from components in the crude oil, more than compensated for the lower light levels and accounts for the nearly equivalent productivity of the oil and control groups of stations.

It does not appear likely from physiological studies of diatoms reported by Steemann Nielsen and Hansen (1959), Sorokin and Konovalova (1973), Marre (1962), Bursa (1961), and Guillard (1962), that the rather subtle changes in temperature and salinity observed in Balaena Bay could have a significant effect on the phytoplankton primary productivity or species distribution. The identification study in Balaena Bay confirms the succession of spring "shade" adapted *Pennatae* diatoms to summer open water "sun" adapted *Centriceae* diatoms discussed by Bursa (1961) which is characteristic of ice-infested Arctic waters.

7.4 Surface melt ponds

The observation of macrophytic sea weeds growing abundantly in melt ponds on Balaena Bay was unexpected. As discussed in Section 7.3 the light levels available for photosynthesis would have been several orders of magnitude greater in this environment than below the ice in the water column while nutrient levels were similar. The diatom cell abundances, in Table 14, indicate very large differences in cell counts between the planktonic (1-15 x 10^3 cells ℓ^{-1}) and melt pond (5-50 x 10^5 cells ℓ^{-1}) water samples. In addition, there were very abundant *Chlorophyta* (green algae) especially *Chaetomorpha melogonium* (Web. & Mohr) Kütz, called filamentous algae in the survey, in Table 18, and Phaeophyta (brown algae), especially *Fucus distichus* L., called a branched algae in the survey in Table 18. Associated with these seaweeds were clumps of blue green algae and diatom colonies. Some indication of the intense growth in these melt ponds is evident in the photographs in Figures 30(a) - (d). Although no quantitative measurements of increase of biomass with time were made, it was clear that the algae were growing because the size of the plants increased from day to day. Since surface melt ponds in areas of ice in the vicinity of Balaena Bay, but far from the oil spill, did not develop such biota, it is important to assess what conditions could have stimulated this bloom. The stimulation of blue green algae is often associated with eutrophic conditions in fresh water (Roeder et al, 1975 ; Snow and Scott, 1975; and Hellebust et al, 1975). The lower nitrogen values found in the melt ponds are interesting since blue green algae are known to have nitrogen fixing capability. It is possible that dissolved nitrogen gas in these surface ponds are cycled through the epiphytic blue-green algae community to the macrophytic brown and green algae and that low nitrogen in the water reflects the high consumption due to the vigorous algae activity. An additional source of nitrogen was available close to the oil spills. This was from nitrogen containing organic molecules in the crude oil. Scott (1975) has estimated that Norman Wells crude contains about 0.5% nitrogen. Perhaps even more significant was the mineral content of the oxidized crude oil which fell over the ice surface following the clean-up burns. In agreement with the high mineral composition (especially Si, ~20%, P, ~10%) of airborne particulate collected down-wind following a fire that burned 200 barrels of crude oil per hour for several weeks in 1973 at an oil well near Glenrock, Wyo. (Van Valin et al, 1975), an analysis of Norman Wells and Swan Hill crude oil reveals the presence of a considerable variety of metals (see Table 22) that would have been present in the soot observed on the ice surface. It is possible that one or more of these metals perhaps, vanadium or zinc, could have been limiting, and when present in the melt ponds, the algal blooms were stimulated. Kanwisher (1957) has studied the capacity of *Fucus* to survive freezing and drying cycles in the Arctic at temperatures as low as -40°C. *Fucus* is able to begin photosynthesis immediately upon thawing. In the areas of melt pond algae growth, the frozen *Fucus* was probably present in the ice from the previous autumn along with pieces of green algae and diatom spores which revived in the melt ponds under what must have been nearly ideal growth conditions.

The consequences of these algae communities to the structure and thermal properties of the ice sheet were considerable. As the algae was strongly radiation absorbing, especially the dark brown *Fucus*, and possibly metabolic heating was present, considerable local melting occured as discussed earlier (Section 6.3.1). This heat was concentrated at the bottom ice-water interface of the melt ponds. Several melt ponds were observed in which the algae melted down through the ice a depth of about 1 m and then fell into the water below, leaving a hole somewhat resembling a seal breathing hole. The extent of coverage of the ice by algae growth in melt ponds suggests that biological activity is a significant factor to consider in heat balance studies of the sea ice regime.

8. CONCLUSIONS

8.1 Light levels in the visible region measured during May and June in Balaena Bay in the area exposed to the winter under ice discharges of crude oil were significantly reduced compared to uncontaminated areas of the bay.

2. Salinity was increased and the temperature slightly raised in the water column directly below the oil contaminated ice, but the effects were restricted to the top few metres of the water column. Chemical composition of the water below the ice was not significantly perturbed by the presence of the oil. Balaena Bay has water properties and hydrography typical of the in-shore Beaufort Sea.

3. Primary productivity by the phytoplankton below the ice in Balaena Bay was moderate (~ 3 mol C m^{-2} yr^{-1}) by Arctic standards and slightly enhanced by the oil discharges.

4. Phytoplankton abundance and diversity in the water under the ice was enhanced by the oil discharge. The phytoplankton consisted mostly of glaciophylic *Pennatae* diatoms.

5. A diverse and abundant algae flora including macrophytes was found in surface melt ponds exposed to airborne combustion products of the crude oil burned from the ice in Balaena Bay. This algae was not noted on the surface of the ice in locations remote from the oil spill area. The algae present in melt ponds included blue-green, brown and green algae species not found to be present in water below the ice.

9. IMPLICATIONS AND RECOMMENDATIONS

9.1 Scientific

1. The reduction in light levels and other perturbations produced by oil entrapped in sea ice have not reduced the spring planktonic primary productivity nor greatly changed phytoplankton diversity. This suggests that in the Arctic, the planktonic component of the food chain is relatively stable when exposed to a crude oil insult compared to other more vulnerable components at higher trophic levels.

2. These results apply to the exposure of an enclosed non-turbid marine bay to two kinds of crude oil, Norman Wells and Swan Hill, and should be extrapolated with caution to other locations or to estimating the effects of other kinds of crude oil on primary productivity. However, in-so-far as the results depend on the physical properties of the crude

oil such extrapolation to other crude oil types is justified.

3. The procedures used to clean up the crude oil at Balaena Bay by burning the crude oil from the ice surface in late spring, produced unexpectedly large and diverse algal production in melt ponds on the ice surface which in themselves caused a significant melting of the ice. This emphasizes the need to have a good understanding of the marine sea ice ecosystem if the response to drilling activity is to be predictable. The timing and location of different clean up procedures are critical to minimizing the effect of crude oil on the environment.

4. The ten-day increase in the open water period produced by an early melt of the ice cover contaminated by crude oil will induce an earlier change-over in the diatom community to the open water *Centriceae* "sun" flora with unkown ecological consequences.

9.2 Offshore drilling

1. The fact that crude oil discharged below the ice during winter spreads over a relatively confined area and then is trapped by the growing ice sheet seems to have limited harmful effects of the oil on the spring plankton primary production. Efforts to remove oil trapped in pockets in the ice sheet during the winter would not be necessary to protect the plankton diatom community especially in deep water.

2. The preferred period to remove the oil from sea ice by combustion or by mechanical means is the short time between brine channel development, when the oil rises through the porous ice and forms pools on the surface of the ice, and breakup. The ecological danger associated with combustion is the uncertainty as to the effects that enhanced production and modified floral and faunal composition over a wide area might have on the total ecosystem.

9.3 Open Question (not verifiable from this study)

1. The spring planktonic component of the total primary production has been assessed and found to be little affected by the crude oil. It is known that the sea ice (epontic) and the benthic contributions are often as large as the planktonic productivity. The sea ice community would likely be very severely reduced by oil contaminated ice since it grows on the under side of the ice surface which would be oil coated. The benthic productivity which occurs in the short open water period would likely be affected only if oil were carried to the bottom adsorbed on sinking detritus.

2. Oil discharges in winter under ice-covered turbid marine waters (such as those in Mackenzie Bay) would produce a similar slight enhancement in spring planktonic productivity, but severly reduce benthic production due to sinking oil at breakup.

10. NEEDS FOR FURTHER STUDIES

10.1 Gaps in knowledge

1. The effect of different types of crude oil on the primary productivity of the ice-covered Arctic marine system is not known.

2. The experimental oil spills conducted in this study were in very clear water. For a more complete understanding of the Beaufort Sea environmental response to oil, information derived from a similar spill experiment in turbid water must be obtained.

3. The reasons for high dark-bottle ^{14}C uptake are not understood.

4. The occurence of high algae productivity in surface melt ponds on sea ice is not well documented nor are the nutrient dynamics of such systems understood.

5. The changes induced by oil in sea ice on the spectral distribution of light in and below the ice are not known and yet such information is vital to understanding the response mechanism of phytoplankton to changes in light-intensity brought about by an oil spill.

10.2 Proposed future work

1. The oil spill site at Balaena Bay should be visited each year for the next three or four years to establish a base line by which its behaviour in 1974/75, when the oil spills were conducted, can be assessed. This is especially important in understanding the mechanism of surface melt pond formation (related to a verification of the proposed oil combustion product hypothesis to explain algae abundances on the surface).

2. An experiment similar in magnitude to Balaena Bay, but in a turbid estuarine environment, should be conducted in the Beaufort Sea.

3. The changes induced in the spectral distributions of light penetrating snow-and ice-covered water should be measured in spring and correlated with biological, chemical and physical water quality parameters. This information is required to properly describe the sea ice environment which will be affected by the off-shore drilling program.

4. A scientific task force should be assembled with defined areas of responsibility to undertake a field program in the Beaufort Sea immediately following the occurence of an accidental blow-out. This group would have no direct clean-up responsibility, but would take advantage of the perturbation to the environment brought about by the large release of oil and gas to increase scientific understanding of the Beaufort Sea and therefore aid in its future management. The initial personnel for the organization of this task force could be obtained from the Beaufort Sea Project investigators, but the task force would have to be kept current by appointment of new members to avoid loss of operational capability.

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ABBREVIATIONS USED

B.O.D.	Biological oxygen demand
CCIW	Canada Centre for Inland Waters
DEW	Distant Early Warning (Station)
D.O.	Dissolved Oxygen
IBP	International Biological Project
IR	Infrared
N.B.S.	National Bureau of Standards
O.R.P.	Oxygen reduction potential
P.A.R.	Photosynthetically active radiation
P.V.C.	Polyvinylchloride
UV	Ultra violet

TABLES

21. Phytoplankton production estimates from several far northern marine locations and from some comparable regions in lower latitudes (from Grainger (1974) with some additions).

22. Analysis of unweathered crude oil samples.

Table 1 Under-ice primary productivity, Balaena Bay, N.W.T., May-June, 1975

A. Dates, stations, and depths of measurements (for station locations see site plan; class of station: C, control; I, influenced by oil; O, in oil)

Date	Station	Depth/m	Time in	Time out	Comment
May 13	DH1(I)	4.5	12:30	16:30	
		6.5	12:50	16:50	
May 16	DH1(I)	2.5	13:15	17:15	
		4.5	13:15	17:15	
May 26	DH1(I)	2.5	9:30	13:35	
		5.0	9:20	13:35	
	DH2(I)	2.5	10:20	14:37	
		5.0	10:10	14:37	
	BH7(C)	2.5	11:25	15:00	
		5.0	10:50	15:00	
May 29	DH1(I)	2.5	9:20	13:20	
		5.0	9:25	13:20	- lost one dark bottle
	DH2(I)	2.5	10:05	14:00	
		5.0	10:10	14:00	
	BH6(C)	2.5	10:30	14:15	
		5.0	10:40	14:15	
	BH7(C)	2.5	9:45	13:30	
		5.0	9:50	13:30	
May 30	BH7(C)	2.5	15:30	19:20	
		5.0	15:30	19:20	
	DH1(I)	2.5	16:50	21:10	
		5.0	16:55	21:10	
	DH2(I)	2.5	16:00	19:57	
		5.0	15:55	19:57	
	CH1(I)	2.5	16:35	20:35	
		5.0	16:25	20:35	
June 1-2	DH1(I)	2.5	17:00	15:40	- first 24 hr set of data
		5.0	17:05	15:40	- no clear ice, snow covered
	DH2(I)	2.5	22:10	19:58	- wet snow around hole
		5.0	22:10	19:58	
	CH1(I)	2.5	18:00	16:20	- water draining from melt
		5.0	18:05	16:20	pond into hole
	BH7(C)	2.5	19:05	17:15	- snow depth 13 cm for
		5.0	19:15	17:15	10 m radius of hole
	BH6(C)	2.5	21:15	19:00	- 13 cm wet snow
		5.0	21:25	19:00	around hole
June 4-5	DH1(I)	2.5	16:30	14:00	
		5.0	16:30	14:00	
	DH2(I)	2.5	18:30	16:15	
		5.0	18:30	16:15	
	CH1(I)	2.5	17:30	15:25	
		5.0	17:30	15:25	
	AMP#1	0.58	21:55	16:50	
	AMP#2	0.25	21:55	16:50	
June 6-7	DH1(I)	2.5	15:00	15:45	
		5.0	15:00	15:45	
	DH2(I)	2.5	10:50	14:55	
		5.0	12:25	14:55	

Table 1 (Cont'd)

Date	Station	Depth/m	Time in	Time out	Comment
June 6-7	CH1(I)	2.5	12:35	15:25	
		5.0	12:35	15:25	
	BH7(C)	2.5	09:50	13:30	
		5.0	09:50	13:30	
June 9	CH1(I)	2.5	02:00	22:15	
		5.0	02:00	22:15	
	SH2(0)	2.5	03:00	23:35	
		5.0	03:00	23:35	
	NW6(C)	2.5	03:30	00:15(June 10)	
		5.0	03:30	00:15(June 10)	
	DH1(I)	2.5	02:30	23:00	
		5.0	02:30	23:00	
June 10	SH1(0)	2.5	22:55(June9)	18:25	- at 14:30 bottles in SH1, NW2, and NW4 were exposed to direct daylight for about 5 min. each (extensive fog present)
		5.0	22:55(June9)	18:25	
	NW2(0)	2.5	00:15	19:30	
		5.0	00:15	19:30	
	NW4(0)	2.5	01:20	22:00	
		5.0	01:20	22:00	
	DH2(I)	2.5	02:05	22:45	- this set frozen, not used
		5.0	02:05	22:45	
June 11-12	BH2(C)	2.5	20:00	17:30	June 12 very foggy
		5.0	20:00	17:30	
	BH8(C)	2.5	20:30	18:20	
		5.0	20:30	18:20	
	FH1(C)	2.5	19:40	17:45	
		5.0	19:40	17:45	
	BH7(C)	2.5	17:25	17:15	
		5.0	17:25	17:15	
June 14	DA1	0.5	13:00	19:15	all June 14 stations are algal melt ponds on surface of ice except DA4 which is a water filled crack in the ice
	UA1	0.325	13:30	19:19	
	DA2	0.125	13:20	19:17	
	UA2	0.25	13:20	19:21	
	DA3	0.5	14:47	19:30	
	UA3	0.375	15:15	19:54	
	DA4	surface	15:30	19:39	
	UA4	0.5	15:15	19:35	
June 16-17	BH7(C)	2.0	17:40	17:20	- light covers not used on holes for this or following experiments on June 22-23 or June 25-26
		5.0	17:40	17:20	
	SH2(0)	2.0	18:42	18:10	
		5.0	18:42	18:10	
	NW6(0)	2.0	19:19	18:19	
		5.0	19:19	18:19	
	SH1(0)	2.0	19:49	18:35	
		5.0	19:49	18:35	
	NW4(0)	2.0	21:10	19:25	
		5.0	21:10	19:25	
	NW2(0)	2.0	22:55	19:10	
		5.0	22:55	19:10	
	DH2(0)	2.0	23:40	19:35	
		5.0	23:40	19:35	

Table 1 (Cont'd)

Date	Station	Depth/m	Time in	Time out	Comment
June 16-17	CH1(I)	2.0	18:15	17:37	
		5.0	18:15	17:37	
	IS1(I)	2.0	20:00	18:57	
		5.0	20:00	18:57	
June 22-23	BH7(C)	2.0	16:00	18:25	
		5.0	16:00	18:25	
	BH4(C)	2.0	18:45	17:25	
		5.0	18:45	17:25	
	FH1(C)	2.0	19:30	18:00	
		5.0	19:30	18:00	
	CH1(I)	2.0	20:40	18:40	
		5.0	20:40	18:40	
	SH1(O)	2.0	21:25	19:00	
		5.0	21:25	19:00	
	IS2(I)	2.0	22:50	19:15	
		5.0	22:50	19:15	
	NW2(O)	2.0	23:25	19:30	
		5.0	23:25	19:30	
June 25-26	BH7(C)	2.0	18:00	20:40	- bright sunlight for full period of incubation
		5.0	18:00	20:40	
	CH1(I)	2.0	20:30	20:50	- colonies of diatoms seen clinging to bottles or ropes when bottles being retrieved after incubation
		5.0	20:30	20:50	
	SH2(O)	2.0	21:15	21:00	
		5.0	21:15	21:00	
	NW2(O)	2.0	23:45	21:15	
		5.0	23:45	21:15	
	#7(O)	2.0	00:30	21:20	
		5.0	01:45	21:20	
	II(C)	surface	19:35	20:10	- no massive colonies of diatoms on bottles or ropes
		1.5	19:35	20:10	
		3.0	19:35	20:10	
		5.0	19:35	20:10	

Table 1 (Cont'd)

B. Productivity results in light and dark bottles (units: m mol C fixed m^{-3} hr^{-1})

(i) Control stations

Station	Depth/m	Date	Light	Dark 1	Dark 2
BH7	5.0	May 26	0.259	0.284	0.215
		29	0.252	0.256	0.271
		30	0.231	0.234	0.228
		June 2	0.0368	0.0991	0.0313
		7	0.0701	0.0600	0.118
		11	0.0872	0.0401	0.0430
		16	0.0516	0.0341	0.0192
		22	0.0372	0.0231	0.0215
		25	0.0374	0.0299	0.0234
	2.5	May 26	0.303	0.143	0.310
		29	0.293	0.230	0.227
		30	0.235	0.239	0.249
		June 2	0.0436	0.0316	0.0325
		7	0.0406	0.0224	0.0373
		11	0.0866	0.0375	0.0146
BH7B	2.0	June 16	0.0474	0.0292	0.0240
		22	0.0429	0.0213	0.0158
		25	0.0328	0.0268	0.0241
BH6	5.0	May 29	0.270	0.254	0.254
		June 2	0.186	0.0923	0.0471
	2.5	May 29	0.254	0.242	0.254
		June 2	0.0877	0.0423	0.0351
BH8	5.0	June 11	0.0905	0.0556	0.0544
	2.5	June 11	0.0827	0.0565	0.0604
BH2	5.0	June 11	0.0776	0.0552	0.0544
	2.5	June 11	0.0804	0.0514	0.0601
BH4	5.0	June 22	0.0332	0.0273	0.0270
	2.0	June 22	0.0284	0.0259	0.0259
II	5.0	June 25	0.0336	0.0226	0.0172
	3.0	June 25	0.0417	0.0264	0.0238
	1.5	June 25	0.0250	0.0245	0.0220
	0.0	June 25	0.00632	0.00293	0.00259
FH1	5.0	June 11	0.102	0.0644	0.0957
		22	0.0382	0.0204	0.0246
	2.5	June 11	0.0972	0.0589	0.0370
	2.0	June 22	0.172	0.0273	0.0165

Table 1 (Cont'd)

(ii) Influenced by oil stations

Station	Depth/m	Date	Light	Dark 1	Dark 2
DH1	5.0	May 26	0.203	0.224	0.320
		29	0.0395	0.236	0.537
		30	0.206	0.231	0.238
		June 2	0.0309	0.0448	0.0370
		5	0.104	0.0744	0.0771
		7	0.0873	0.0601	0.0846
		9	0.312	0.130	0.0923
	2.5	May 26	0.0284	0.262	0.00811
		29	0.252	0.287	0.226
		30	0.237	0.227	0.213
		June 2	0.529	0.0267	0.0229
		5	0.100	0.0939	0.170
		7	0.152	0.152	0.0831
		9	0.244	0.248	0.228
DH2	5.0	May 26	0.338	0.159	0.184
		29	0.190	0.255	0.261
		30	0.193	0.214	0.192
		June 2	0.125	0.0606	0.0865
		5	0.123	0.0860	0.0457
		7	0.0658	0.0632	0.0586
		16	0.0607	0.0481	0.0513
	2.5	May 26	0.223	0.203	0.174
		29	0.227	0.0276	0.232
		30	0.207	0.194	0.231
		June 2	0.456	0.111	0.0435
		5	0.131	0.0778	0.0503
		7	0.0999	0.0868	0.177
	2.0	June 16	0.0466	0.0118	0.0174
CH1	5.0	May 30	0.302	0.225	0.234
		June 2	0.0662	0.0375	0.0372
		5	0.0989	0.0996	0.0668
		7	0.0963	0.0954	0.125
		9	0.313	0.194	0.142
		16	0.0416	0.0216	0.0212
		22	0.0325	0.0246	0.0333
		25	0.0330	0.0148	0.0205
	2.5	May 30	0.269	0.269	0.226
		June 2	0.0273	0.0324	0.0366
		5	0.0801	0.0317	0.0538
		7	0.0878	0.0338	0.0963
		9	0.360	0.182	0.245
	2.0	June 16	0.0474	0.0416	0.0253
		22	0.0362	0.00798	0.0139
		25	0.0262	0.0114	0.0128
IS1	5.0	June 16	0.194	0.0303	0.0245
	2.0	June 16	0.0499	0.0383	0.0237
IS2	5.0	June 22	0.104	0.0298	0.0358
	2.0	June 22	0.0302	0.0297	0.0256

Table 1 (Cont'd)

(iii) In oil stations

Station	Depth/m	Date	Light	Dark 1	Dark 2
NW2	5.0	June 9	0.143	0.107	0.101
		16	0.0451	0.0829	0.0351
		22	0.0439	0.0323	0.0324
		25	0.0238	0.0137	0.0259
	2.5	June 9	0.148	0.0978	0.0759
	2.0	June 16	0.0415	0.0344	0.0258
		22	0.0419	0.0168	0.0272
		25	0.0411	0.0131	0.0188
NW4	5.0	June 9	0.117	0.100	0.0664
		16	0.0424	0.0386	0.0274
	2.5	June 9	0.141	0.0923	0.0872
	2.0	June 16	0.0403	0.0213	0.0270
NW6	5.0	June 9	0.253	0.177	0.225
		16	0.0432	0.0325	0.0299
	2.5	June 9	0.223	0.109	0.114
	2.0	June 16	0.0379	0.0349	0.0615
SH1	5.0	June 9	0.111	0.444	0.169
		16	0.0329	0.0299	0.0260
		22	0.0218	0.0182	0.0230
	2.5	June 9	0.155	0.0859	0.0191
	2.0	June 16	0.0337	0.0215	0.0279
		22	0.0313	0.0281	0.0324
SH2	5.0	June 9	0.193	0.152	0.0822
		16	0.0631	0.0253	0.0478
		25	0.0266	0.0175	0.0132
	2.5	June 9	0.213	0.103	0.102
		16	0.0263	0.0210	0.0150
	2.0	June 25	0.0452	0.00978	0.0159
#7	5.0	June 25	0.0337	0.0229	0.0222
	2.0	June 25	0.0277	0.0210	0.0212

(iv) Surface melt ponds

Station	Depth/m	Date	Light	Dark 1	Dark 2
AMP#1	0.58	June 5	0.0488	0.0206	0.0198
AMP#2	0.25	June 5	0.0196	0.0320	0.259
DA1	0.5	June 14	0.0755	0.0491	0.0534
DA2	0.125	14	0.137	0.100	0.0834
DA3	0.5	14	0.467	0.119	0.270
DA4	0.0	14	0.0435	0.0916	0.0421
UA1	0.325	14	0.304	0.0685	0.302
UA2	0.25	14	0.168	0.0379	0.0356
UA3	0.375	14	0.0812	0.0928	1.183
UA4	0.5	14	0.0974	0.0284	0.113

Table 2

Irradiance under ice in Balaena Bay N.W.T., May-June, 1975

(downwelling (1), upwelling (2), units, $\mu E\ m^{-2}\ s^{-1}$)

Date	Time (MST)	Location	Depth /m																
			0	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5
May 11	15:45	DH1 (1)	1050	63.7	58.8	46.2	38.5	28.0	24.5	19.6	17.1	13.6	11.3	9.80					
		(2)	390	0.49	0.42	0.38	0.35	0.35	0.34	0.34	0.34	0.42	0.46	0.50					
May 18	17:05	NW hole	1150		13.0	13.3	12.7	10.4	9.66	10.1	9.38	7.98	7.28						
			-		0.35	0.34	0.35	0.32	0.32	0.31	0.29	0.25	0.49						
May 18	18:05	DH1	1150		16.1	9.10	6.44	4.69	3.64	2.80	2.31	2.03	1.75	1.54					
					0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.04					
May 21	12:30	NW hole	1600		7.98	7.56	7.42	7.42	7.42	7.42	7.14	6.72	5.74						
					0.31	0.29	0.28	0.25	0.24	0.24	0.24	0.21	0.00						
May 21	15:25	DH1	1600		12.9	8.68	3.08	2.80	2.24	1.96	1.75	1.54	1.33	1.19	0.98				
					0.10	0.10	0.10	0.08	0.07	0.07	0.06	0.07	0.07	0.06	-				
May 28	08:40	BH6 (c)	1125		3.53	3.78	3.81	3.85	3.84	3.57	3.54	3.42	3.30	3.09	2.98	2.73	2.58	2.49	1.82
			820		0.17	0.14	0.13	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.15	0.17	0.17	0.18	-
May 28	08:40	BH6	1125		4.06	4.06	4.02	4.06	3.96	3.78	3.53	3.36	3.29	3.12	2.91	2.80	2.55	2.55	1.82
			820		0.18	0.13	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.17	0.17	0.17	0.18	0.20	-
May 28	09:10	BH7	970			2.53	2.76	2.87	3.01	3.07	3.15	3.12	3.49	3.54	3.42	3.46	3.04	2.66	
			830			0.20	0.17	0.15	0.14	0.14	0.14	0.14	0.14	0.15	0.14	0.13	0.98	-	
May 28	09:10	BH7 (C)	970			2.10	2.48	2.74	2.88	3.00	3.01	3.26	3.51	3.47	3.42	3.25	2.98	2.38	
			830			0.18	0.17	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.14	0.13	0.10	-	

Date	Time (MST)	Location	Depth /m																
			0	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5
May 28	09:35	DH2	800		1.08	0.98	0.88	0.91	0.78	0.73	0.81	0.84	0.80	0.80	0.69	0.78	0.97	0.73	0.38
			480		0.06	0.05	0.04	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	-
May 28	09:35	DH2 (C)	800		0.64	0.63	0.59	0.66	0.67	0.69	0.70	0.71	0.71	0.76	0.64	1.00	0.84	0.69	0.49
			480		0.05	0.05	0.04	0.03	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.01	0.01	-
May 28	09:55	DH1	800		4.48	3.50	3.04	2.17	1.54	1.22	1.08	0.87	0.83	0.74	0.76				
			480		0.04	0.04	0.06	0.04	0.03	0.03	0.03	0.01	0.02	0.02	-				
May 28	09:55	DH1 (C)	800		1.78	1.68	1.40	0.91	0.84	0.67	0.63	0.62	0.60	0.59	0.56				
			480		0.04	0.03	0.03	0.06	0.02	0.01	0.01	0.01	0.01	0.01	-				
June 1	17:35	CH1 (C)	750		91.1	80.5	72.9	62.3	58.7	53.2	46.6	43.7	41.7	38.6	31.8	29.3			
			349		2.24	1.96	1.82	1.62	1.68	1.88	1.55	1.54	1.62	1.65	1.54	1.27			
June 1	17:35	CH1	750		89.9	79.9	72.8	64.7	58.5	53.5	48.9	43.4	41.7	37.8	33.3	29.4			
			349		2.24	1.96	1.90	1.75	1.64	1.65	1.55	1.53	1.60	1.62	1.53	1.47			
June 1	18:25	BH7	581		4.90	4.76	4.91	5.18	5.11	5.18				4.48					
			420		0.42	0.35	0.43	0.42	0.42	0.42				0.28					
June 2	21:50	DH2	187	3.29		1.82		1.27		0.78		0.50		0.39		0.29			
			124	0.28		0.27		0.20		0.18		0.18		0.22		0.18			
June 4	16:05	DH1 (C)	1025	27.2	17.6	14.3	14.3	11.1	11.5	11.1	9.94	9.52	7.84	7.84		6.72			
			505	0.85	0.76	0.20	0.29	0.57	0.59	0.55	0.50	0.49	0.49	0.62		0.07			
June 4	17:05	CH1 (C)	999		91.7		90.3		82.6	76.4		63.0		54.6		44.8		40.6	
			421		3.01		2.73		2.52	2.38		2.24		2.24		1.96		0.01	
June 4	18:00	DH2	845		14.0	9.24		7.28		6.86		6.58		6.16		5.32		3.64	
			490		0.34	0.34		0.34		0.34		0.34		0.34		0.34		-	

Table 2 (Cont'd)

Date	Time (MST)	Location	Depth /m																
			0	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5
June 4	21:10	BH7 (C)	283		10.5	10.3		10.1		10.8		10.2		9.10		8.12			
			204		0.70	0.56		0.56		0.49		0.42		0.42		0.35			
June 10	16:10	CH1	1450	77.0	77.0	77.0		77.0		63.0		53.2		43.4		42.0		37.8	
			580	15.4	14.0	11.2		7.70		6.30		5.46		3.78		4.34		-	
June 10	17:30	NW6	1200	68.6	54.6	56.0		54.6		28.0		21.0		18.2					
			320	18.2	14.0	4.20		7.28		7.00		4.20		-					
June 10	17:50	DH1	800	21.0	18.9	22.4		16.8		19.6		19.6		11.3		21.0			
			200	16.1	9.10	6.58		6.30		5.74		4.48		4.34		-			
June 10	18:05	SH2	950		51.8	57.8		40.6		33.6		29.4		26.6		22.4		21.0	
			350		5.88	4.48		3.08		2.80		2.24		1.68		1.54		-	
June 10	19:20	SH1	1150		68.6	71.4		57.4		39.2		40.6							
			250		4.06	3.08		2.10		2.38		-							
June 10	19:45	NW2	740		43.4	39.2		37.8		35.0		30.8		26.6		26.6			
			290		3.64	2.80		2.66		2.24		1.96		1.82		-			
June 10	20:15	NW4	740		28.0	28.7		22.4		16.8		11.9		9.94		6.16			
			120		11.9	9.1		8.4		8.4		7.00		5.88		-			
June 12	17:00	BH7	505		36.5	34.7	34.2	33.7	33.7	33.5	33.3	29.4	26.6	24.5	23.5	21.3	17.6		
			270		7.35	7.14	6.86	6.02	5.81	4.34	4.06	3.84	3.50	3.37	2.80	2.46	1.82		
June 12	17:30	BH2	485	35.7	36.8	33.6	23.5	21.8	20.3	13.0	11.3								
			188	13.7	14.4	13.0	12.9	12.3	12.3	7.3	7.6								
June 12	17:45	FH1	490	15.7	14.7	14.0	13.7	12.7	11.9	11.2	9.94								
			245	8.40	8.82	7.98	7.84	7.84	7.84	7.28	6.86								

Date	Time (MST)	Location	Depth /m																
			0	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5
June 12	18:20	BH8	630	22.4	23.9	19.6	18.2	17.1	15.1	14.8	12.5	10.9	9.94						
			295	16.1	15.7	13.2	11.6	9.66	7.98	6.86	6.16	5.46	5.46						
June 12	17:21	BH7B	1320		68.2	72.1	69.3	63.7	58.1	52.5	51.7	50.7	46.9	38.1	34.3	31.5	30.1		
			515		53.5	42.7	39.9	35.7	31.5	27.3	24.5	21.7	19.9	19.6	17.5	16.1	11.9		
June 17	17:50	CH1	865	38.5	35.7	32.2	28.7	25.2	22.7	18.2	17.1	16.5	15.7	14.8	13.6	11.2			
			462	17.1	16.8	16.1	15.4	13.7	13.3	12.6	11.5	10.6	9.52	8.68	8.40	7.98			
June 17	18:10	SH2	870	38.5	27.3	23.1	20.3	20.3	23.1	19.6	17.6	13.9	12.7	11.2	10.1	9.10			
			205	32.2	24.9	20.3	16.1	13.3	9.10	8.82	10.8	9.80	8.96	7.70	7.42	6.58			
June 17	18:19	NW6	770	65.8	51.1	47.6	44.1	38.5	33.6	25.9	24.5	21.3							
			235	23.1	17.9	14.8	16.1	15.1	11.5	10.5	9.80	8.12							
June 17	18.35	SH1	630	39.3	35.0	34.7	30.1	27.7	25.9	23.5	20.7								
			285	36.7	32.9	27.3	22.7	19.3	18.5	17.1	14.3								
June 17	18:57	IS1	720	56.0	53.5	66.5	60.9	55.3	46.9										
			285	39.9	35.3	35.7	35.0	31.5	27.3										
June 17	19:10	NW2	1020	41.3	39.2	74.2	68.5	63.0	58.8	55.3	53.2	39.9	17.2	18.9					
			235	7.98	6.72	11.2	7.14	7.14	6.30	5.88	5.32	7.14	15.8	13.3					
June 17	19:25	NW4	985	75.6	56.7	37.1	35.0	34.3	29.1	22.7	16.4	31.2	30.8	13.3	10.6				
			158	63.0	21.0	21.7	18.9	16.8	13.0	11.9	10.5	7.00	2.94	9.94	8.54				

Table 2 (Cont'd)

Date	Time (MST)	Location	Depth /m -																	
			0	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5
June 23	17:25	BH4	1000	364			231						111						41.9	
			232	13.4			7.14						3.64						0.14	
June 23	18:00	FH1	1050	273			154						99.4							
			340	12.5			11.2						11.2							
June 23	18:25	BH7B	1050	195							120						75.6			
			237	8.26							4.97						3.92			
June 23	18:40	CH1	970	193							57.4				46.9					
			280	9.66							8.96				3.82					
June 23	19:00	SH1	1000	178							93.8				43.4					
			275	6.72							4.90				2.94					
June 23	19:15	IS2	920	174					115		91.0									
			300	10.4					7.56		7.00									

Table 3

SEA ICE

ALBEDO RESULTS

May-June, 1975

BALAENA BAY, N. W. T. (measured 30cm above surface)

May 28

BH6	1125,820	0.729	23cm snow
BH7	970,830	0.856	15cm snow
DH2	800,480	0.600	rough snow
DH1	800,480	0.600	rough snow

June 1

CH1	750,349	0.465	wet porous ice
BH7	581,420	0.723	15cm snow on ice fresh
BH6	309,206	0.667	23cm snow packed
DH2	187,124	0.663	~30cm snow packed

June 4

DH1	1025,505	(wet snow)	0.493
CH1	999,421		0.421
DH2	845,490	(rough snow)	0.580
	765,185	(oil emulsion in water)	0.242
	650,81	(thick oil ∿ 1mm)	0.125

June 4

BH7	283,204	(10cm snow)	0.721

June 10

BH7	1500,780	(wet snow)	0.520
CH1	1450,580		0.400
NW6	1200,320	(pitted ice-brown stained from oil)	0.267
DH1	800,200	(water surface)	0.250
SH2	950,350	(crystalline melt ice-black particles blue transparent)	0.368
SH1	1150,250	(blue ice, clean water)	0.217
NW2	740,290	(brown stained ice and snow)	0.392
NW4	740,120	(oily ice)	0.162

June 12

BH7	505,207	0.410
BH2	485,188	0.388
FH1	490,245	0.500
BH8	295,63.0	0.214

June 17

BH7B	1320,515	0.390
CH1	865,462	0.534
SH2	870,205	0.236
NW6	770,235	0.305
SH1	630,285	0.452
IS#1	720,285	0.396
NW2	1020,285	0.230
NW4	985,158	0.160

June 23

BH4	1000,232	(granular wet ice)	0.232
FH1	1050,340	(white-green wet ice crystal-granular)	0.323
BH7B	1050,237	(wet granular ice)	0.226
CH1	775,280	(surface of melt pond ∿ 5cm deep)	0.289
SH1	1000,275	(white granular ice)	0.275
IS#2	920,300	(white granular ice)	0.326

Table 4

Attenuation coefficient, K_{water}, of water under sea ice in Balaena Bay, N.W.T. May-June, 1975. (units of m^{-1})

Location	May 17	May 21	May 25	May 28	June 1	June 4	June 10	June 12	June 17	June 23
DH1	0.476	0.281	0.186	0.423		0.164	-			
DH2			0.050		0.402					
BH7						0.092		0.191		
BH6				0.095	0.130					
CH1					0.196	0.155	0.117		0.201	0.322
NW6							0.278		0.274	
NW4							0.278		0.332	
NW2							0.092		0.136	
SH2							0.162		0.208	
SH1							0.186		0.177	0.311
BH8								0.192		
BH2								0.352		
FH1								0.122		0.213
IS#1									0.229	
IS#2										0.260
BH7B									0.152	0.158
BH4										0.284

Table 5

Attenuation coefficient, K_{water} of open water in Balaena Bay, N.W.T.

Sept. 5-10, 1974 (units of m^{-1})

Station	K water $/m^{-1}$
I - 1	0.336
2	0.266
3	0.252
4	0.268
5	0.343
II - 1	0.325
2	0.238
3	0.258
4	0.275
5	0.325
III - 1	0.270
2	0.129
3	0.298
4	0.256
5	0.245
V - 1	0.221
3	0.250
5	0.275
VI - 1	0.360
2	0.426
3	0.370
VII - 1	0.330
2	0.260
3	0.244
4	0.308
5	0.400

Table 6

Attenuation Coefficient of ice and water in Balaena Bay, N.W.T.

June , 1975

Location	June 17			June 23			June 23 (comments)
	ice thickness /cm	K_{ice}/cm^{-1}	K_{H_2O}/m^{-1}	ice thickness /cm	K_{ice}/cm^{-1}	K_{H_2O}/m^{-1}	
SH1	142	0.015	.177	107	0.0086	.311	(white granular ice)
SH2	117	0.024	.208				
NW2	135	0.016	.136				
NW4	112	0.021	.332				
NW6	117	0.017	.274				
IS#1	122	0.012	.229				
CH1	130	0.017	.201	89	0.0099	.322	(5cm deep surface melt pond)
BH7B	152	0.015	.152	117	0.011	.158	(wet granular ice)
BH4				33	0.012	.284	(granular wet ice)
FH1				46	0.018	.213	(white-green wet ice crystal granular)
IS2				86	0.0099	.260	(white granular surface)

Table 8 (Contd)

BH3

Depth	May 24 (ppt)	June 16 (ppt)	June 18 (ppt)	June 22 (ppt)
0.0		1.99	1.95	0.94
0.5		2.05	1.96	1.83
1.0		2.12	1.99	1.83
1.5		5.41	5.00	8.50
2.0	30.57	26.66	25.08	27.17
2.5	30.57	30.12	29.38	28.64
3.0	30.64	30.34	30.12	29.15
3.5	30.64			
4.0	30.64	30.87	30.72	29.45
4.5	30.64			
5.0	30.72	30.94	30.94	29.75
5.5	30.72			
6.0	30.72	31.17	31.09	30.34
6.5	30.72			
7.0	31.32	31.24	31.55	30.34
8.0		31.62		

BH4

Depth	May 24 (ppt)	June 11 (ppt)	June 16 (ppt)	June 18 (ppt)	June 22 (ppt)
0.000		1.619	2.930	2.958	1.390
0.500		1.673	2.930	2.941	1.827
1.000		1.477	3.030	2.930	6.463
1.500	31.956	2.487	5.363	5.911	15.970
2.000	31.956	31.207	26.589	27.166	28.474
2.500	31.956	31.207	31.058	30.462	28.913
3.000	31.956	31.282	31.207	31.058	29.427
3.500	31.956				
4.000	31.956	31.356	31.806	31.581	30.314
4.500	31.956				
5.000	31.956	31.956	31.956	31.806	30.240
5.500	31.956			31.956	
6.000	32.031	32.182	32.031		30.462
6.500	32.031			32.558	
7.000	32.031	32.332	32.031		30.983
7.500	32.106			32.483	
8.000	32.408	32.031	32.483		30.388

Table 8 (Contd)

BH5

Depth	May 24 (ppt)
2.000	30.873
2.500	30.948
3.000	31.023
3.500	31.023
4.000	31.023
4.500	31.023
5.000	31.061
5.500	31.061
6.000	31.061
6.500	31.061
7.000	31.061
7.500	31.098
8.000	31.173
8.500	31.437
9.000	31.475
9.500	31.475
10.000	31.512

BH6

Depth	May 24 (ppt)	May 27 (ppt)	June 1 (ppt)	June 3 (ppt)	June 11 (ppt)	June 16 (ppt)	June 18 (ppt)	June 22 (ppt)
0.000	30.537		29.575	1.336	1.542	2.925	2.714	0.729
0.500			31.731	5.998	1.542	2.997	2.764	0.729
1.000		31.806	31.431	7.936	1.542	3.030	2.764	0.773
1.500		31.881	31.956	8.174	2.487	6.580	6.172	14.777
2.000	31.956	31.881	31.956	24.876	29.427	28.401	26.805	27.687
2.500	31.956	31.881	31.956	25.872	31.207	30.685	30.834	29.381
3.000	31.956	31.881	31.956	26.302	31.207	31.581	31.132	30.125
3.500	31.956	31.956	31.956	26.445				
4.000	31.994	31.956	31.956	26.661	31.207	31.806	31.731	30.648
4.500	31.994	31.956		26.805				
5.000	31.994	31.956	32.031	27.021	31.282	31.956	31.806	30.948
5.500	31.994	31.956		27.166				
6.000	31.994	31.956	32.182	28.474	31.282	32.182	31.956	31.023
6.500	31.994	31.956		28.913				
7.000	31.994	31.956	32.182	28.766	31.356	32.483	32.182	31.550
7.500	31.994	32.031		29.207				
8.000	32.031	32.257	32.182	29.648	31.806	32.483	32.483	31.625
8.500	32.332	32.332		30.166				
9.000	32.408	32.408	32.558	31.506	31.956	32.558	32.558	31.776
9.500	32.408	32.483		32.408				
10.000					32.106			31.776

Table 8 (Contd)

BH7

Depth	May 24 (ppt)	May 26 (ppt)	May 27 (ppt)	June 01 (ppt)	June 03 (ppt)	June 05 (ppt)	June 06 (ppt)	June 07 (ppt)	June 09 (ppt)	June 10 (ppt)
0.000					11.272	8.442	6.706	1.997	0.245	2.371
0.500				30.798	11.522	12.658	6.884	3.578	2.837	2.371
1.000			30.125	30.798	13.167	17.877	7.122	4.000	3.345	2.371
1.500	31.061		30.125	31.249	18.819	23.236	7.122	4.880	3.635	2.326
2.000	31.061	30.873	30.199	31.249	30.723	30.199	28.274	30.050	30.873	31.023
2.500	31.061	30.948	31.023	31.249	30.948	31.098	30.498	31.249	30.948	31.023
3.000	31.061	30.948	31.023	31.249	30.948	31.098	30.573	31.249	30.948	31.098
3.500	21.061	31.023	31.023	31.249	30.948	31.098	30.573			31.098
4.000	31.061	31.023	31.023	31.249	30.948	31.249	30.648	31.173	31.023	31.173
4.500	31.061	31.098	31.023	31.249	30.948	31.249	30.723			
5.000	31.098	31.098	31.023	31.249	30.948	31.249	30.723	31.098	31.098	31.173
5.500	31.098	31.098	31.023	31.249	30.948	31.249	30.723			
6.000	31.098	31.098	31.061	31.249	30.948	31.249	30.723	31.399	31.098	31.324
6.500	31.098	31.098	31.098	31.249	30.948	31.249	30.723			
7.000	31.173	31.173	31.173	31.324	30.948	31.249	30.798	31.399	31.475	31.475
7.500	31.361	31.437	31.475	31.625	31.249	31.324	30.948			
8.000	31.550	31.625	31.625	31.776	31.550	31.701	31.249	31.550	31.776	31.776
8.500	31.625	31.625	31.625	31.776	31.625	31.852	31.249			
9.000		31.701			32.003	32.003	31.324	31.852		

BH7A

Depth	June 11 (ppt)
0.000	3.351
0.500	3.379
1.000	3.385
1.500	3.470
2.000	30.423
2.500	30.948
3.000	31.173
4.000	31.173
5.000	31.173
6.000	31.249
7.000	31.475
8.000	31.928
9.000	31.776

Table 8 (Contd)

BH7B

Depth	1452 June 16 (ppt)	1790 June 16 (ppt)	June 18 (ppt)	June 22 (ppt)	June 25 (ppt)
0.000	1.684	2.117	1.466	1.022	1.100
0.500	1.881	2.332	2.310	1.275	1.162
1.000	4.063	2.442	3.517	1.472	1.991
1.500	4.585	5.998	5.709	19.617	21.388
2.000	27.383	28.255	26.805	28.766	29.944
2.500	30.314	31.207	31.132	30.240	31.058
3.000	31.731	31.282	31.581	30.909	31.207
4.000	31.806	31.656	31.956	31.731	31.731
5.000	32.182	31.806	32.257	31.806	31.956
6.000	32.332	31.956	32.408	31.956	32.408
7.000	32.558	32.257	32.709	32.332	32.558
8.000	32.709	32.558	32.861	32.483	32.634
9.000	33.164		32.936	32.634	33.164

BH8

Depth	June 11 (ppt)	June 16 (ppt)	June 18 (ppt)	June 22 (ppt)
0.000	1.124	2.042	1.731	0.648
0.500	0.965	2.042	1.720	0.609
1.000	1.058	2.136	1.686	0.566
1.500	3.232	4.787	5.065	14.323
2.000	29.455	27.541	26.740	26.958
2.500		30.050	29.529	29.307
3.000	30.423	30.498	30.125	30.125
4.000	30.573	30.873	30.423	30.798
5.000	30.573	30.948	30.723	30.948
6.000	30.573	31.249	30.948	31.399
7.000	31.098	31.625	31.023	31.625

Table 8 (Contd)

I		II			III		IV	
Depth	June 24 (ppt)	Depth	June 24 (ppt)	June 25 (ppt)	Depth	June 24 (ppt)	Depth	June 24 (ppt)
0.000	0.452	0.000	0.457	0.367	0.000	0.457	0.000	0.348
0.500	0.452	0.500	0.468	0.407	0.500	0.484	0.500	0.359
1.000	4.603	1.000	1.720	4.776	1.000	5.123	1.000	4.949
1.500	16.018	1.500	13.487	16.084	1.500	16.811	1.500	12.467
2.000	27.541	2.000	27.176	29.011	2.000	27.760	2.000	28.274
2.500	29.752	2.500	29.752	30.050	2.500	29.752	2.500	29.752
3.000	30.274	3.000	30.199	30.199	3.000	30.199	3.000	30.125
4.000	30.873	4.000	30.873	30.873	4.000	30.274	4.000	30.498
5.000	30.873	5.000	31.249	31.098	5.000	31.249	5.000	30.948
6.000	31.249	6.000	31.249	31.475	6.000	31.399	6.000	31.249
7.000	31.625	7.000	31.399	31.475	7.000	31.625	7.000	31.249
8.000	31.701	8.000	31.625	31.625	8.000	31.625	8.000	31.249
9.000	31.776	9.000	31.625	31.701	9.000	31.625	9.000	31.249
10.000	32.003	10.000	31.625	31.776	10.000	31.701	10.000	31.249
		11.000	31.701	31.701	11.000	31.701	11.000	31.249
		12.000	31.701		12.000	31.701	12.000	31.249
		13.000	31.701		13.000	31.701	13.000	31.249
		14.000	31.701				14.000	31.249
		15.000	31.701				15.000	31.249
		16.000	31.701				16.000	31.249
		17.000	32.003				17.000	31.249
		18.000	31.701				18.000	31.249
							19.000	31.249
							20.000	31.249

FH1

Depth	June 11 (ppt)	June 18 (ppt)	June 22 (ppt)
0.000	1.003	1.953	0.457
0.500	1.058	1.942	0.528
1.000	0.948	1.925	0.620
1.500	1.058	5.414	13.423
2.000	29.455	25.800	24.939
2.500	30.948	29.233	28.421
3.000	30.948	30.050	28.642
4.000	30.948	30.349	29.011
5.000	30.948	30.873	29.455
6.000	31.399	31.023	30.125

Table 8 (Contd)

FH2

Depth	June 18 (ppt)
0.000	1.997
0.500	1.986
1.000	1.969
1.500	4.897
2.000	26.450
2.500	30.199
3.000	30.498
4.000	30.873
5.000	31.023
6.000	31.324
7.000	31.625

B. <u>'Influenced' by oil stations</u>

NW Hole

Depth	May 11 (ppt)	May 12 (ppt)	May 15 (ppt)	May 16 (ppt)	May 20 (ppt)
0.500	29.207				
1.000	29.575				
1.500	29.427		30.537		
2.000	30.834	30.909	30.834	30.834	31.058
2.500	31.058	30.983	30.909	30.909	31.058
3.000	31.058	31.058	30.983	31.058	31.058
3.500	31.058	31.058	31.058	31.207	31.132
4.000	31.058	31.207	31.058	31.207	31.207
4.500	31.058	31.207	31.058	31.282	31.207
5.000	31.058	31.207	31.132	31.282	31.282
5.500	31.058	31.207	31.207	21.282	31.282
6.000	31.058	31.207	31.282	31.282	31.282
6.500	31.058	31.282		31.356	31.356
7.000	27.600	27.383			

Table 8 (Contd)

Hole 1

Depth	May 12 (ppt)	May 16 (ppt)	May 20 (ppt)
1.000		31.058	
1.500		31.581	
2.000	31.282	31.581	30.834
2.500	31.356	31.581	30.909
3.000	31.431	31.581	30.909
3.500	31.506	31.581	30.909
4.000	31.506	31.656	30.909
4.500	31.506	31.656	30.909
5.000	31.431	31.656	30.983
5.500	31.356	31.656	30.983
6.000	31.581	31.656	30.983
6.500	31.581	31.731	30.983
7.000	31.581	31.731	31.020
7.500	31.806	31.806	31.058
8.000		31.956	31.207
8.500			31.356

Hole 2

Depth	May 12 (ppt)	May 16 (ppt)	May 20 (ppt)
1.500		31.506	
2.000	31.356	31.431	30.760
2.500	31.356	31.506	31.058
3.000	31.431	31.581	31.058
3.500	31.506	31.581	31.132
4.000	31.506	31.581	31.207
4.500	31.506	31.581	31.207
5.000	31.506	31.656	31.207
5.500	31.506	31.656	31.207
6.000	31.506	31.656	31.282
6.500	31.506	31.656	31.282
7.000	31.581	31.731	31.356
7.500	31.656	31.806	31.506
8.000	31.806	31.956	31.731
8.500		32.031	31.806
9.000		32.031	31.956

Table 8 (Contd)

DH1 1635		DH1 1915		DH1 1920		DH1 1925		DH1 1955	
Depth	June 7 (ppt)	Depth	June 7 (ppt)	Depth	June 7 (ppt)	Depth	June 7 (ppt)	Depth	June 7 (ppt)
0.000	0.375	0.500	0.403	1.000	1.107	1.000	1.118	2.000	30.125
0.500	0.839	1.000	0.457	2.000	30.498				
1.000	1.052	2.000	27.395						
1.500	1.394								
2.000	30.798								
5.000	30.948								
7.000	31.249								

DH1

Depth	May 10 (ppt)	May 12 (ppt)	May 16 (ppt)	May 20 (ppt)	May 22 (ppt)	May 23 (ppt)	May 24 (ppt)	May 27 (ppt)
0.000								
0.500	10.288	8.353	8.055	8.234	8.413	8.353	8.833	9.013
1.000	10.104	8.234	8.114	8.234	8.533	8.234	8.833	10.288
1.500	10.227	8.473	8.833	9.073	9.254	8.772	9.436	10.410
2.000	30.834	31.058	31.506	30.909	31.207	30.760	31.806	31.806
2.500	31.132	31.282	31.506	30.983	31.506	31.058	31.806	31.806
3.000	31.207	31.282	31.506	30.983	31.806	31.132	31.956	31.881
3.500	31.207	31.356	31.506	30.983	31.881	31.207	31.956	31.881
4.000	31.282	31.282	31.506	30.983	31.881	31.207	31.956	31.956
4.500	31.282	31.356	31.581	30.983	31.956	31.282	31.956	31.956
5.000	31.356	31.282	31.581	30.983	31.956	31.282	31.956	31.956
5.500	31.356	31.431	31.581	31.058	31.956	31.356	31.956	31.956
6.000	31.431	31.356	31.618	31.058	31.956	31.506	31.956	31.956
6.500	31.506	31.506	31.618	31.058	32.031	31.656	31.956	31.956
7.000	31.581	31.506		31.058	32.182	31.656	32.031	32.031
7.500				31.207	32.182	31.956	32.257	

Table 8 (Contd)

DH1 (Contd)

Depth	June 1 (ppt)	June 3 (ppt)	June 6 (ppt)	June 7 (ppt)	June 8 (ppt)	June 12 (ppt)	June 16 (ppt)
0.000		1.075	1.211	1.455	1.314	1.559	2.775
0.500	9.254	1.581	1.281	1.783	1.832	2.183	2.797
1.000	9.557	8.533	1.308	2.073	1.931	1.936	2.819
1.500	11.148	31.431	1.662	2.498	2.051	38.737	6.114
2.000	31.431	31.881	28.109	31.656	31.132	2.260	27.528
2.500	31.656	31.956	30.314	32.257	31.881	30.760	30.685
3.000	31.656	31.956	30.685	32.332	31.881	31.806	31.207
3.500	31.731	31.956				31.806	
4.000	31.731	31.956	31.356	32.332	31.881		31.806
4.500	31.731	31.956				31.956	
5.000	31.731	31.956	31.506	32.408	31.881		31.956
5.500	31.731	31.956				32.106	
6.000	31.731	31.956	31.506	32.483	31.881		32.408
6.500	31.731	31.956				32.257	
7.000	31.731	31.956	31.656	32.483	32.182		
7.500		32.182				32.408	

DH2

Depth	May 22 (ppt)	May 23 (ppt)	May 24 (ppt)	May 27 (ppt)	June 1 (ppt)	June 3 (ppt)	June 6 (ppt)
0.000						1.265	1.499
0.150					28.274		
0.250					30.349		
0.500	31.806	31.058	31.881	31.956	30.798	4.647	2.073
1.000	31.806	31.058	31.881	31.956	30.798	30.983	2.238
1.500	31.806	31.058	31.956	31.956	30.723	31.806	2.680
2.000	31.806	31.058	31.956	31.956	30.798	31.881	31.058
2.500	31.881	31.058	31.956	31.956	30.798	31.956	31.656
3.000	31.881	31.058	31.956	31.956	30.873	31.956	31.731
3.500	31.881	31.132	31.956	31.956	30.873	32.031	31.731
4.000	31.881	31.132	31.956	31.956	30.948	32.031	31.806
4.500	31.881	31.207	31.956	31.956	30.948	32.031	31.806
5.000	31.881	31.207	31.956	31.956	30.948	32.031	31.881
5.500	31.881	31.207	31.956	31.956	30.948	32.031	31.881
6.000	31.956	31.282	31.956	31.956	30.948	32.031	31.881
6.500	31.956	31.506	31.956	31.956		32.031	31.881
7.000	31.956	31.581	31.956	32.106	30.948	32.031	31.956
7.500	32.106	31.806	32.031	32.332		32.182	31.956
8.000	32.332	32.031	32.408	32.558		32.634	32.182
8.500	32.408	32.332	32.483	32.558	31.475	32.785	32.332
9.000	32.483	32.408	32.558	32.558		32.785	32.483
9.500	32.483	32.558	32.558	32.634			32.483

Table 8 (Contd)

DH2 (Contd)

Depth	June 7 (ppt)	June 9 (ppt)	June 16 (ppt)	June 18 (ppt)
0.000	1.004	1.032	1.881	1.602
0.150				
0.250				
0.500	3.042	1.450	1.985	2.029
1.000	3.500	2.986	2.156	2.321
1.500	6.004	3.573	9.618	5.940
2.000	31.956	31.806	28.766	26.733
2.500	32.031	31.806	30.018	30.240
3.000	32.182	31.881	30.983	30.983
3.500	32.257			
4.000	32.257	31.956	31.207	31.431
4.500				
5.000	32.257	31.881	31.431	31.806
5.500				
6.000	32.257	31.956	31.506	31.956
6.500				
7.000	32.332	32.332	32.031	32.031
7.500				
8.000	32.558	32.558	31.806	32.483
8.500				
9.000	32.709	32.709	32.183	

CH1

Depth	May 29 (ppt)	June 1 (ppt)	June 3 (ppt)	June 6 (ppt)	June 7 (ppt)	June 8 (ppt)	June 12 (ppt)	June 18 (ppt)	June 22 (ppt)	June 25 (ppt)
0.000		3.237	0.002	2.276	2.847	3.338	3.097	1.581	1.717	1.189
0.250				2.416						
0.500		26.302	0.004	2.416	3.242	3.360	3.036	1.996	1.728	1.194
0.750				2.416						
1.000	31.806	27.745	0.010	2.416	3.293	3.360	3.025	2.117	1.755	6.463
1.250				2.416						
1.500	31.881	30.537	0.031	2.416	3.590	3.304	2.947	5.824	12.455	17.017
1.750			0.039							
2.000	31.881	31.881	31.249	29.752	31.731	31.132	30.760	27.528	28.766	30.314
2.500	31.956	31.881	31.249	30.798	31.731	31.881	31.656	29.944	30.314	31.058
3.000	31.956	31.881	31.249	30.873	31.956	31.881	31.731	31.207	30.834	31.132
3.500	31.956	31.881	31.249	30.873						
4.000	31.956	31.881	31.249	30.873	31.956	31.881	31.956	31.806	31.207	31.731
4.500	31.956	31.881	31.249							
5.000	31.956	31.881	31.249	30.948	32.182	31.956	32.182	32.031	31.581	31.881
5.500	31.994	31.956	31.249							
6.000	31.994	31.956	31.249	30.948	32.182	31.956	32.332	32.182	31.806	32.332
6.500	31.994	31.956	31.249							
7.000	32.031	32.031	31.249	31.098	32.182	32.182	32.408	32.332	32.106	32.634
7.500	32.257	32.332	31.324							
8.000	32.408	32.558	31.475	31.550	32.861	32.709	32.709	32.558	32.182	32.634
8.500			31.852							
9.000									32.634	

Table 8 (Contd)

NW6

Depth	June 8 (ppt)	June 11 (ppt)	June 16 (ppt)	June 18 (ppt)
0.000	4.378	0.642	3.034	0.560
0.500	4.516	1.460	2.640	1.009
1.000	4.516	1.681	2.668	1.692
1.500	4.551	4.833	6.943	5.530
2.000	28.715	28.789	26.812	25.656
2.500	29.752	30.873	30.498	29.529
3.000	29.901	30.948	30.648	30.125
4.000	30.125	31.023	30.948	30.798
5.000	30.199	31.023	31.249	31.098
6.000	30.498	31.098	31.625	31.098

#5

Depth	June 25 (ppt)
0.000	0.066
0.500	0.056
1.000	0.457
1.500	2.949
2.000	5.077
2.500	26.812
3.000	28.642
4.000	29.381
5.000	30.125
6.000	30.873
7.000	31.550
8.000	31.249

#7

Depth	June 25 (ppt)
0.000	1.554
0.500	1.498
1.000	1.664
1.500	16.414
2.000	28.274
2.500	30.125
3.000	30.125
4.000	30.349
5.000	30.873
6.000	31.023
7.000	31.550
8.000	31.550
9.000	31.701

D. <u>Surface melt ponds</u>

Small Pond near BH7

Depth	June 5 (ppt)
0.000	3.800
0.100	5.589

Large Pond near BH7

Depth	June 5 (ppt)
0.000	1.747
0.100	3.373
0.250	4.862
0.500	6.411
0.600	7.003

Table 8 (Contd)

Newly Formed Pond 1

Depth	June 5 (ppt)
0.150	5.239

Newly Formed Pond 2

Depth	June 5 (ppt)
0.150	5.530

Tidal Crack Hole BH7

Depth	June 5 (ppt)
0.500	0.213
1.000	0.213
1.500	0.213
2.000	29.752

Large Melt Pond

Depth	June 6 (ppt)
0.000	3.232
0.250	5.239
0.500	7.003
0.650	7.241

Medium Melt Pond

Depth	June 6 (ppt)
0.000	2.388
0.300	4.949

Small Melt Pond

Depth	June 6 (ppt)
0.000	3.260
0.250	7.900

.5M Diam. Melt Pond

Depth	June 6 (ppt)
0.000	3.232
0.250	4.057

20 cm. Diam. Hole near CH1

Depth	June 7 (ppt)
0.000	2.617
0.250	5.589
0.500	6.293
0.600	6.293

DA1

Depth	June 14 (ppt)
0.000	-0.004
0.250	-0.004
0.375	0.018

DA2

Depth	June 14 (ppt)
0.000	4.372
0.125	5.530

Table 8 (Contd)

DA3

Depth	June 14 (ppt)
0.000	4.200
0.125	4.430
0.250	5.065
0.375	5.530
0.500	5.385
0.600	6.411

DA4

Depth	June 14 (ppt)
0.000	1.383
0.125	1.416
0.250	1.498

UA1

Depth	June 14 (ppt)
0.000	2.556
0.125	2.556
0.250	3.345
0.325	3.612

UA2

Depth	June 14 (ppt)
0.000	2.053
0.125	2.136
0.250	2.668

UA3

Depth	June 14 (ppt)
0.000	4.453
0.125	4.660
0.250	4.891

UAA

Depth	June 14 (ppt)
0.000	1.498
0.125	2.053
0.250	3.914
0.375	4.085
0.500	4.057
0.600	3.965

Table 9. Water temperatures at Balaena Bay, May-June 1975

(depth in meters, see site plan for station locations)

A. Control Stations

BH1

Depth	May 24
0.5	-
1.0	-
1.5	-
2.0	-1.8
2.5	
3.0	-1.8
snow	
ice	

BH2

Depth	May 24	June 11	June 16	June 18
surface	-	+0.1	+0.1	+0.1
0.5	-1.95	+0.1	+0.2	+0.1
1.0	-1.95	+0.1	+0.3	+0.1
1.5	-1.9	+0.1	+0.7	+0.7
2.0	-1.9	-0.4	+0.3	+0.6
2.5	-1.9	-0.6	0.0	+0.4
3.0	-1.9	-0.2	-0.2	+0.1
3.5	-1.9	-	-	-
4.0	-1.9	-0.8	-0.3	0.0
4.5	-1.9	-	-	-
5.0	-1.9	-0.8	-0.2	-0.1
5.5	-1.8	-	-	-
6.0		-0.5	0.0	-0.2
6.5				-0.1
snow	20 cm			
ice	2 m			

Table 9 (Contd)

BH3

Depth	May 24	June 16	June 18	June 22
surface	-	+0.1	+0.2	+0.3
0.5	-	+0.1	+0.1	+0.5
1.0	-	+0.1	+0.1	+0.9
1.5	-1.8	+0.1	+1.0	+1.6
2.0	-1.8	+0.1	+0.4	+1.4
2.5	-1.8	-0.2	+0.3	+1.0
3.0	-1.8	-0.5	0.0	+0.6
3.5	-1.8	-	-	-
4.0	-1.8	-0.5	-0.3	+0.5
4.5	-1.8	-	-	-
5.0	-1.8	-0.6	-0.5	+0.2
5.5	-1.8	-	-	-
6.0	-1.8	-0.5	-0.4	+0.2
6.5	-1.75	-	-	-
7.0	-1.5	-0.5	0.0	+0.2
7.5	-1.4	-	-	-
8.0		-0.3	0.0	+0.4
8.5		-0.2		
snow	25 cm			
ice	< 2 m			

BH4

Depth	May 24	June 16	June 11	June 18	June 22
surface	-	+.1	+ .1	0.0	+ .2
.5	-	+.1	+ .1	0.0	+ .2
1	-	+.1	+ .1	0.0	+1.0
1.5	-1.85	+.6	+ .1	+ .6	+1.4
2	-1.8	+.1	- .7	+ .1	+1.4
2.5	-1.8	-.2	-1.0	0.0	+1.0
3	-1.8	-.4	-1.2	- .3	+ .5
3.5	-1.8	-	-	-	-
4	-1.8	-.5	-1.3	- .4	+ .1
4.5	-1.8	-	-	-	-
5	-1.8	-.6	-1.3	- .5	0.0
5.5	-1.8	-	-	-	-
6	-1.8	-.6	-1.3	- .5	- .2
6.5	-1.8	-	-	-	-
7	-1.75	-.6	- .8	- .4	+ .1
7.5	-1.7	-	-	-	-
8	-1.5	-.5	- .8	- .8	- .2
8.5	-1.4	-	-	-	-
9.0		-.4	- .7	- .5	- .1
snow	30.5 cm				
ice	2 m				

Table 9 (Contd)

BH5

Depth	May 24
.5	-
1	-
1.5	-
2	-1.7
2.5	-1.8
3	-1.8
3.5	-1.8
4	-1.8
4.5	-1.8
5	-1.8
5.5	-1.8
6	-1.8
6.5	-1.8
7	-1.8
7.5	-1.7
8	-1.6
8.5	-1.5
9	-1.4
9.5	-1.35
10	-1.3
10.5	-1.2
snow	45.7 cm
ice	2 m

BH6

Depth	May 24	May 27	June 3	June 1	June 11	June 16	June 18	June 22
Surface	-1.85	-	+ .2	-1.4	+ .1	+ .4	+.1	+ .1
.5	-1.8	-	- .3	-1.5	+ .1	+ .2	+.1	+ .1
1	-1.8	-1.85	- .4	-1.5	+ .1	+ .1	+.1	+ .1
1.5	-1.8	-1.85	- .8	-1.5	+ .1	+1.0	+.6	+1.1
2	-1.8	-1.85	-1.3	-1.5	- .4	+ .6	+.2	+1.4
2.5	-1.8	-1.8	-1.5	-1.5	- .7	- .3	+.1	+ .9
3	-1.8	-1.8	-1.6	-1.5	-1.0	- .4	-.2	+ .5
3.5	-1.8	-1.75	-1.6	-1.5	-	-	-	-
4	-1.8	-1.8	-1.6	-1.5	-1.1	- .5	-.3	+ .2
4.5	-1.8	-1.8	-1.6	-	-	-	-	-
5	-1.8	-1.8	-1.6	-1.5	- .9	- .6	-.4	+ .1
5.5	-1.8	-1.8	-1.6	-	-	-	-	-
6	-1.8	-1.8	-1.6	-1.5	-1.0	- .5	-.4	- .2
6.5	-1.8	-1.8	-1.6	-	-	-	-	-
7	-1.8	-1.75	-1.5	-1.5	- .8	- .5	-.5	0.0
7.5	-1.8	-1.65	-1.5	-	-	-	-	-
8	-1.7	-1.55	-1.3	-1.4	- .7	- .6	-.5	- .1
8.5	-1.45	-1.5	-1.2	-	-	-	-	-
9	-1.4	-1.45	-1.2	-1.1	- .6	- .5	-.5	- .1
9.5	-1.4	-1.4	-1.1	-	-	-	-	-
10	-1.1	-1.2	-1.0	-1.0	- .6	- .5	-.4	- .2
snow	30.5 cm				-			- .2 (10.6)
ice	2 m				- .6(11m)			

Table 9 (Contd)

BH7

Depth	May 24	May 26	May 27	June 3	June 1	June 5	June 6	June 7	June 9	June 10
Surface	-	-	-	- .6	-	- .1	- .2	+0.2	- .1	+ .1
.5	-	-	-	- .6	-1.4	- .4	- .3	- .1	- .1	+ .1
1	-	-	-1.8	- .7	-1.4	- .7	- .4	- .2	- .1	+ .1
1.5	-1.8	-	-1.75	-1.0	-1.5	-1.0	- .4	- .3	- .1	0.0
2	-1.8	-1.85	-1.8	-1.5	-1.5	-1.3	-1.2	-1.4	-1.4	- .4
2.5	-1.8	-1.85	-1.75	-1.6	-1.5	-1.3	-1.4	-1.5	-1.4	-1.1
3	-1.8	-1.8	-1.7	-1.6	-1.5	-1.3	-1.5	-1.5	-1.4	-1.1
3.5	-1.8	-1.8	-1.7	-1.7	-1.5	-1.3	-1.5	-	-	-1.1
4	-1.75	-1.8	-1.7	-1.7	-1.5	-1.4	-1.5	-1.5	-1.4	-1.2
4.5	-1.75	-1.75	-1.75	-1.7	-1.5	-1.5	-1.4	-	-	-
5	-1.75	-1.75	-1.7	-1.7	-1.5	-1.5	-1.4	-1.6	-1.4	-1.2
5.5	-1.7	-1.75	-1.75	-1.7	-1.5	-1.5	-1.4	-	-	-
6	-1.7	-1.75	-1.75	-1.7	-1.5	-1.5	-1.4	-1.6	-1.5	-1.4
6.5	-1.7	-1.7	-1.75	-1.7	-1.5	-1.5	-1.4	-	-	-
7	-1.65	-1.65	-1.65	-1.7	-1.4	-1.5	-1.3	-1.6	-1.3	-1.3
7.5	-1.6	-1.6	-1.5	-1.5	-1.2	-1.5	-1.3	-	-	-
8	-1.45	-1.5	-1.35	-1.3	-1.1	-1.2	-1.2	-1.4	- .9	- .9
8.5	-1.3	-1.35	-1.2	-1.2	-1.0	-1.1	-1.1	-	-	-
9	-1.15	-1.15	-1.0	-1.0	- .7	- .9	- .8	-0.9	- .5	- .4
9.5	20.3-25.4 cm	-1.0		-0.8		- .6	- .6	-		
10	2 m							- .5		
snow										
ice										

BH7A

Depth	June 11
Surface	+.2
.5	+.2
1	+.2
1.5	+.1
2	-.3
2.5	-.7
3	-.7
3.5	-
4	-.7
5	-.7
6	-.9
7	-.9
8	-.7
9	-.2
10	-.1

Table 9 (Contd)

BH7B

Depth	June 16	June 18	June 16	June 22	June 25
Surface	+.7	+ .2	+.5	+1.1	+1.5
.5	+.6	+ .1	+.4	+ .5	+ .6
1	+.5	0.00	+.2	+ .2	+ .5
1.5	+.4	+ .9	+.1	+1.2	+2.5
2	+.3	+1.0	+.6	+1.3	+2.0
2.5	+.1	+ .3	+.2	+1.25	+1.8
3	-.1	+ .1	0.0	+ .8	+1.5
4	-.1	- .2	- .3	+ .4	+ .8
5	-.4	- .3	- .4	+ .1	+ .5
6	-.5	- .3	- .5	0.0	+ .5
7	-.5	- .2	- .5	0.0	+ .5
8	-.3	- .1	- .4	+ .1	+ .4
9	+.1	+ .1	0.0	+ .4	+ .8
9.5	-	+ .2	+.1 (9.25)	+ .5	+ .9
	(1740)		(1452)		

BH8

Depth	June 11	June 16	June 18	June 22
Surface	+ .1	+.2	+ .1	+ .2
.5	+ .1	+.2	+ .1	+ .3
1	0	+.3	+ .1	+ .2
1.5	- .1	+.5	+1.0	+1.5
2	- .4	+.5	+ .6	+1.4
2.5	-	+.1	+ .3	+1.0
3	- .9	-.1	0.0	+ .6
3.5	-	-	-	-
4	- .9	-.4	- .3	+ .5
5	- .9	-.5	- .3	+ .1
6	-1.1	-.5	- .4	0.0
7	- .7	-.5	- .3	0.0
8	- .4	-.1	- .2	+ .3

Table 9 (Contd)

	June 24				June 25
	Station				
Depth	I	II	III	IV	II
Surface	+ .5	+ .7	+ .5	+ .4	+1.0
.5	+ .3	+ .5	+ .5	+ .4	+ .7
1	+ .5	+ .5	+ .3	+ .3	+ .5
1.5	+1.2	+1.2	+1.3	+ .7	+1.2
2	+1.8	+ .9	+1.0	+1.0	+1.1
2.5	+1.5	+ .9	+1.0	+ .7	+1.0
3	+1.2	+ .5	+ .6	+ .6	+ .9
4	+ .5	+ .5	+ .4	+ .5	+ .7
5	+ .4	+ .2	+ .2	+ .1	+ .4
6	+ .2	0.0	0.0	0.0	+ .1
7	+ .4	- .2	- .2	- .4	- .2
8	+ .1	- .5	- .2	- .3	- .1
9	0.0	- .5	- .3	- .1	- .2
10	- .1	- .4	- .4	- .1	- .3
11	- .1	- .5	- .4	- .1	- .2
12		- .5	- .4	- .5	- .1
13		- .5	- .4	- .4	
14		- .5	- .4	- .3	
15		- .4		- .2	
16		- .4		- .2	
17		- .4		- .2	
18		- .4		- .2	
19		- .4		- .2	
20				- .2	

FH1

Depth	June 11	June 18	June 22
surface	+ .1	+ .1	+ .4
.5	+ .1	+ .1	+ .2
1	+ .1	0.0	+ .2
1.5	+ .1	+1.0	+2.1
2	- .4	+ .9	+1.5
2.5	- .7	+ .3	+1.3
3	- .8	+ .1	+1.0
3.5	-	-	-
4	- .8	- .1	+ .5
5	- .9	- .3	+ .4
6	-1.0	0.0	+ .4
7	- .7	0.0(6.5)	+ .8

Table 9 (Contd)

FH2 Temp.

Depth	June 18
surface	+ .2
.5	+ .1
1	0.0
1.5	+ .6
2	+ .7
2.5	+ .4
3	+ .1
4	- .3
5	- .4
6	- .3
7	- .2
8	- .1

B. <u>'Influenced' by oil stations</u>

NW Hole

Depth	May 11	May 12	May 15	May 16	May 20
.5	-1.8			-1.8	-1.8
1	-1.8		-1.9	-1.8	-1.8
1.5	-1.8		-1.8	-1.8	-1.8
2	-1.7	-1.8	-1.8	-1.8	-1.75
2.5	-1.8	-1.8	-1.7	-1.75	-1.75
3	-1.8	-1.8	-1.8	-1.75	-1.75
3.5	-1.8	-1.8	-1.8	-1.6	-1.75
4	-1.8	-1.8	-1.8	-1.7	-1.75
4.5	-1.8	-1.8	-1.8	-1.7	-1.8
5	-1.8	-1.8	-1.8	-1.7	-1.8
5.5	-1.8	-1.8	-1.8	-1.7	-1.8
6	-1.8	-1.7	-1.8	-1.7	-1.8
6.5	-1.6	-1.8	-1.7	-1.7	-1.8
7.0		-1.7	-1.6	-1.6	-1.6
7.5		-1.5			

Table 9 (Contd)

Hole 1

Depth	May 12	May 16	May 20
.5	-1.8	-1.8	-1.8
1	-1.8	-1.8	-1.8
1.5	-1.8	-1.7	-1.8
2	-1.8	-1.8	-1.8
2.5	-1.8	-1.8	-1.8
3	-1.8	-1.8	-1.8
3.5	-1.8	-1.8	-1.8
4	-1.8	-1.8	-1.8
4.5	-1.8	-1.8	-1.8
5	-1.8	-1.8	-1.8
5.5	-1.8	-1.8	-1.8
6	-1.8	-1.8	-1.8
6.5	-1.7	-1.7	-1.8
7	-1.7	-1.65	-1.8
7.5	-1.5	-1.6	-1.7
8.0		-1.4	-1.5
8.5		-1.3	-1.4

Hole 2

Depth	May 12	May 16	May 20
.5	-1.9	-1.8	-1.85
1	-1.9	-1.8	-1.8
1.5	-1.9	-1.8	-1.8
2	-1.9	-1.8	-1.8
2.5	-1.9	-1.8	-1.8
3	-1.8	-1.8	-1.8
3.5	-1.8	-1.8	-1.8
4	-1.9	-1.8	-1.8
4.5	-1.8	-1.8	-1.8
5	-1.8	-1.8	-1.8
5.5	-1.9	-1.8	-1.8
6	-1.9	-1.8	-1.8
6.5	-1.9	-1.8	-1.8
7	-1.8	-1.7	-1.8
7.5	-1.7	-1.6	-1.7
8	-1.6	-1.5	-1.6
8.5		-1.4	-1.4
9.0		-1.3	-1.2
9.5		-1.2	-1.1

Table 9.(Contd)

DH1

Depth	May 10	May 12	May 16	May 20	May 22	May 23	May 24	May 27	June 3
Surface	-	-	-	-	-	-	-	-	+ .2
.5	0.0	0.0	- .2	- .5	- .4	- .5	- .3	- .4	+ .2
1	-0.1	0.0	- .35	- .6	- .4	- .4	- .3	- .55	- .2
1.5	- .25	- .2	- .6	- .7	- .5	- .5	- .4	- .6	-1.3
2	-1.4	-1.5	-1.8	-1.6	-1.5	-1.6	-1.55	-1.7	-1.3
2.5	-1.7	-1.6	-1.8	-1.7	-1.6	-1.7	-1.65	-1.7	-1.5
3	-1.7	-1.7	-1.8	-1.7	-1.7	-1.7	-1.7	-1.8	-1.5
3.5	-1.7	-1.8	-1.8	-1.7	-1.7	-1.7	-1.7	-1.85	-1.5
4	-1.8	-1.8	-1.85	-1.7	-1.7	-1.7	-1.7	-1.85	-1.5
4.5	-1.8	-1.8	-1.85	-1.8	-1.7	-1.7	-1.7	-1.85	-1.5
5	-1.8	-1.8	-1.8	-1.8	-1.7	-1.7	-1.7	-1.85	-1.5
5.5	-1.8	-1.8	-1.8	-1.8	-1.8	-1.75	-1.7	-1.85	-1.5
6	-1.8	-1.8	-1.8	-1.8	-1.8	-1.7	-1.7	-1.85	-1.5
6.5	-1.7	-1.8	-1.8	-1.8	-1.6	-1.7	-1.65	-1.8	-1.5
7	-1.6	-1.7	-1.8	-1.8	-1.6	-1.6	-1.55	-1.7	-1.5
Bottom	-1.5	-1.5	-1.5	-1.6	-1.5	-1.5	-1.4	-1.5	-1.3
				-1.5	-1.3	-1.4	-1.3		-1.3

DH1 (Contd)

Depth	June 1	June 6	June 7	June 8	June 12	June 16
Surface	-	+ .3	+ .6	+ .2	+1.4	+ .4
.5	+ .2	+ .3	+ .2	+ .2	+ .6	+ .2
1	- .2	+ .1	+ .1	+ .1	+ .2	+ .2
1.5	- .4	+ .1	+ .1	+ .1	+ .2	+ .7
2	-1.5	-1.0	-1.1	- .9	- .3	+ .5
2.5	-1.5	-1.2	-1.4	-1.2	- .6	+ .2
3	-1.5	-1.3	-1.5	-1.4	- .7	- .2
3.5	-1.5	-	-	-	-	-
4	-1.6	-1.4	-1.5	-1.4	- .8	- .2
4.5	-1.6	-	-	-	-	-
5	-1.6	-1.4	-1.5	-1.4	- .8	- .4
5.5	-1.6	-	-	-	-	-
6	-1.6	-1.4	-1.5	-1.4	- .8	- .1
6.5	-1.6	-	-	-	-	-
7	-1.6	-1.4	-1.5	-1.2	- .8	0.0
7.5	-1.3	-	-	-	-	-
		-1.0	-1.0	-1.0	- .7	

DH1 June 7

hour

Depth	1635	1915	1920	1925	1955
surface	+ .5	-	-	-	-
.5	+ .4	+ .2	-	-	-
1	+ .3	+ .1	+ .1	+ .1	-
1.5	+ .1	-	-	-	-
2	- .1	-1.3	-1.0	-	-1.2
5	-1.5	-	-	-	-
7	-1.4	-	-	-	-

Table 9 (Contd)

DH2

Depth	May 22	May 23	May 24	May 27	June 3	June 1	June 6	June 7	June 9	June 16	June 18
Surface	-	-	-	-	+ .3	15cm+ .1	+ .5	+ .2	+ .5	+1.1	+1.0
.5	-1.75	-1.8	-1.6	-1.7	-..2	25cm-1.0	+ .2	0	+ .5	+ .7	+ .5
1	-1.8	-1.8	-1.6	-1.7	- .8	-1.3	+ .1	- .1	+ .2	+ .5	+ .5
1.5	-1.8	-1.8	-1.6	-1.7	-1.5	-1.4	+ .1	- .35	+ .1	+ .7	+ .8
2	-1.8	-1.8	-1.6	-1.7	-1.6	-1.5	-1.0	-1.4	-1.0	+ .5	+1.0
2.5	-1.8	-1.8	-1.6	-1.75	-1.6	-1.6	-1.4	-1.5	-1.2	+0.0	+ .5
3	-1.8	-1.8	-1.6	-1.75	-1.6	-1.6	-1.4	-1.56	-1.2	- .1	+ .3
3.5	-1.8	-1.8	-1.6	-1.75	-1.6	-1.5	-1.4	-1.60	-	-	
4	-1.8	-1.8	-1.6	-1.75	-1.6	-1.5	-1.4	-1.6	-1.4	- .4	0.0
4.5	-1.8	-1.8	-1.6	-1.75	-1.6	-1.6	-1.4	-	-	-	
5	-1.8	-1.8	-1.6	-1.75	-1.6	-1.6	-1.4	-1.6	-1.4	- .4	- .2
5.5	-1.8	-1.8	-1.6	-1.75	-1.6	-1.6	-1.4	-	-	-	
6	-1.8	-1.8	-1.6	-1.8	-1.6	-1.6	-1.4	-1.6	-1.4	- .5	- .3
6.5	-1.7	-1.7	-1.55	-1.7	-1.6	-	-1.3	-	-	-	
7	-1.7	-1.7	-1.5	-1.65	-1.6	-1.6	-1.3	-1.6	-1.3	- .5	- .3
7.5	-1.6	-1.6	-1.5	-1.6	-1.5	-	-1.3	-	-	-	
8	-1.5	-1.5	-1.3	-1.5	-1.3	-	-1.3	-1.4	-1.1	- .4	- .3
8.5	-1.3	-1.4	-1.15	-1.5	-1.2	-1.3	-1.1	-	-	-	
9	-1.2	-1.2	-1.0	-1.4	-1.1	-	-1.0	-1.1	- .8	- .1	
9.5	-1.0	-1.1	-0.8	-1.25	-0.8	- .8	- .8	-	-	-	
Bottom	-0.9	-1.0	-0.8	-1.2			- .7	- .8	- .6	-0.0	

Clear Hole CH7 Temp.

Depth (M)	May 29	June 3	June 1	June 6	June 7	June 8	June 12	June 18	June 22	June 25
Surface	-	+ .2	+ .1	+ .1	- .1	0.0	- .1	+ .5	+ .5	+1.0
.5	-	+ .1	- .8	.25:+ .1	- .1	- .1	- .1	+ .5	+ .4	+ :5
1	-1.7	+ .1	-1.0	.5 : 0	- .1	- .1	0.0	+ .4	+ .3	+ .9
1.5	-1.7	+ .1	-1.4	.75: 0	- .2	- .1	- .1	+ .6	+1.3	+2.5
2 1.75	-1.7	+ .1	-1.5	1 :- .1	-1.4	-1.0	- .3	+1.0	+1.3	+1.7
2.5	-1.7	-1.5	-1.5	1.25:- .1	-1.6	-1.2	- .7	+ .5	+1.0	+1.6
3	-1.7	-1.5	-1.5	1.5 :- .1	-1.6	-1.4	- .9	+ .1	+ .9	+1.5
3.5	-1.7	-1.5	-1.6	2 :-1.0	-	-	-	-	-	-
4	-1.7	-1.5	-1.6	2.5 :-1.4	-1.6	-1.4	- .9	- .1	+ .6	+1.3
4.5	-1.7	-1.5	-1.6	3 :-1.4	-	-	-	-	-	-
5	-1.7	-1.5	-1.6	-1.4	-1.6	-1.5	- .8	- .4	+ .4	+ .6
5.5	-1.7	-1.5	-1.6	-1.5	-	-	-	-	-	-
6	-1.7	-1.5	-1.6	-	-1.6	-1.4	- .8	- .5	+ .1	+ .4
6.5	-1.65	-1.5	-1.6	-1.5	-	-	-	-	-	-
7	-1.6	-1.5	-1.55	-	-1.6	-1.3	- .8	- .4	0.0	+..5
7.5	-1.5	-1.5	-1.3	-1.5	-	-	-	-	-	-
8	-1.3	-1.3	-1.0	-	-1.3	- .8	- .6	- .3	0.0	+ .3
Bottom	-0.9	-0.8	- .6	-1.5	- .6	-	-	-	-	-
		-0.6		-		- .5	- .3	0.0	+ .5	+ .7
				-1.3					-	
				- .6					+ .5	

Table 9.(Contd)

IS1

Depth	June 13	June 16	June 18
Surface	+.5	+ .2	+ .4
.5	+.4	+ .1	+ .1
1	+.4	+ .1	0.00
1.5	+.3	+ .4	+0.5
2	-.2	+ .6	+ .8
2.5	-.6	+ .3	+ .5
3	-.7	0.0	0.0
4	-.7	- .5	0.0
5	-.1	0.00	0.0
6	-	-	0.0

IS2

Depth	June 13	June 22
Surface	-.2	+ .5
.5	-.2	+ .2
1	-.2	+ .4
1.5	-.2	+1.5
2	-.3	+1.2
2.5	-.7	+1.0
3	-.7	+1.0
4	-.7	+ .7
5	-.1	+ .8

C. <u>In oil stations</u>

SH1

Depth	June 9	June 11	June 16	June 18	June 22
Surface	- .4	+.4	+.4	+ .5	+ .2
.5	- .7	+.3	+.3	+ .1	+ .2
1	-1.1	+.1	+.1	+ .1	+ .2
1.5	-1.2	-.1	+.4	+ .5	+ .8
2	-1.3	-.3	+.5	+ .9	+1.3
2.5	-1.4	-.6	+.1	+ .5	+1.0
3	-1.4	-.7	-.1	0.0	+1.0
3.5	-	-	-	-	-
4	-1.3	-.7	-.3	+ .1	+ .7
4.5	-	-	-	-	-
5	-1.3	-.8	-.5	- .1	+ .5
5.9	-1.0	-.6	-.2	- .1	+ .5
7	-	-.3	-	0.0	+ .5

Table 9.(Contd)

SH2

Depth	June 8	June 10	June 12	June 16	June 18
Surface	- .2	+ .3	+ .4	+1.1	+ .6
.5	- .2	+ .05	+ .2	+ .7	+ .2
1	- .2	0.0	+ .1	+ .4	+ .1
1.5	- .2	0.0	+ .1	+ .6	+ .6
2	- .9	- .8	- .3	+ .5	+ .1
2.5	-1.1	-1.2	- .7	+ .1	+ .5
3	-1.4	-1.3	- .8	- .1	+ .2
3.5	-	-	-	-	-
4	-1.4	-1.3	- .8	- .4	- .3
4.5	-	-	-	-	-
5	-1.5	-1.4	- .8	- .5	- .4
5.5	-	-	-	-	-
6	-1.5	-1.4	- .8	- .5	- .5
6.5	-	-	-	-	-
7	-1.45	-1.3	- .7	- .5	- .4
7.5	-	-	-	-	-
8	-1.1	-1.1	- .7	- .3	- .4
8.5	-	-	- .6	-	-
9	- .9	- .6	- .4	- .1	- .2

NW2

Depth	June 8	June 11	June 16	June 18	June 22
Surface	-1.1	+ .4	+.2	+ .5	+ .5
.5	-1.3	+ .2	+.3	+ .1	+ .4
1	11	+ .1	+.2	+ .1	+ .4
1.5	-1.4	0.0	+.5	+ .7	+1.8
2	-1.4	- .3	+.4	+1.0	+1.5
2.5	-1.4	- .6	+.1	+ .5	+1.1
3	-1.4	- .7	-.1	+ .1	+ .8
3.5	-	-	-	-	-
4	-1.4	- .8	-.3	- .1	+ .5
4.5	-	-	-	-	-
5	-1.4	- .7	-.5	- .3	+ .3
5.5	-	-	-	-	-
6	-1.4	- .7	-.5	- .2	0.0
6.5	-	-	-	-	-
7	-1.1	- .7	-.3	- .2	+ .1
7.5	-	-	-	-	-
8	-1.0	- .5	-.1	0.0	+ .6

Table **9** · (Contd)

NW4

Depth	June 9	June 11	June 16	June 18
Surface	- .1	+.2	+ .4	+ .5
.5	- .1	+.1	+ .4	+ .3
1	- .1	+.1	+ .2	+ .5
1.5	- .1	+.1	+ .8	+ .9
2	-1.1	-.3	+ .5	+ .9
2.5	-1.3	-.8	+ .2	+ .6
3	-1.4	-.8	0.0	+ .1
3.5	-	-	-	-
4	-1.4	-.8	- .3	0.0
5	-1.4	-.8	- .4	- .4
6	-1.4	-.9	- .5	- .4
7	-1.1	-.8	- .5	- .3
8	-1.0	-.8	- .4	- .3
8.5	-	-.5	-	-
9	-	-	- .2	- .2

NW6

Depth	June 8	June 11	June 16	June 18
Surface	- .2	+.4	+ .3	+ .4
.5	- .2	+.1	+ .2	+ .2
1	- .2	+.1	+ .2	+ .1
1.5	- .2	+.1	+ .5	+ .5
2	-1.0	-.2	+ .4	+ .9
2.5	-1.1	-.7	0.0	+ .4
3	-1.4	-.9	- .1	0.0
3.5	-	-	-	-
4	-1.4	-.9	- .3	- .1
4.5	-	-	-	-
5	-1.4	-.9	- .4	- .1
5.5	-	-	-	-
6	-1.2	-.6	- .3	- .3
6.5	-	-	-	-
7	1.0	-.6	- .1	- .1

Table 9.(Contd)

June 25

Depth	Station #5	Station #7
Surface	+ .5	+ .5
.5	+ .4	+ .4
1	+1.0	+1.1
1.5	+2.3	+2.5
2	+1.9	+2.0
2.5	+1.7	+1.8
3	+1.5	+1.5
4	+1.1	+1.0
5	+ .6	+ .6
6	+ .6	+ .4
7	+ .5	+ .5
8	+ .5	+ .3
9	+ .7	+ .7
10		+ .7

D. <u>Surface melt ponds</u>

Algal Melt Ponds
Small near BH7

Depth	June 5
Surface	+ .9
10 cm	+2.0

Algal Melt Ponds
Large near BH7

Depth	June 5
Surface	+ .6
10 cm	+ .9
25 cm	+1.2
50 cm	+2.2
60 cm	+2.2

Algal Melt Ponds
Newly Formed Pond 1

Depth	June 5
15 cm deep	+.2

Algal Melt Ponds
Newly Formed Pond 2

Depth	June 5
15 cm deep	+.5

Algal Melt Ponds
Tidal Crack Hole

Depth	June 5
.5	+ .1
1	+ .1
1.5	+ .1
2	- .7
3	-1.0

Table 9.(Contd)

Algal Melt Ponds near CH1
Large

Depth	June 6
Surface	+.1
.25	+ .9
.5	+ .9
.65	+1.0

Algal Melt Ponds near CH1
Medium

Depth	June 6
Surface	+.5
.3M	+.5

Algal Melt Ponds near CH1
Small

Depth	June 6
Surface	+.2
.25	+.5

Algal Melt Ponds near CH1
.5 M diam

Depth	June 6
Surface	+.6
.25	+.6
.4	+.5

Algal Melt Ponds
20 cm. Diam. Hole near CH1

Depth	June 7
Surface	+.1
.25	+.5
.5	+.5
.6	+.5

DA1

Depth	June 14
0	+ .8
.25	+ .7
.375	+1.0 (A)
.5	+1.1

DA2

Depth	June 14
0	+2.2
.125	+3.2 (A)

Table 9. (Contd)

DA3

Depth	June 14
0	+1.8
.125	+1.8
.25	+1.5
.375	+1.4
.5	+3.5
(.6) Bottom	+4.1

DA4

Depth	June 14
0	+.4
.125	+.4
.25	+.3

UA1

Depth	June 14
0	+ .8
.125	+ .7
.25	+1.4
.325	+2.5
Bottom	+2.7

UA2

Depth	June 14
0	+ .9
.125	+ .1
.325	+1.1

UA3

Depth	June 14
0	+1.2
.125	+1.0
.25	+0.9
.375	+0.7

UA4

Depth	June 14
0	+ .4
.125	+ .4
.25	+ .7
.375	+ .7
.5	+1.0
Bottom (.6)	+1.0

Table 10. Conductivity and salinity of ice cores from Balaena Bay at 22°C

Core	Depth /cm	Conductivity $/\mathrm{k}\mu\mho\mathrm{cm}^{-1}$	Salinity (p.p.t.)
Control (May 25, 1975)	0-24	4.28	2.26
	24-51	1.26	0.60
	88-113	1.77	0.88
SH2 (May 11, 1975)	0-20	1.49	0.72
	20-40	1.99	1.00
	57-77	2.38	1.21
	77-93	1.43	0.69
	93-113	0.35	0.10
	113-133	1.27	0.60
	133-150	1.83	0.91
	150-159	1.72	0.85
NW2 (core #1) (May 24, 1975)	0-7	0.361	0.11
	7-25	3.88	2.04
	25-43	1.96	0.98
	43-73	5.55	2.98
	73-81	5.04	2.69
	81-101	7.37	4.20
	101-130	1.82	0.90
NW2 (core #2) (May 20, 1975)	0-29	4.12	2.17
	29-33	4.06	2.14
	33-35	2.53	1.29
	54-74	0.73	0.31
	74-107	3.68	1.93

Table 11(a) Water quality results from

Balaena Bay, N.W.T. (units, mg per litre)

location date 5.0m depth		alkalinity total $CaCO_3$	calcium Ca^{+3}	chloride Cl^-	magnesium Mg^{+2}	nitrogen $NO_3^+ + NO_2^+$	phosphorus total P	potassium K^+
May 25								
	DH2	117	360	17200	1220	.010	.025	360
	BH7	118	360	17100	1240	.005	.025	360
June 8								
	DH1	103	265	12000	855	-	-	270
	CH1	118	350	16400	1220	.020	.032	360
	DH2	69.5	210	9700	700	.005	.020	200
	NW2	119	360	17000	1240	.005	.029	360
	NW4	118	360	16100	1240	.005	.031	360
	SH1	118	340	16400	1240	.010	.030	370
	SH2	99.0	290	13000	975	-	-	300
	NW6	109	325	14300	1130	-	-	340
June 11								
	BH6	119	360	16500	1240	.005	.029	365
	BH7A	118	360	16700	1240	.010	.031	360
	BH8	118	350	16900	1240	.010	.031	360
June 30								
	NW6	110	340	15100	1130	.005	.025	330

Table 11(a) Cont'd

location date 5.0 depth	sodium Na^+	sulphate SO_4^{-2}	colour (Hazen units)	ph	conductance /µmhoscm^{-1}at 25°C	turbidity (Jackson units)
May 25						
DH2	9900	2460	5	7.2	48500	0.2
BH7	9700	2500	5	7.7	48700	0.1
June 8						
DH1	7050	1800	5	7.5	36100	0.2
CH1	9700	2500	<5	7.8	48500	0.2
DH2	5800	1550	<5	7.8	47100	0.2
NW2	9700	2630	<5	7.8	48300	0.1
NW4	9700	2500	<5	7.8	48200	0.1
SH1	9700	3850	<5	7.9	48300	0.2
SH2	8100	2000	5	7.6	40700	0.2
NW6	9100	2200	5	7.8	45100	0.2
June 11						
BH6	9700	2500	<5	7.9	48600	0.2
BH7A	9700	2400	<5	7.8	48300	0.2
BH8	9700	2450	<5	7.9	48200	0.2
June 30						
NW6	9100	2300	<5	8.1	45000	0.2

Table 11(b) Water quality results from

Balaena Bay, N.W.T. (units, mg per litre)

location date 2.5m depth	alkalinity total $CaCo_3$	calcium Ca^{+3}	chloride Cl^-	magnesium Mg^{+2}	nitrogen $NO_3^+ + NO_2^+$	phosphorus total P	potassium K^+
May 25							
DH2	117	360	17100	1240	.020	.027	360
BH7	119	350	17400	1240	.020	.024	360
June 4 (algal melt pond)	2.1	43	2020	152	<0.005	0.030	44
June 8							
DH1	82.6	250	12000	845	-	-	270
CH1	117	360	16400	1210	.015	.035	355
DH2	116	350	16700	1210	.010	.029	355
NW2	95.0	280	12900	960	.005	.029	275
NW4	117	360	16600	1240	.005	.030	350
SH1	119	360	16800	1240	.005	.032	360
SH2	81.1	220	10700	780	-	-	250
NW6	74	205	9300	670	-	-	220
June 11							
BH6	116	340	16000	1200	.005	.030	350
BH2A	119	360	16300	1240	.005	.032	355
BH8	116	350	16400	1210	.010	.032	350
June 26 (II control)	112	340	15400	1170	.010	.035	335
June 30							
NW6	115	350	16200	1200	.010	.028	345

Table 11(b) Cont'd

location date 2.4 depth	sodium Na^+	sulphate SO_4^{-2}	colour (Hazen units)	ph	conductance $/\mu mhoscm^{-1}$ at 25°C	turbidity (Jackson units)
May 25						
DH2	9800	2550	5	7.8	48500	0.2
BH7	9700	3550	5	7.8	48400	0.1
June 4 (algal melt pond)	1220	375	<5	7.1	7280	0.2
June 8						
DH1	7100	1800	5	7.6	36100	0.2
CH1	9600	2600	<5	7.8	48400	0.2
DH2	9600	2550	<5	7.5	29700	0.2
NW2	7600	1950	<5	7.7	38500	0.4
NW4	9600	2400	<5	7.8	47100	0.1
SH1	9600	2500	<5	7.8	47700	0.1
SH2	6600	1650	5	7.3	33600	0.3
NW6	5500	1400	5	7.3	29600	0.2
June 11						
BH6	9400	3100	<5	7.8	46600	0.2
BH2A	9600	2500	<5	7.8	47900	0.1
BH8	9500	2450	<5	7.9	48200	0.1
June 26 (II control)	9200	2300	<5	8.0	45700	0.2
June 30						
NW6	9400	2400	<5	8.0	47200	0.3

Table 12(a) Absorbance (A) of ice cores

Run #	Sample	Path Length	A_{300}	A_{400}	A_{500}	A_{600}	A_{700}
1	Control (*)	0.50 cm	0.257	0.241	0.231	0.237	0.250
2	Control	1.01 cm	0.705	0.526	0.472	0.450	0.456
3	NW2(7) (long)	1.01 cm	0.832	0.815	0.803	0.779	0.766
4	NW2(7)	0.50 cm	0.460	0.458	0.426	0.410	0.417
5	NW2(4)	1.20 cm	0.619	0.582	0.572	0.551	0.562
6	NW2(4)	1.70 cm	0.754	0.769	0.772	0.717	0.707
7	NW2(4)	1.67 cm	0.759	0.734	0.710	0.686	0.702
8	SH2 (40cm deep)	1.50 cm	> 2	1.907	1.841	1.797	1.795
9	SH2(3)	.75 cm	0.347	0.288	0.267	0.254	0.250
10	SH2(3)	1.19 cm	0.604	0.459	0.405	0.395	0.399

Table 12(b) Attenuation Coefficients (K_λ) (cm^{-1})

Run #	Sample	K_{300}	K_{400}	K_{500}	K_{600}	K_{700}
1	control(*)	0.514	0.482	0.470	0.474	0.500
2	control	0.698	0.521	0.468	0.446	0.451
3	NW2(7) (long)	0.824	0.807	0.795	0.771	0.758
4	NW2(7)	0.920	0.916	0.852	0.820	0.834
5	NW2(4) (long)	0.516	0.478	0.477	0.459	0.468
6	NW2(4)	0.444	0.452	0.454	0.422	0.416
7	NW2(4)	0.454	0.440	0.425	0.411	0.420
8	SH2 (40cm deep)	(off scale)	1.82	1.75	1.71	1.71
9	SH2(3)	0.463	0.384	0.356	0.339	0.333
10	SH2(3)	0.508	0.386	0.335	0.328	0.330

(* all samples were cut 90° to core length unless marked long. i.e. cut parallel to core length).

Table 13. General Observations on Weather and Ice Conditions

Date	Comments
May 8	- snow cover on ice complete, 20-25 cm and temperature >0°C
May 9	- temperature > 0°C, warm and sunny
May 11	- warm weather and very bright, >0°C
May 13	- colder weather, -9°C
May 14	- blowing snow, -12°C
May 15	- clear and cold, -10°C
May 17	- clear, cold, -9°C, windy
May 18	- clear, cold, -8°C - no trace of algal growth seen in holes drilled or in cores recovered - snow cover becoming thin on ice close to camp
May 20	- cold, -9°C, windy with blowing snow
May 21	- warmer, -6.5°C, no wind
May 22	- windy, cold, -11°C, bright
May 23	- clear
May 24	- ice appears very permeable to water as shown by drainage through walls of 10 inch auger holes during drilling - bright, -3°C
May 25	- snow cover obscured spill site detail except clear ice melt produced by oil burn
May 26	- some oil appeared on surface (SH2) and the snow appeared darker over the circular boom areas on the spill site compared to the Bay in general
May 27-31	- there was no substantial change in the appearance of the ice surface which was completely snow covered
June 1	- slight oil film visible on DH1
June 1-2	- the oil appeared on the surface at every spill to give approximately one third oil coverage of spill area - the snow on the Bay appeared to extend in ridges and drifts separated by extensive wet turquoise blue clear ice areas, first noted melt pond drainage through ice
June 2	- after heavy rain all day - water in CH1 was slightly turbid
June 3	- ice-plug formed in CH1 at fresh water/sea water interface - general appearance as June 2, but extensive surface water of brown-green colour around shore tidal cracks in Bay and in oil spill bay
June 4-5	- snow drifts very localized over about half the surface of Bay - oil on surface of spill area about one half coverage
June 5	- 1310, observed water fountaining above ice surface - tide effect - no oil observed on DH1, DH2
June 6	- snow coverage reduced to about one third area of Bay - clear ice appears to have dark blue pattern as well as previous shade of blue
June 7	- DH2 - oil globules on top - DH1 - oily film on surface - ice and oil appearance similar to June 6 - after burn of oil aerial photos and observations indicated SW contamination of ice surface by soot particles extending ∼ 1 km out on Bay from spill area
June 8-10	- very distinct snow pattern separating blue clear ice areas over Bay - oil in spill area covers smaller total area than before burn

Table 13. General Observations on Weather and Ice Conditions (Cont'd)

Date	Comments
June 8	- oil globules on surface of CH1 - NW2 drilled - $\sim$ 1 ft down to water surface - all other holes, water at surface of ice - NW4 drilled - oil monolayer on top - DH2 - oil on surface - about ½ covered by black layer - monolayer everywhere
June 9	- some oil film seen on NW2 productivity bottles - DH2 - oil thick over surface
June 10	- small crustacea (shrimp-like) collected around productivity bottles - 2.5 m, NW2 - small crustacea clustered around bottle, none at NW4, and are beginning to appear at almost all the holes
June 11	- BH2 - drainage current observed, making cond/temp reading difficult
June 12	- most of the melt ponds drained - DH2 extremely oily
June 14	- DH4 - a crack $\bar{c}$ column of melt channels $\sim$ 3 cm diam.
June 16	- SH2 - some oily burned residue in hole - SH2 - burn residue particles seen in hole
June 18	- SH2 - black residue in hole - DH2 - slick of oil 1 mm thick over ½ hole
June 21	- surface of bay is uniformly white - ice so porous that water drained out leaving a crystalline ice - snow over surface - water remains in algal melt ponds and short drainage channels from these holes
June 22	- Van Dorn washed with lux detergent to get rid of oil - extensive melt pond development under bright sunlight - BH4 - (1750) strong current down hole - CH1 - oil pockets in ice, none on surface - SH2 - clear, no oil
June 25	- NW2 - burn left heavy residue in hole, little light penetration
June 29	- flowers appeared on tundra - algal melt ponds $\sim$ 46 cm deep - large blooms - not open to bottom yet
June 30	- spill area completely open - 5 to 10 m open water strip around shore of Bay and island - snow (or drained-ice crystal) pattern covers about one third surface of Bay - clear ice appears milky blue with dark blue patches over thinner sections.

Table 14 Plankton abundance (cells per liter)

Date	Station	Depth/m	Abundance/cells per liter
May 28,1975	BH7	2.5	768
June 4,1975	BH7	2.5	14,800
June 1,1975	BH7	5.0	1,000
June 11,1975	BH7	5.0	13,600
May 28,1975	DH2	2.5	11,700
June 1,1975	DH2	2.5	2,180
June 1, 1975	DH2	5.0	1,090
June 8, 1975	DH2	5.0	14,100
June 4, 1975	AMP #1	surface near CH1	634,000
June 4, 1975	AMP #2	surface near CH1	668,000
June 4, 1975	AMP #3	surface near CH1	4,110,000
June 4, 1975	AMP #4	surface near CH1	581,000
June 4, 1975	DH1	8.0	559,000

Table 15(a). Algae content of surface melt ponds in Balaena Bay, N.W.T., June 4, 1975

Station	Date	Biota
AMP #1	June 4	*Focus distichus* L. Epiphytic bluegreens abundant.
AMP #3	June 4	*Chaetomorpha melogonium* (Weber & Mohr) Kutz. Epiphytic bluegreens abundant. *Sorapion kjellmanii* (Willie) Rosenv. (Epiphyte, few)
		Percursaria percursa (C. Ag.) Rosenv. (Few)
		Stictyosiphon tortilis (Rupr.) Reinke (Few) Endophytic *Bolbocoleon piliferum* Pringsheim (Abundant) Bluegreens abundant.

Table 15(b) Algae content of surface melt ponds in Balaena Bay, N.W.T., June 14, 1975

Sample	Biota Identification
UA1	1. *Chaetomorpha melagonium* (Weber & Mohr) Kütz ω/*Pilayella littoralis* (L.) Kjellm. *Sphacelaria arctica* Harv. *Cladophora* sp.
	2. *Fucus distichus* L.
	3. *Chaetomorpha capillaris* (Kütz) Børq. ω/*Chaetobolus gibbus* Rosenv.
UA2	1. *Fucus distichus* L.
	2. *Sphacelarica arctica* Harv. ω/*Ectochaete wittrockii* (Wille) Kylin *Chaetomorpha capillaris* (Kütz) Børq.
	3. *Chaetomorpha melogonium* (Weber & Mohr) Kütz
DA2	1. *Fucus distichus* L. (with epiphytes)
	2. *Stictyosiphon tortilis* (Rupr.) Reinke (with epiphytes)
	3. *Chaetomorpha melagonium* (Weber & Mohr) Kütz (with epiphytes)
	4. *Pilayella littoralis* (L) Kjellm (among others)
DA3	1. Diatom colonies and blue green algae
	2. *Chaetomorpha melagonium* (Weber & Mohr) Kütz with epiphytes: *Chaetobolus gibbus* Rosenv. *Pilayella littoralis* (L.) Kjellm. (Blue green algaes & diatoms)
	3. *Fucus distichus* L. ω/epiphytes

Table 16

Abundance percents (relative) for algal melt ponds (MP-June 4, 1975; DA and UA-June 14, 1975)

Identification Number	MP1	MP2	MP3	MP4	DA1	DA2	DA3	DA4	UA1	UA2	UA3	UA4
0	0	0	0	0	0	0	0	0	0	0	0	1
210	0	0	25	25	0	0	0	0	0	0	0	0
220	0	25	5	5	0	0	0	0	0	0	0	0
230	0	0	1	0	0	0	0	0	0	0	0	0
310	1	1	0	1	0	1	0	0	1	1	0	0
320	0	0	1	0	0	1	1	0	1	1	1	0
330	0	1	1	0	0	0	0	0	1	0	0	0
340	0	0	5	0	0	0	0	0	0	0	0	0
350	0	0	0	0	0	0	0	0	0	1	0	0
360	1	1	1	1	5	5	5	5	5	5	5	1
370	5	5	5	5	0	1	0	0	0	0	0	0
380	1	1	5	5	0	1	1	0	1	1	1	0
390	1	0	0	0	0	1	0	0	0	0	0	0
395	1	1	0	0	0	0	0	0	0	0	0	0
400	0	1	1	1	0	0	0	0	0	0	0	0
420	1	1	5	5	1	5	1	1	5	5	1	0
440	0	0	1	0	0	0	0	0	0	0	0	0
450	0	0	1	0	0	0	0	0	1	1	0	0
460	1	1	5	1	1	5	1	0	5	5	1	0
470	5	0	0	1	0	0	0	0	1	0	1	0
480	1	1	5	0	0	1	0	0	1	0	0	0
490	25	5	5	5	1	5	1	0	5	5	5	1
500	25	5	5	5	1	5	5	1	5	5	5	1
510	0	1	0	0	0	0	0	0	0	0	0	0
520	1	1	1	1	0	1	1	0	1	1	1	0
540	1	1	1	1	0	0	0	0	0	0	1	0
570	1	5	5	5	0	1	1	0	5	1	5	1
590	1	1	1	0	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0	0	1	0	0
710	1	0	1	1	0	0	0	0	0	0	1	0
810	0	0	0	0	0	0	1	0	0	0	0	0
820	0	0	0	0	0	0	1	0	0	0	0	0
910	1	1	0	1	0	0	0	0	0	0	1	0
920	0	1	0	0	0	0	0	0	0	0	0	0
930	5	5	25	1	0	0	0	0	0	0	0	0
940	0	1	1	1	0	0	1	0	0	0	1	0
1120	1	0	0	0	0	0	0	0	0	1	1	1
1210	1	0	0	1	0	0	0	0	0	0	0	0
1220	0	0	1	0	0	0	0	0	0	0	0	0
1230	0	0	1	0	0	0	0	0	0	0	0	0
1310	0	0	0	1	0	0	0	0	0	0	0	0
1350	0	1	0	0	0	0	0	0	0	0	0	0
Total	71	67	114	73	9	33	20	7	38	34	31	6

Table 17. Identification Code for Microbiota from Balaena Bay, N. W. T. May-June, 1975

000	ALGAE (unidentified filamentous)
100	ANNELIDEA
110	POLYCHAETA
200	CHLOROPHYTA (green algae)
210	*Bolbocoleon*
211	*B. piliferum*
220	*Chaetomorpha*
221	*C. melagonium*
230	*Percursaria*
231	*P. percursa*
240	*Ulothrix*
300	CHRYSOPHYTA (diatoms)
310	*Amphora*
320	*Amphiprora*
330	*Biddulphia*
340	*Caloneis*
350	*Campylodiscus*
355	*Ceratoneis*
360	*Chaetoceros*
370	*Cocconeis*
380	*Coscinodiscus*
390	*Cymbella*
395	*Cyclotella*
400	*Diploneis*
410	*Eucamphia*
411	*E. greenlandia*
420	*Fragilaria*
430	*Gomphonema*
440	*Grammatophora*
450	*Gyrosigma*
460	*Licmophora*
470	*Melosira*
471	*M. jurgensii*
480	*Mastogloia*
490	*Navicula*
500	*Nitzschia*
501	*N. closterium*
502	*N. delicatissima*
503	*N. frigida*
504	*N. longissima*
505	*N. seriata*
510	*Pinnularia*
520	*Pleurosigma*
530	*Rhizosolenia*
540	*Rhoicosphenia*
541	*R. curvata*
550	*Stauroneis*
560	*Surirella*
570	*Synedra*
580	*Thalassiosira*
590	*Trachyneis*
600	CILIATA
700	CILIOPHORA (cilicates)
710	*Spirostomum*
720	*Tintinnopsis*
721	*T. karajacensis*
722	*T. parvula*
730	*Didinium*
740	*Vorticella*
800	CRUSTACEA
810	*Copepoda*
830	*Nauplius*
900	CYANOPHYTA (blue-green algae)
910	*Anabaena*
920	*Calothrix*
930	*Epiphytic*
940	*Oscillatoria*
1000	EUGLENOPHYTA
1010	*Euglenoidea*
1100	MASTIGOPHORA
1110	*Cryptomonas*
1120	*Distephanus*
1121	*D. speculum*
1200	PHAEOPHYTA (brown algae)
1210	*Fucus*
1211	*F. distichus*
1220	*Sorapion*
1221	*S. kjellmanii*
1230	*Stictyosiphon*
1231	*S. tortilis*
1300	PYRROPHYTA
1310	*Ceratium*
1320	*Dinophysis*
1321	*D. arctica*
1330	*Gonyaulax*
1331	*G. catenata*
1340	*Minuscula*
1341	*M. bipes*
1350	*Peridinium*
1400	ROTIFERA
1500	SARCODINA

Table 18. Ice surface algae survey west of oil spill

Number Position	Hole type type	depth cm.	diam. cm.	Algae present	Position	Hole type type	depth cm.	diam. cm.	Algae present
25	4	3.8	5.1	ABC	3-74	4			B
25	4	1.3	5.1	A	75	2		10.2	ABC
26	4	1.3	10.2 x 5.1	B	15-76	4	small		BC
26	4	1.3	12.7	BC	77	2	12.7	12.7	AB
26	4	many small holes		C	84	4			B
28					78	4		12.7	A
28	1	30.5	27.9	ABC	79	1	30.5	25.4	ABC
5-28	4	1.3	12.7	BC	20-90	4		5.1	ABC
29	2	10.2	20.3	ABC	91	2	10.2	17.8	BC
29	4	10.2	20.3	ABC	30-92	4			ABC
29	5	7.6	-	BC		a lot of filamentous are thru the ice			
15-30	4	-	-	BC	93	2	7.6	15.2	ABC
8-33	4	-	-	A	93	4		10.2	AC
8-40	4			A	94	4		10.2	BC
8-43	4			A	95	4		7.6	A
42	5			D	95	4		7.6	BC
6-50	4		12.7	A	100	filamentous everywhere			
5-50	4		12.7	ABC	100	2	15.2	12.7	ABC
51	4			BC	100	4		10.2	A
7-52	4		5.1 to 12.7	ABC	101	2	15.2	15.2	BC
55	4		20.3	A	101	2	12.7	12.7	ABC
56	2	25.4	25.4	ABCD	5-105	4			A
56	4		7.6	AC	5-105	4		5.1	AB
11-57	4			A	110	4		15.2	B
2-58	2	5.1	17.8	BC	25-110	4			A
60	4			BC	110	2	15.2	20.3	ABC
60	4		17.8	ABC	110	2	15.2	15.2	ABC
6-61	4			A	9-110	4			ABC
1-61				C	20-115	4	small →		BC
63	4			AB	120	small patches of ABC (9 holes)			
62	4			A	120		17.8	20.3	BC
63	5		76.2	D	120		20.3	10.2	BC
65	4		7.6	A	122	5			D
66	2	15.2	15.2	A	125	2	12.7	10.2	
2-66	4		15.2	A	135	1	30.5	27.9	ABC

Table 18 Algae survey (Cont'd)

Position	Hole type			Algae present	Position	Hole type			Algae present
	type	depth cm.	diam. cm.			type	depth cm.	diam. cm.	
67	1	30.5	30.5	ABC	14-135	4		3.8	A
68	2	12.7	15.2	ABC	140	5			D
68	2	25.4	30.4	ABC	15-145	2	15.2	12.7	BC
68	2	25.4	27.9	AC	160	2	25.4	27.9	ABC
17-69	4			A	162	4		12.7	ABC
70	5		25.4	D	8-163	4			A
3-69	4			C	170	5			D
72	1	30.5	25.4	ABC	2-170	2	25.4	12.7	ABC
73	2	17.8	15.2	B	3-171	2	12.7	12.7	BC
73	4		10.2	BC	14-175	2	15.2	15.2	BC
73	2	12.7	12.7	ABC	1-176	2	20.4	20.3	ABC
74	1	35.6	22.9	ABC	176	4		7.6	BC
3-176	4		7.6	A					
180	5			D					
181	2	12.7	17.8	A					
10-182	2	15.2	12.7	A					

Algae Present

A	branched algae (brown algae), (*Fucus disticus* L.)
B	filamentous algae (green algae (*Chaetomorpha melagonium* (Weber and Mohr) Kütz)
C	slime algae (blue-green algae)
D	gel algae (diatoms)

hole type

1	deep open	
2	shallow open	
3	closed	
4	surface	< 3cm deep
5	crack	

Table 19 Summary of number of planktonic genera in control and oil groups of stations in Balaena Bay, N. W. T., May-June, 1975

(mean # genera/sample)

Control

	Level of Abundance				
Total no. of genera	1%	5%	25%	50%	Total
	18.2	32	10	6	230
mean of 41 samples	4.44	0.78	0.244	0.146	5.61
RMS	4.71	1.08	0.56	0.38	5.89
±DEV	3.19 (67.7%)	0.58 (53.3%)	0.25 (44.6%)	0.13 (33.4%)	3.90 (66.2%)

Oil

	324	66	22	10	422
mean of 67 samples	4.84	0.985	0.328	0.149	6.30
RMS	4.97	1.56	0.66	0.39	6.66
±DEV	4.07 (81.9%)	0.89 (56.8%)	0.32 (48.9%)	0.13 (33.4%)	5.53 (83.0%)

% increase in mean	9%	26%	34%	2%	12.3%
ΔRMS ±ΣDEV	5.9% (149.6%)	44.4% (110.1%)	17.9% (93.5%)	2.6% (66.8%)	13.1% (149.2%)

Table 20 Mean primary productivity results,
May-June, 1975 Balaena Bay, N.W.T.
(m mol C m^{-3} h^{-1})

4 hr. incubation			
	Light ($\bar{L}$)	Dark ($\bar{D}$)	$\bar{L}-\bar{D}$
control	0.264 ± 0.025	0.246 ± 0.036	0.018
influenced by oil	0.245 ± 0.089	0.230 ± 0.084	0.015
in oil	0.222 ± 0.025	0.141 ± 0.048	0.081
combined oil	0.241 ± 0.076	0.213 ± 0.077	0.028
24 hr. incubation			
control	0.0624 ± 0.0255	0.0369 ± 0.0145	0.0255
influenced by oil	0.0886 ± 0.0427	0.0528 ± 0.0259	0.0358
in oil	0.0519 ± 0.0254	0.0318 ± 0.0143	0.0201
combined oil	0.0733 ± 0.0355	0.0441 ± 0.0211	0.0292

Table 21 Phytoplankton production estimates from several far northern marine locations and from some comparable regions in lower latitudes (from Grainger (1974) with some additions)

Author	Location	Production estimate
Far northern marine		
Apollonio (1959)	Arctic Ocean	50 mmol C/m^2/year
Apollonio (MS, 1956)	Cornwallis I., Canada	16mmol C/m^2/day over summer (reasonable extrapolation to about 1.2mol C/m^2/year)
McLaren (1969)	Baffin I., land-locked fjord	1 mol C/m^2/year
Steemann Nielsen (1958)	West Greenland, 3 locations	2.4, 7.9, 8.2mol Cm^2/yr.
Petersen (1964)	West Greenland	3 mol C/m^2/year
Bagge & Niemi (1971)	Gulf of Finland	2.5-3.3mol C/m^2/year
Welch & Kalff (1975)	Resolute Bay, N.W.T.	2.7 molC/m^2/year
Grainger (1974)	Frobisher Bay	4.2-8.3 molC/m^2/year
Lower latitude marine		
Platt (1971)	St. Margarets Bay, Nova Scotia	15.8 mol g C/m^2/year
Parsons, LeBrasseur & Barraclough (1970)	Str. of Georgia British Columbia	10 mol C/m^2/year
Ryther & Yentsch (1958)	off New York	8.3-13.3mol C/m^2/year
Steven (1971)	near Barbados	8.7 mol C/m^2/year
Sorokin and Konovalova (1973)	Japan Sea near Vladivostok	8-25 mmol C/m^2/d (winter bloom) under ice

Table 22

Analysis of Unweathered Crude Oil Samples

(provided by Norcor Engineering & Research Ltd., Yellowknife)

Element	Crude Oil	
	Norman Wells	Swan Hill
Sulphur	1.76%	2.90%
Aluminum (Al_2O_3)	< 0.5 p.p.m.	< 0.5 p.p.m.
Barium	< 0.5 p.p.m.	< 0.5 p.p.m.
Calcium (CaO)	< 0.5 p.p.m.	5 p.p.m.
Copper	< 0.5 p.p.m.	< 0.5 p.p.m.
Iron (Fe)	0.3 p.p.m.	0.3 p.p.m.
Lead	0.5 p.p.m.	20 p.p.m.
Magnesium (MgO)	< 0.5 p.p.m.	< 0.5 p.p.m.
Nickel	1 p.p.m.	< 0.5 p.p.m.
Silicon (SiO_2)	< 0.5 p.p.m.	< 0.5 p.p.m.
Sodium (Na_2O)	< 1 p.p.m.	1 p.p.m.
Tin	< 0.5 p.p.m.	< 0.5 p.p.m.
Vanadium	3 p.p.m.	< 0.5 p.p.m.
Zinc	-	20 p.p.m.

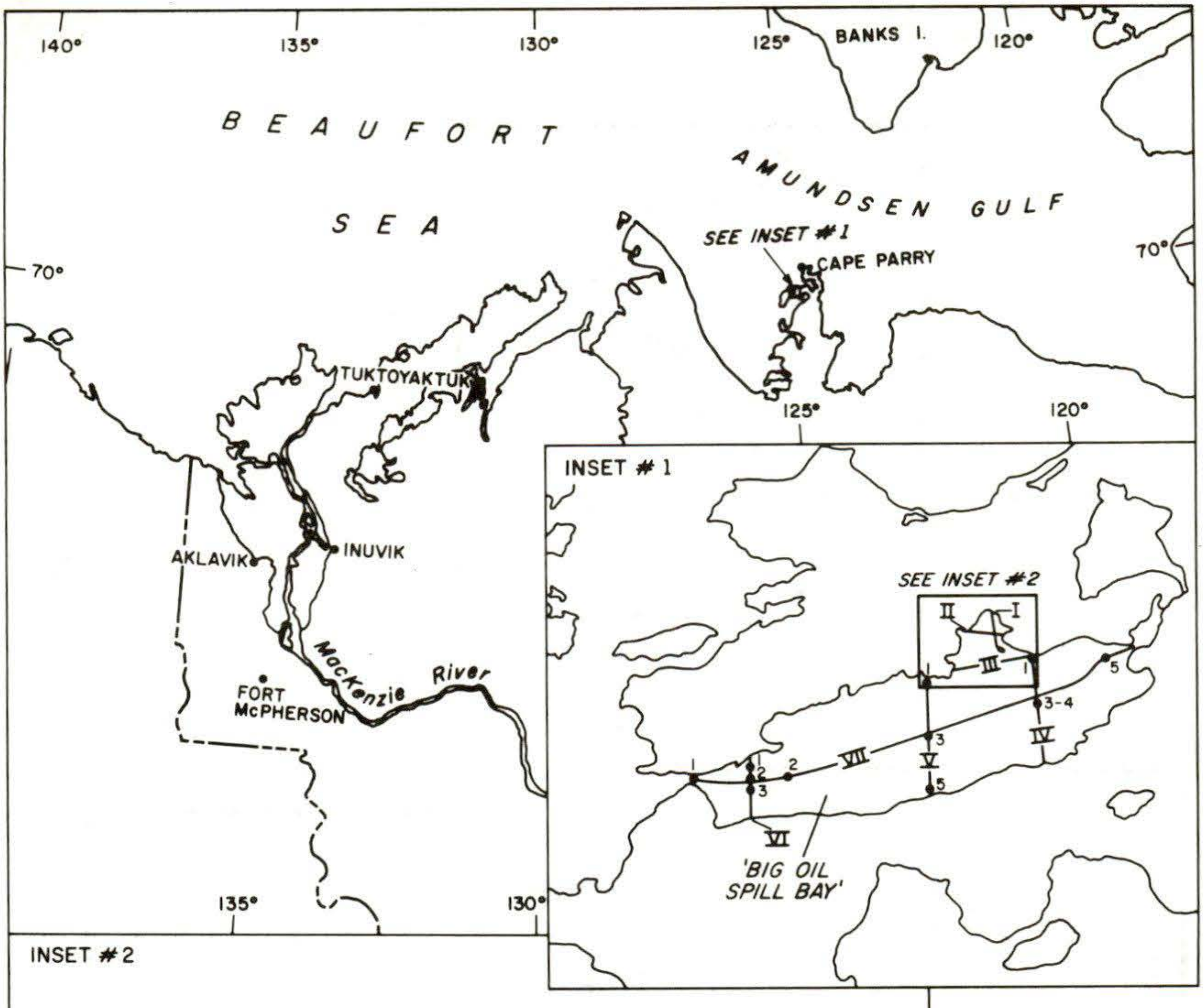

Figure 1(a). Map of site showing September, 1974 survey stations.

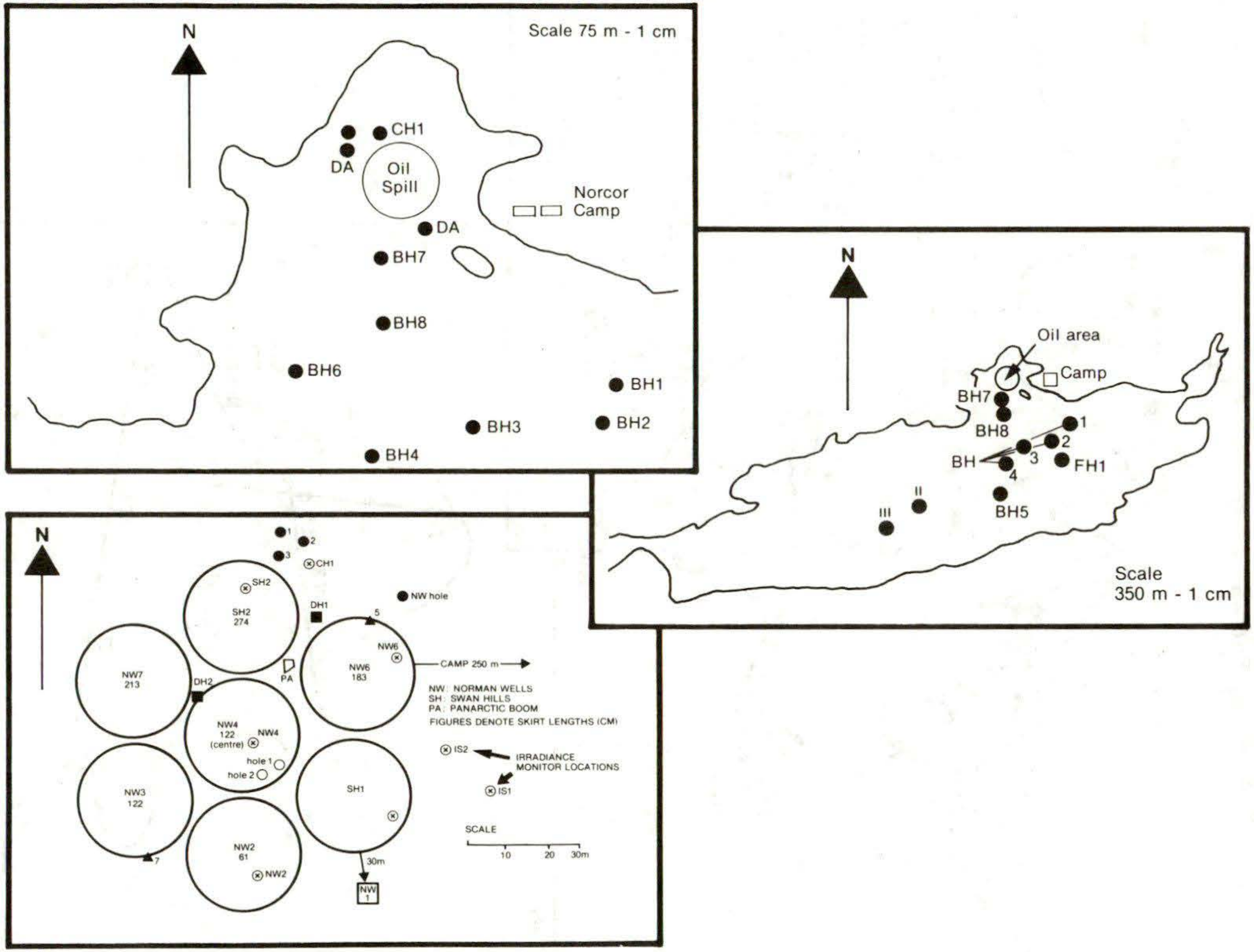

Figure 1(b). Map of site showing May - June, 1975 survey stations.

Figure 2(a). Photograph of the oil spill site taken from a helicopter. Balaena Bay, May 26, 1975, surface melt effect of early May burn lower centre.

Figure 2(b). Photograph of the oil spill site taken from a helicopter. Balaena Bay, June 7, 1975.

Figure 2(c). Photograph of the oil spill site taken from a helicopter. Balaena Bay, June 10, 1975.

Figure 2(d). Photograph of the oil spill site taken from a helicopter. Balaena Bay, June 30, 1975.

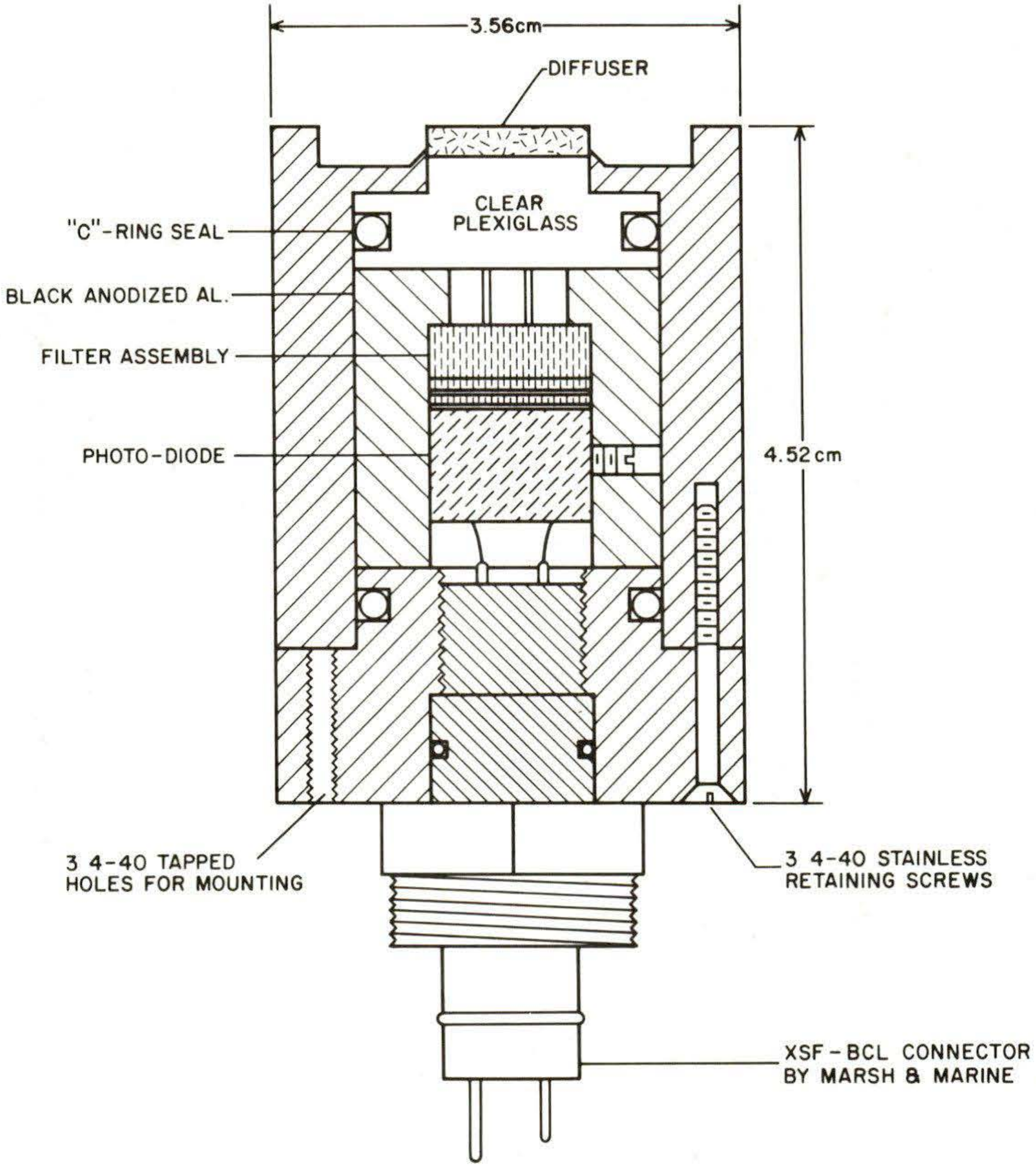

Figure 3(a). Construction details of the L1-192S underwater irradiance quantum sensor.

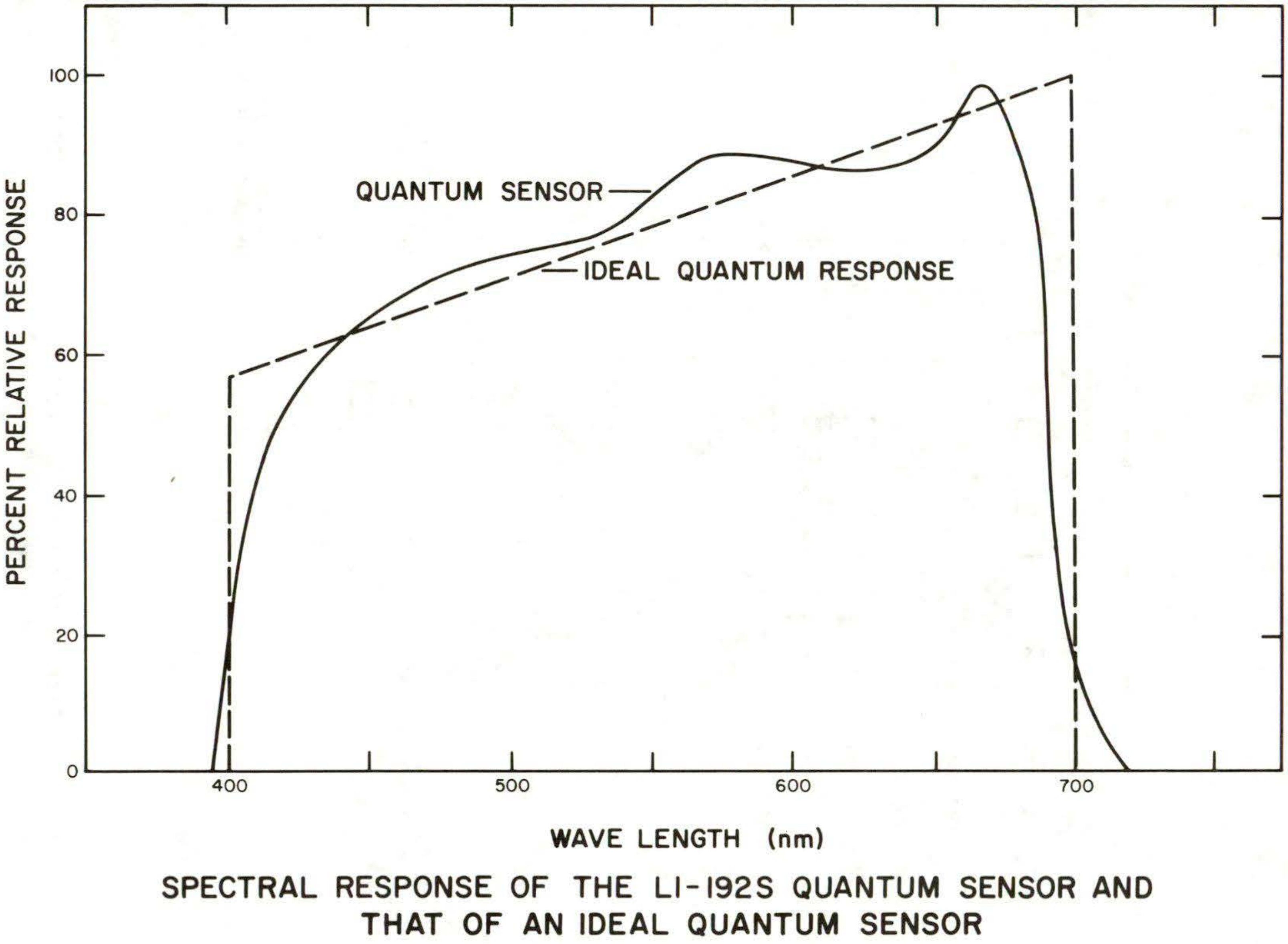

Figure 3(b). Spectral response of the L1-192S quantum sensor and that of an ideal quantum sensor.

Figure 4. Photograph of H. Chew holding the light sensor support ready for deployment through ice in Balaena Bay, N.W.T. June 4, 1975.

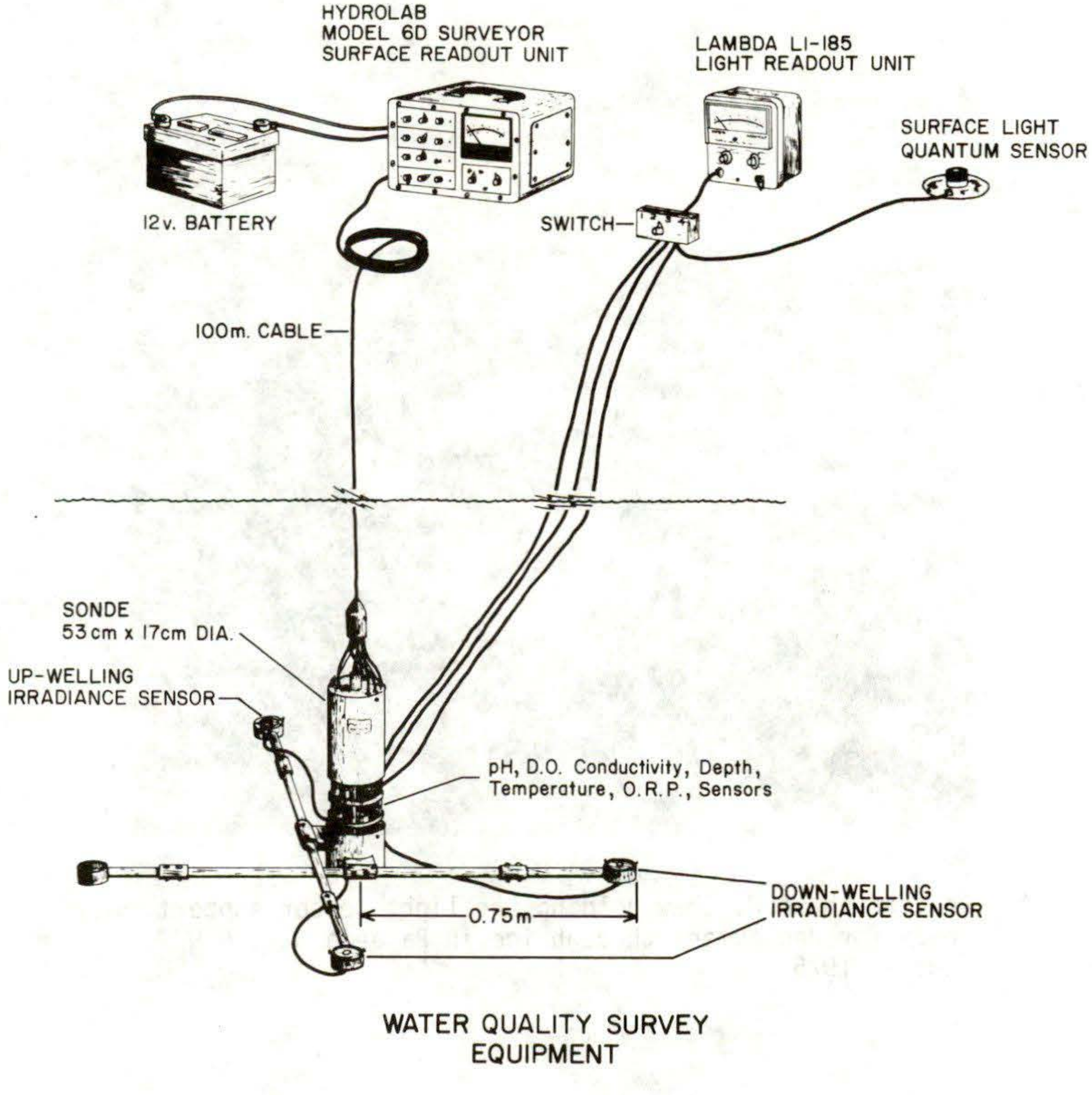

Figure 5. Water quality survey equipment showing configuration of underwater irradiance sensors.

Figure 6. Photograph of Hydrolab Surveyor, September, 1974, (modified to accept Lambda irradiance sensors) on the shore of the oil spill cove in Balaena Bay next to inflatable boat used for survey.

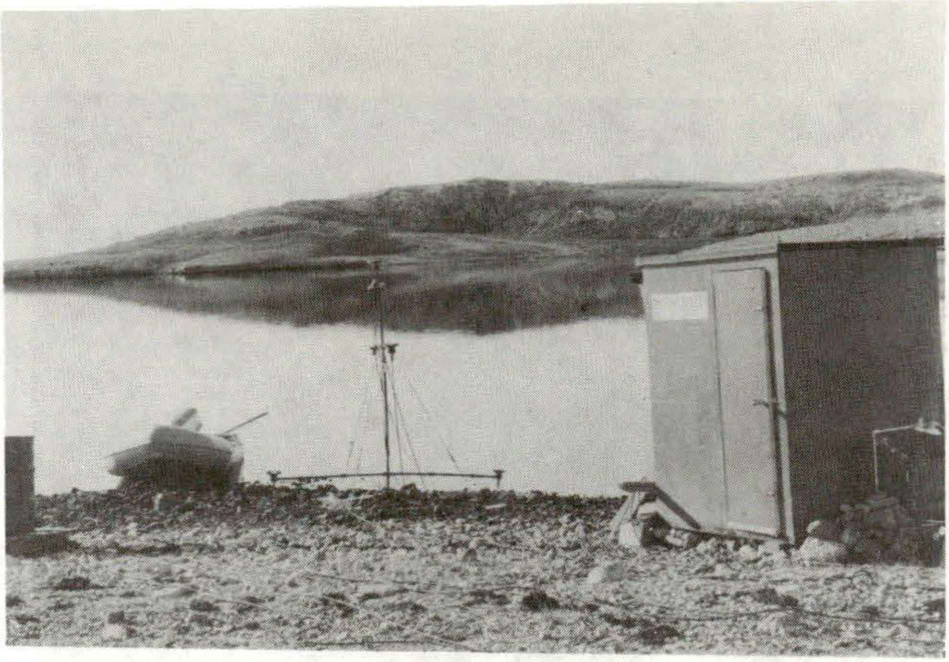

Figure 7(a). Photograph of equipment shelter (right) and irradiance monitor support (centre) in oil spill cove, Balaena Bay, N.W.T., September, 1974 looking west from shore at camp.

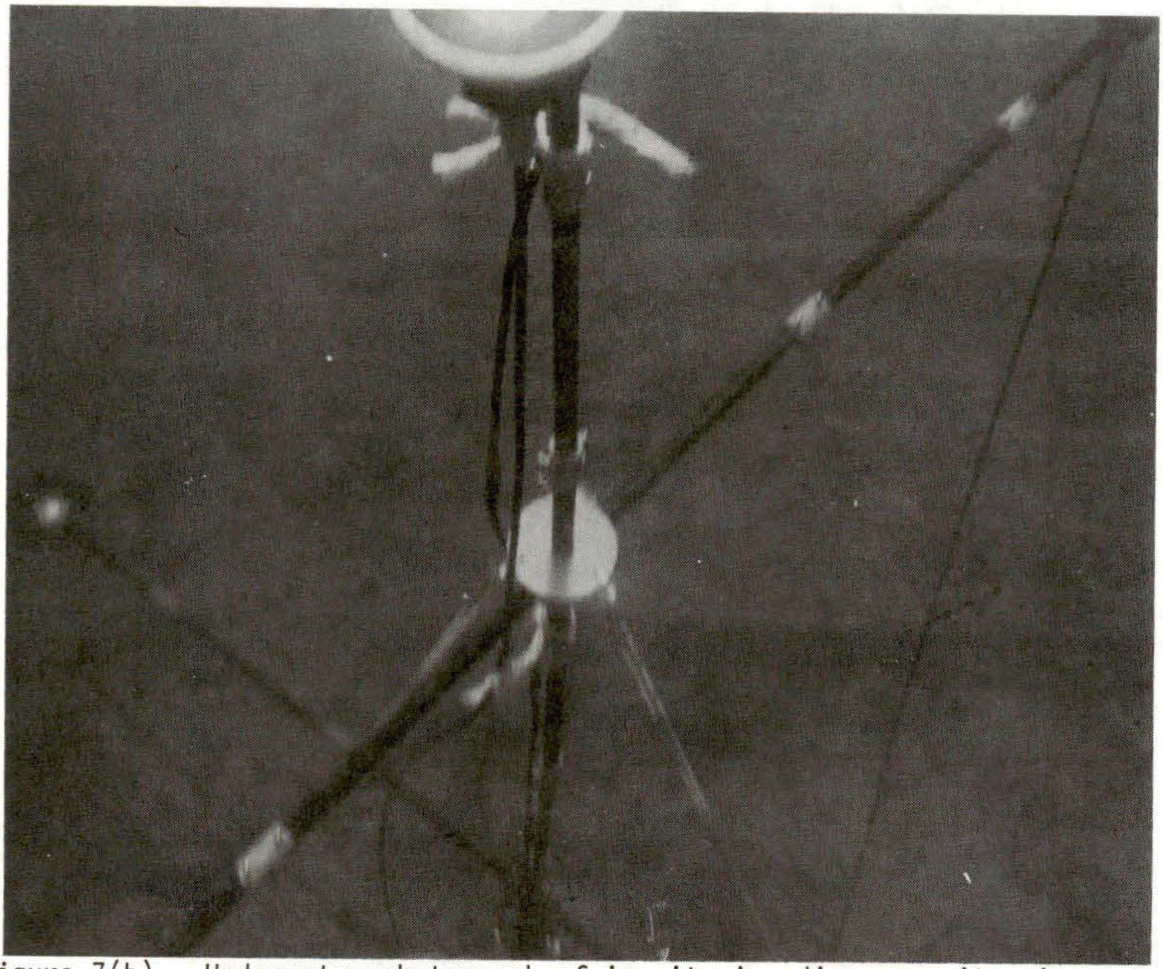

Figure 7(b). Underwater photograph of in situ irradiance monitor in Balaena Bay.

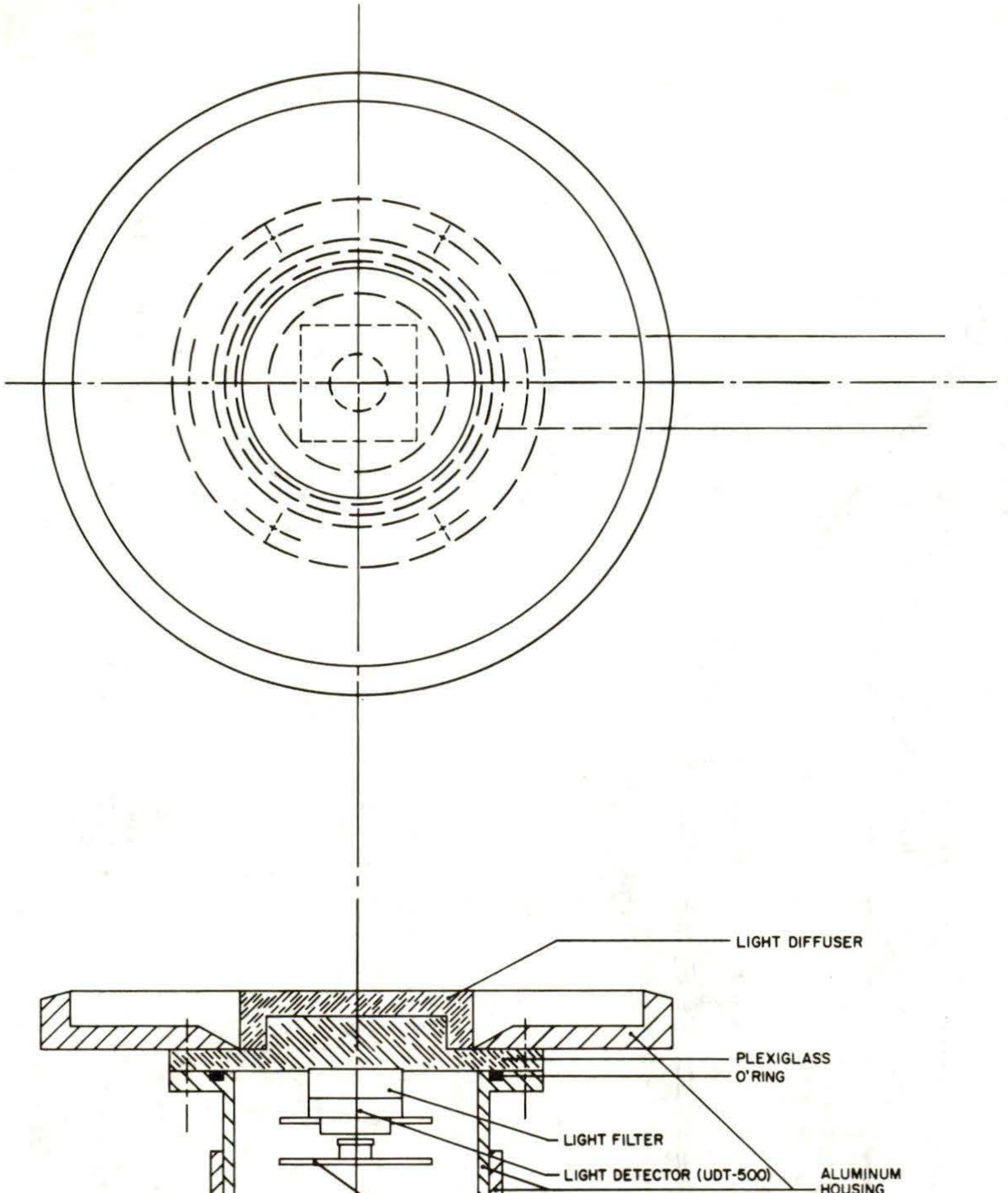

Figure 8. Underwater irradiance sensors used in monitor.

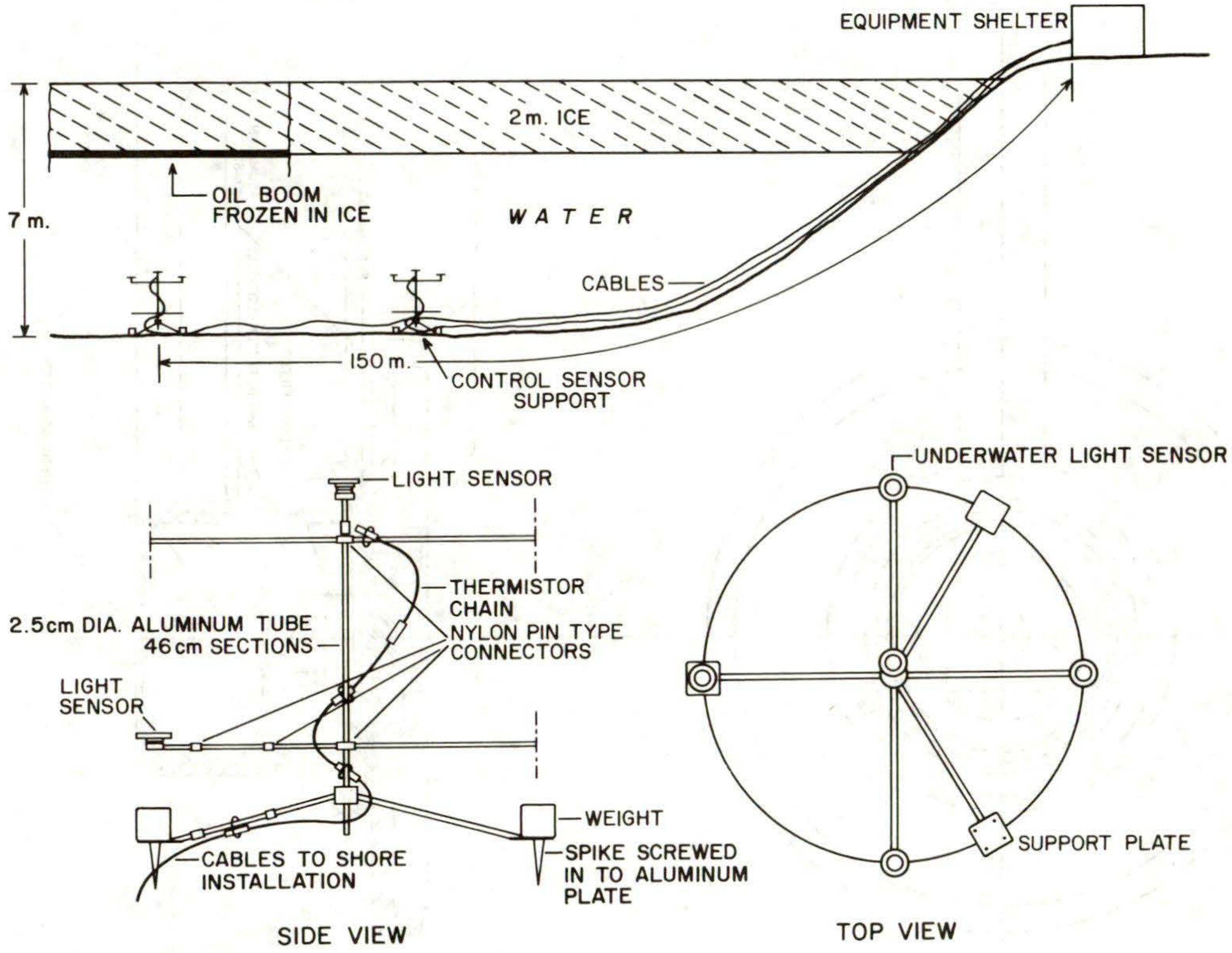

Figure 9. Irradiance sensor support and deployment details.

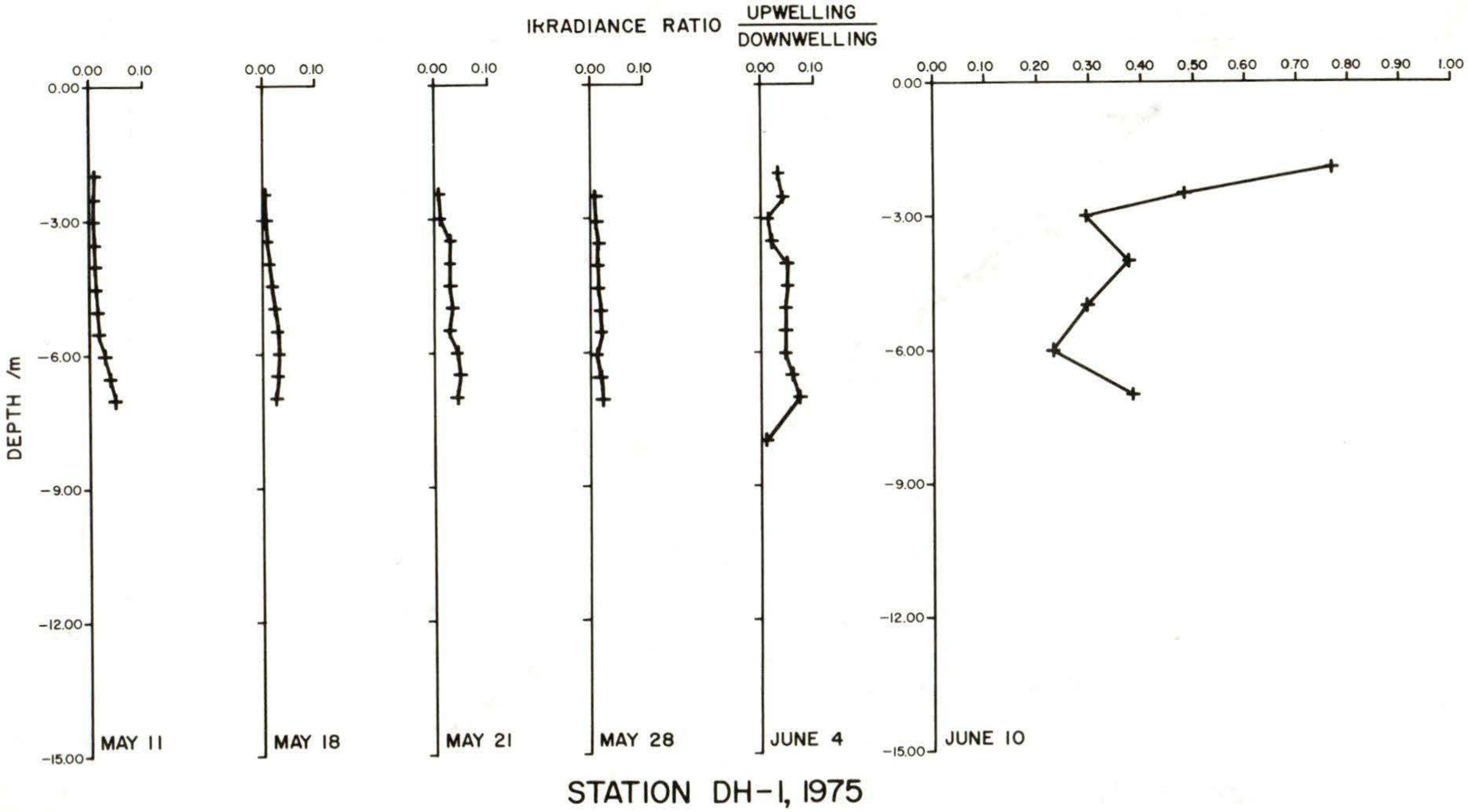

Figure 10. Depth profiles in the diffuse reflectance function (upwelling to downwelling irradiance ratios) for Station DH-1.

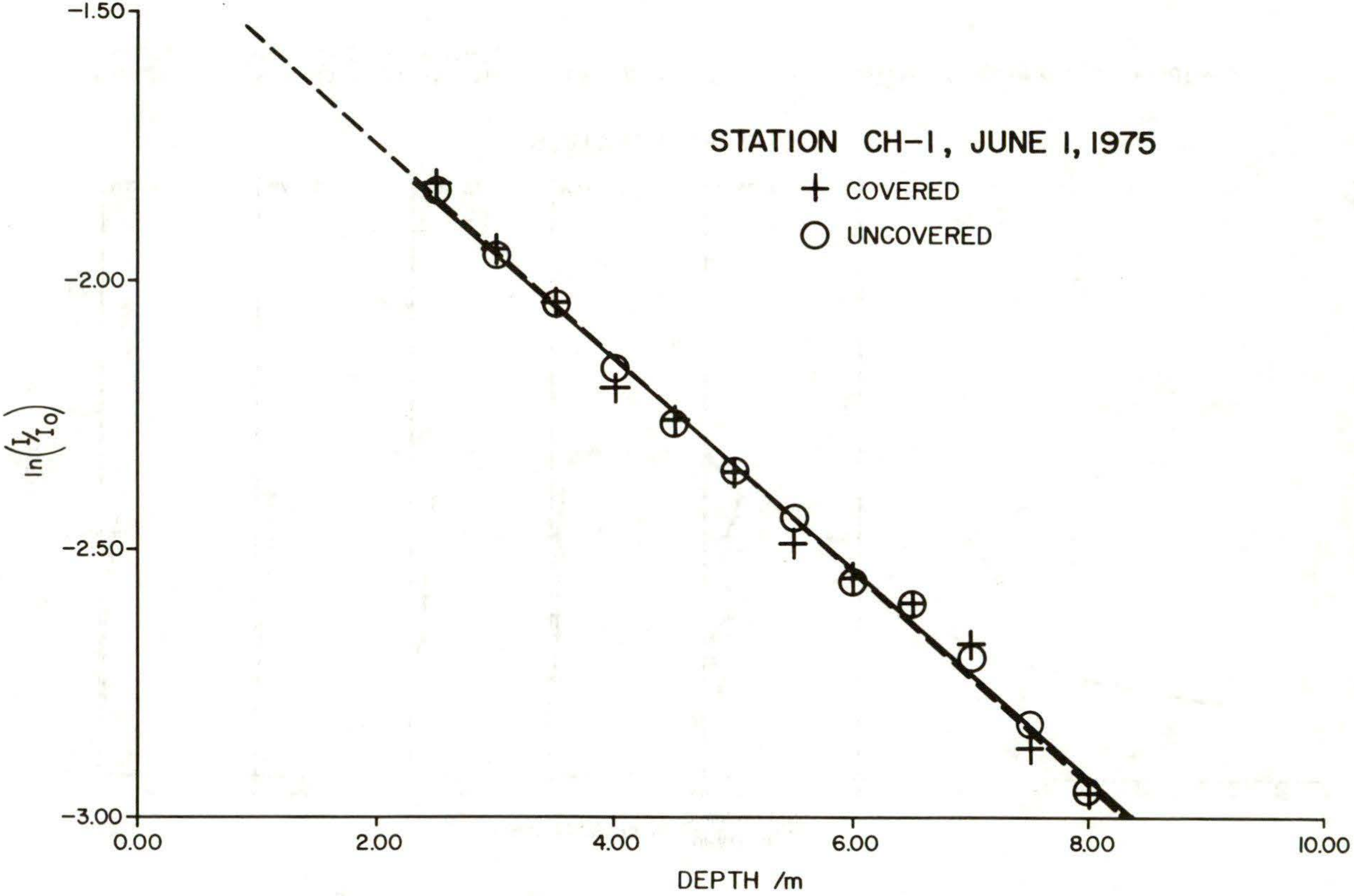

Figure 11. Plot of $\ln(I/I_0)$ vs depth at station CH-1, June 1, 1975.

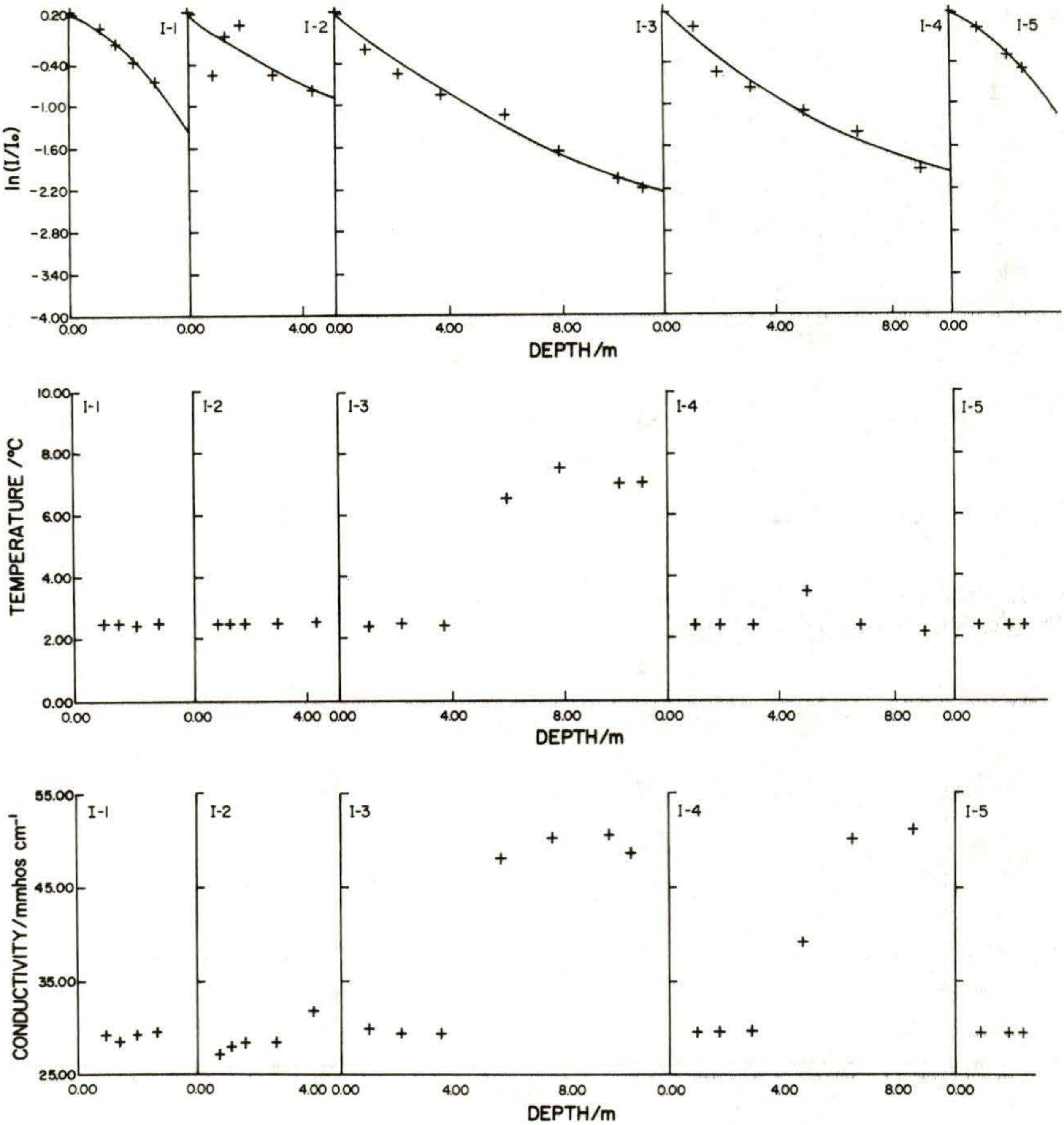

Figure 12. September, 1974, Water quality measurements: $\ell n(I/I_0)$, temperature and conductivity at Stations I-1, I-2, I-3, I-4 and I-5. (See Figure 1(a) for station locations.)

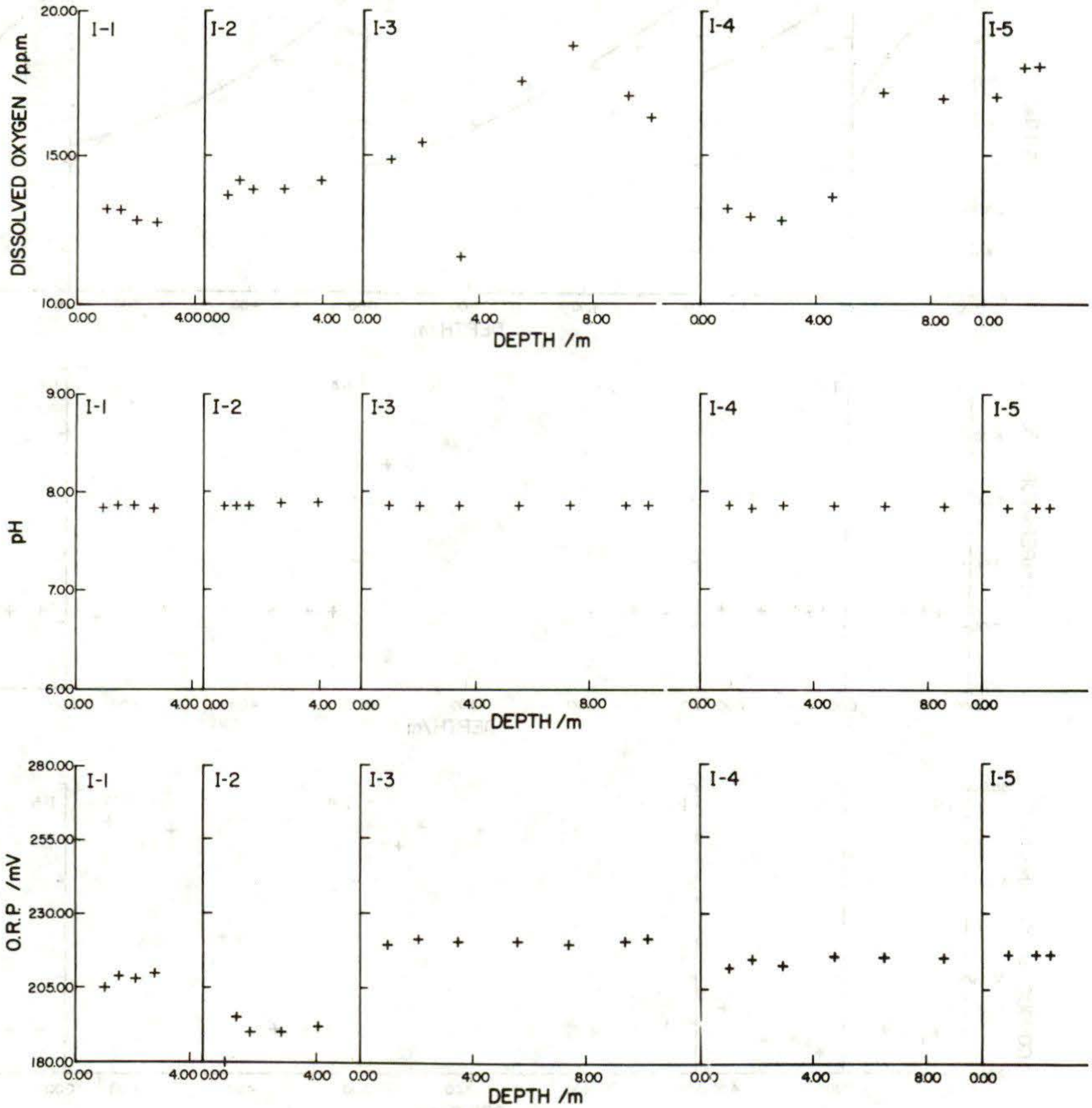

Figure 13. September, 1974, Water quality measurements: Dissolved oxygen/p.p.m., pH, O.R.P. at Stations I-1, I-2, I-3, I-4 and I-5. (See Figure 1(a) for station locations.)

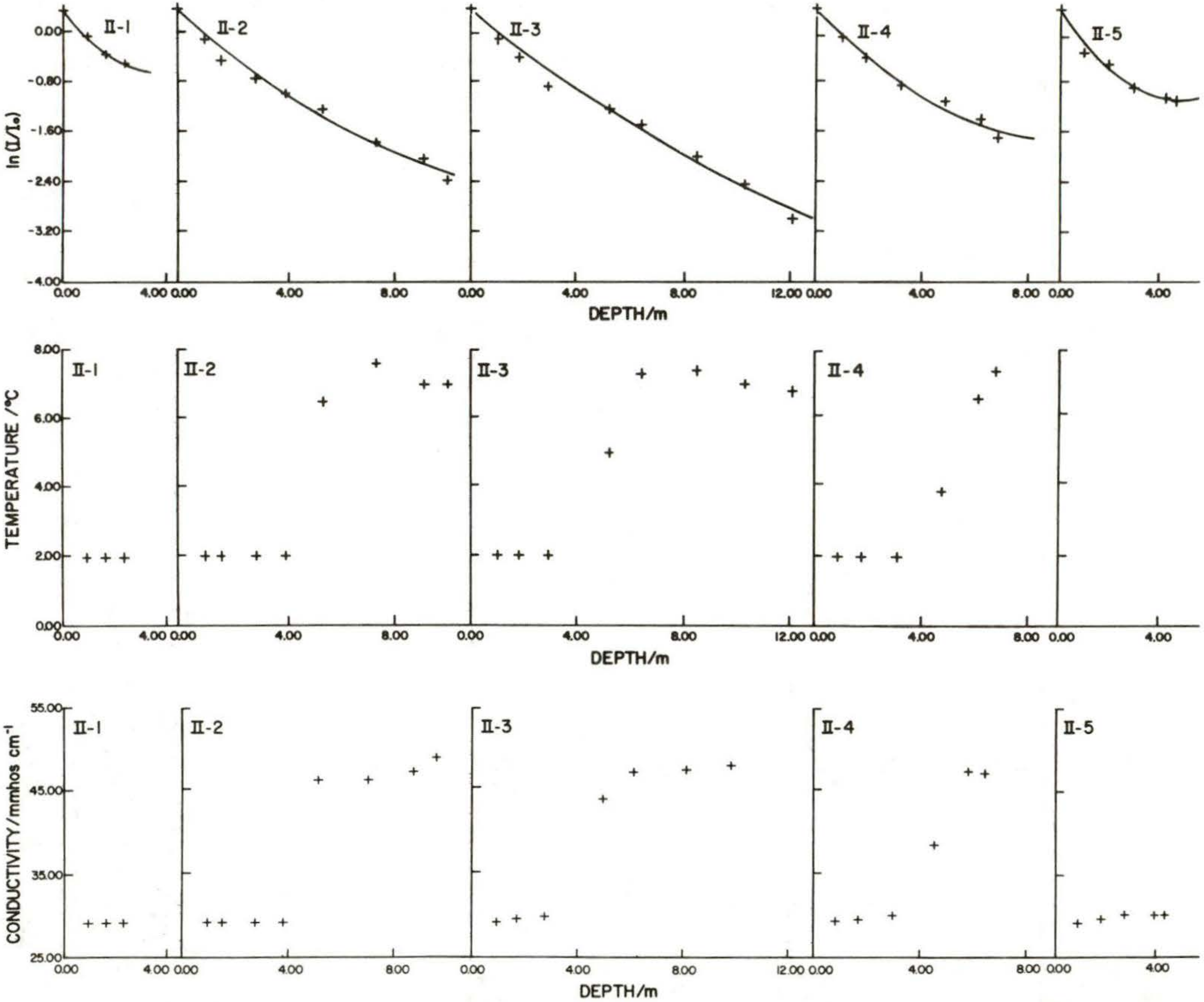

Figure 14. September, 1974, Water quality measurements: $\ell n(In/I_0)$, temperature and conductivity at Stations II-1, II-2, II-3, II-4 and II-5. (See Figure 1(a) for station locations.)

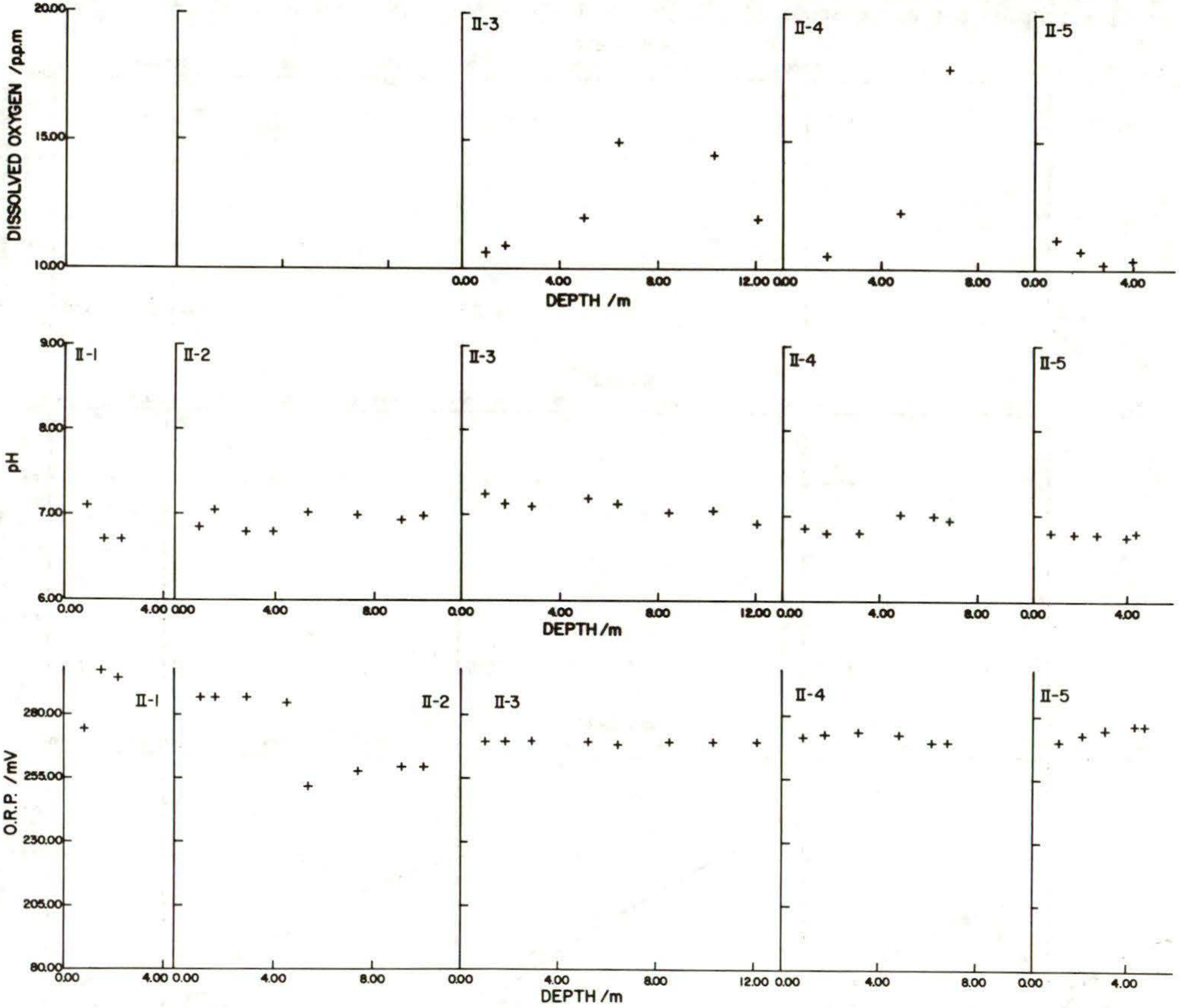

Figure 15. September, 1974, Water quality measurements: Dissolved oxygen/p.p.m., pH, O.R.P./mV at Stations II-1, II-2, II-3, II-4 and II-5. (See Figure 1(a) for station locations.)

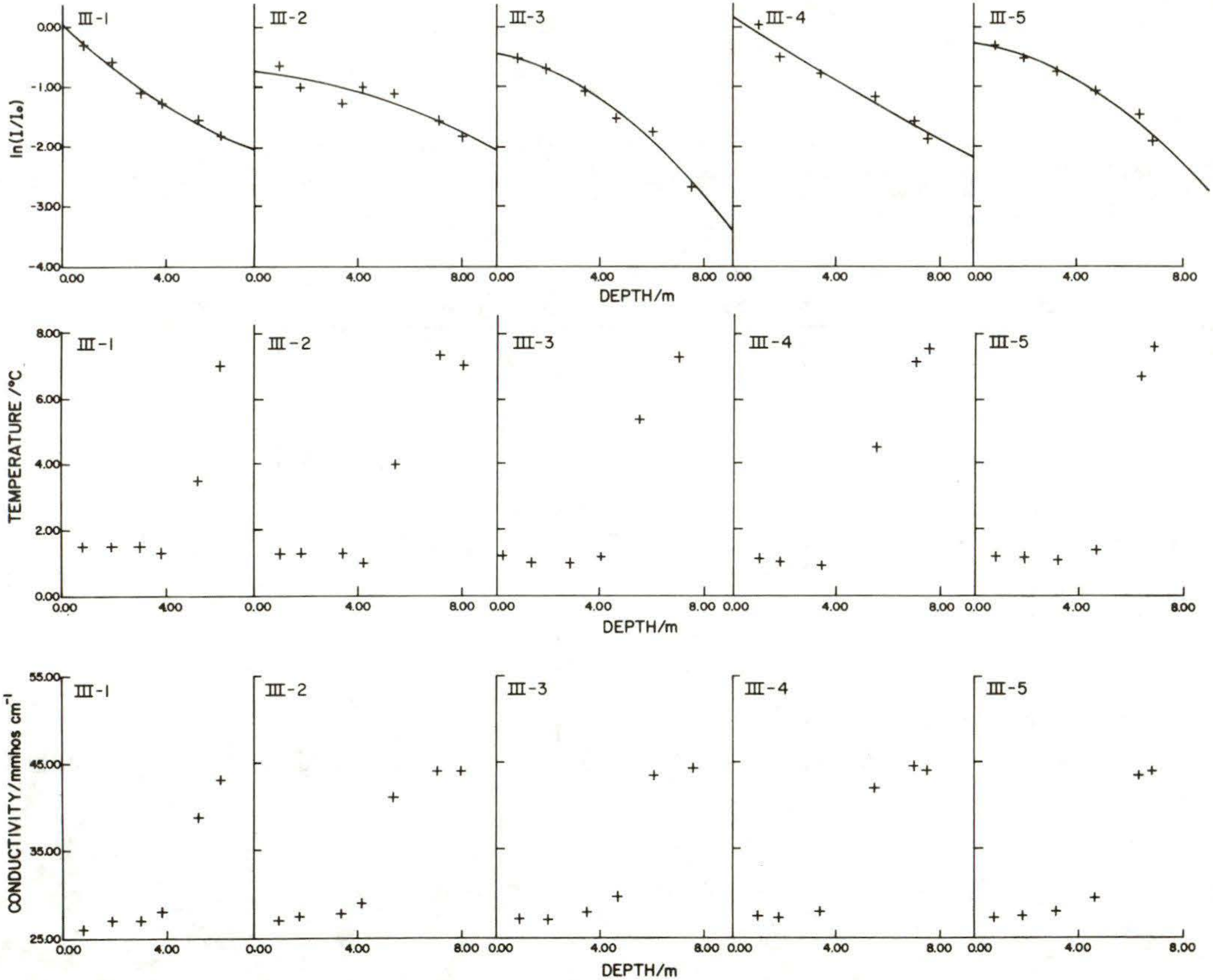

Figure 16. September, 1974, Water quality measurements: $\ell n(I/I_0)$, temperature and conductivity at Stations III-1, III-2, III-3, III-4 and III-5. (See Figure 1(a) for station locations.)

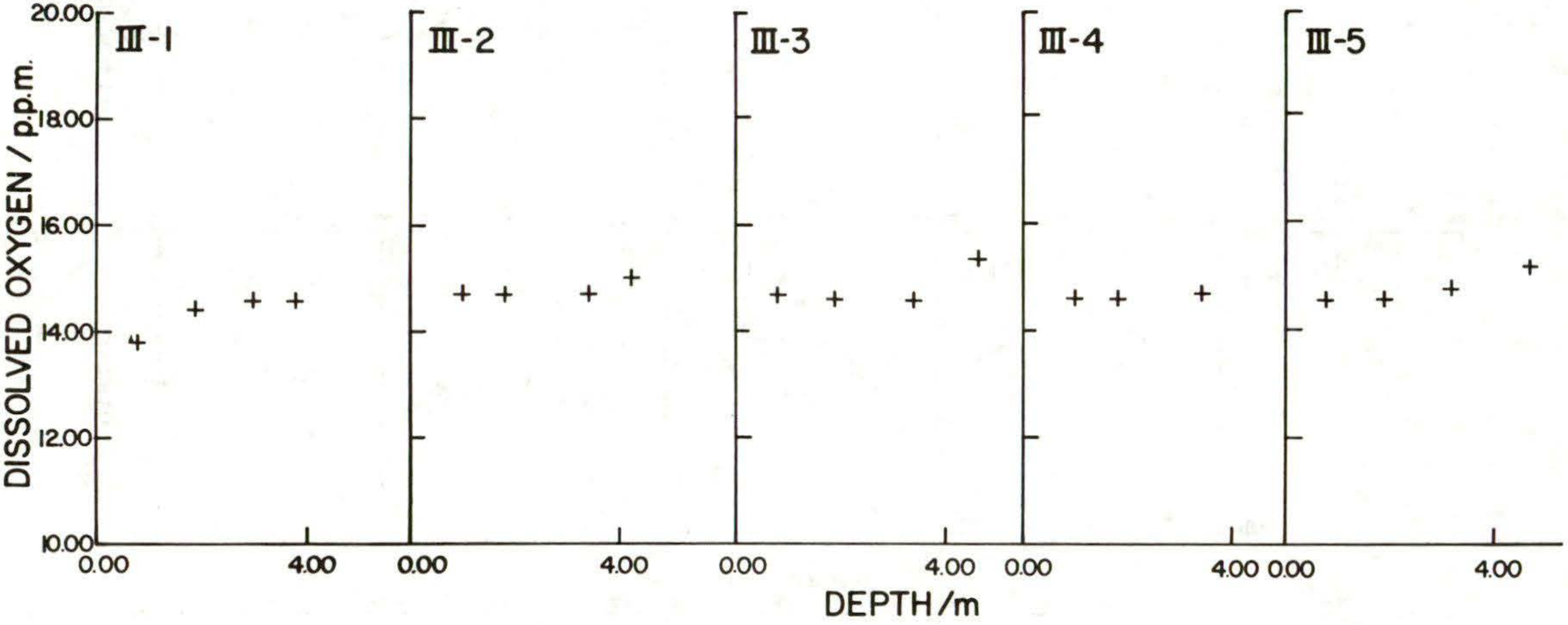

Figure 17. September, 1974, Water quality measurements: Dissolved oxygen/p.p.m. at Stations III-1, III-2, III-3, III-4 and III-5. (See Figure 1(a) for station locations.)

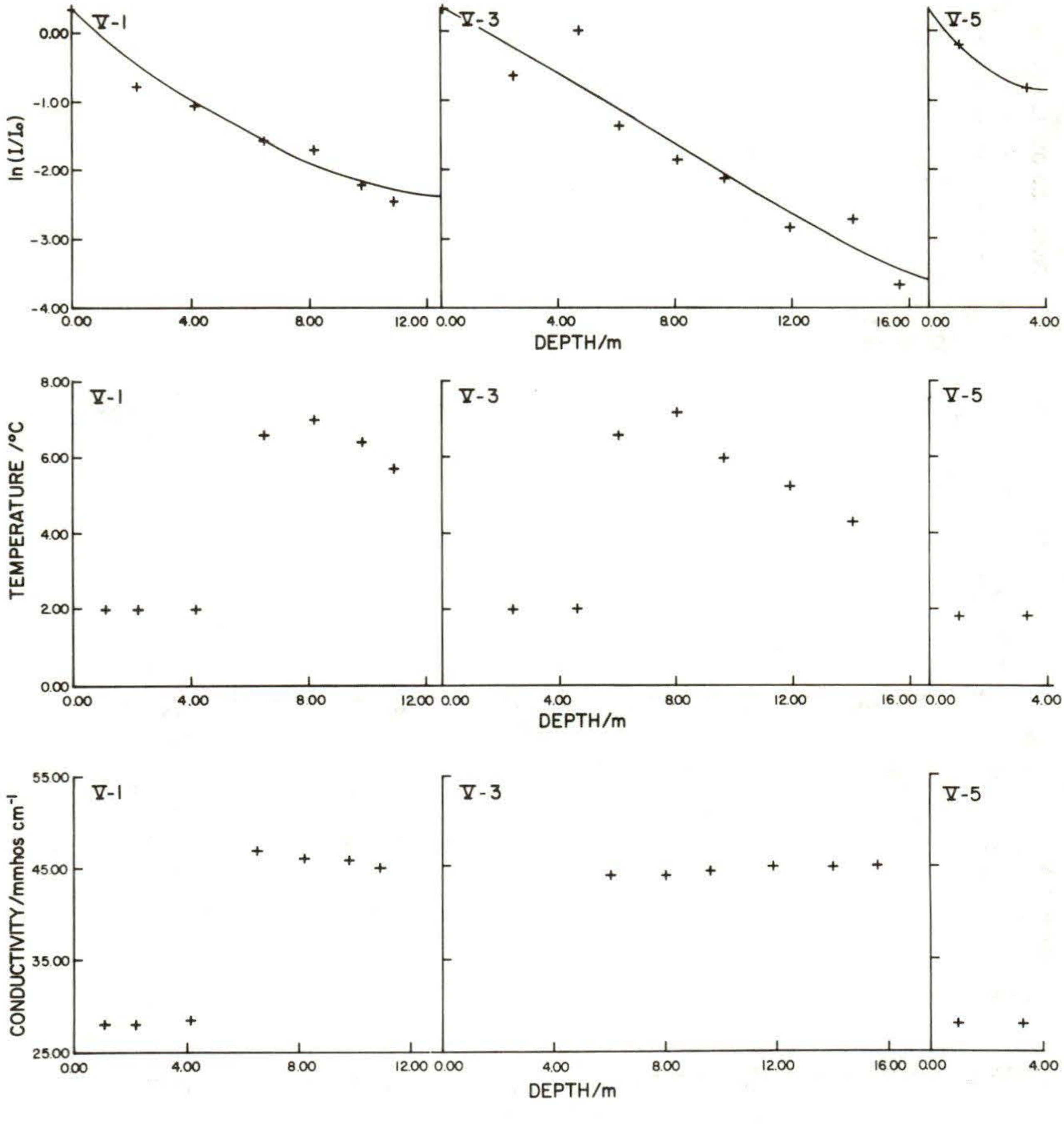

Figure 18. September, 1974, Water quality measurements: $\ell n(I/I_0)$, temperature and conductivity at Stations V-1, V-3 and V-5. (See Figure 1(a) for station locations.)

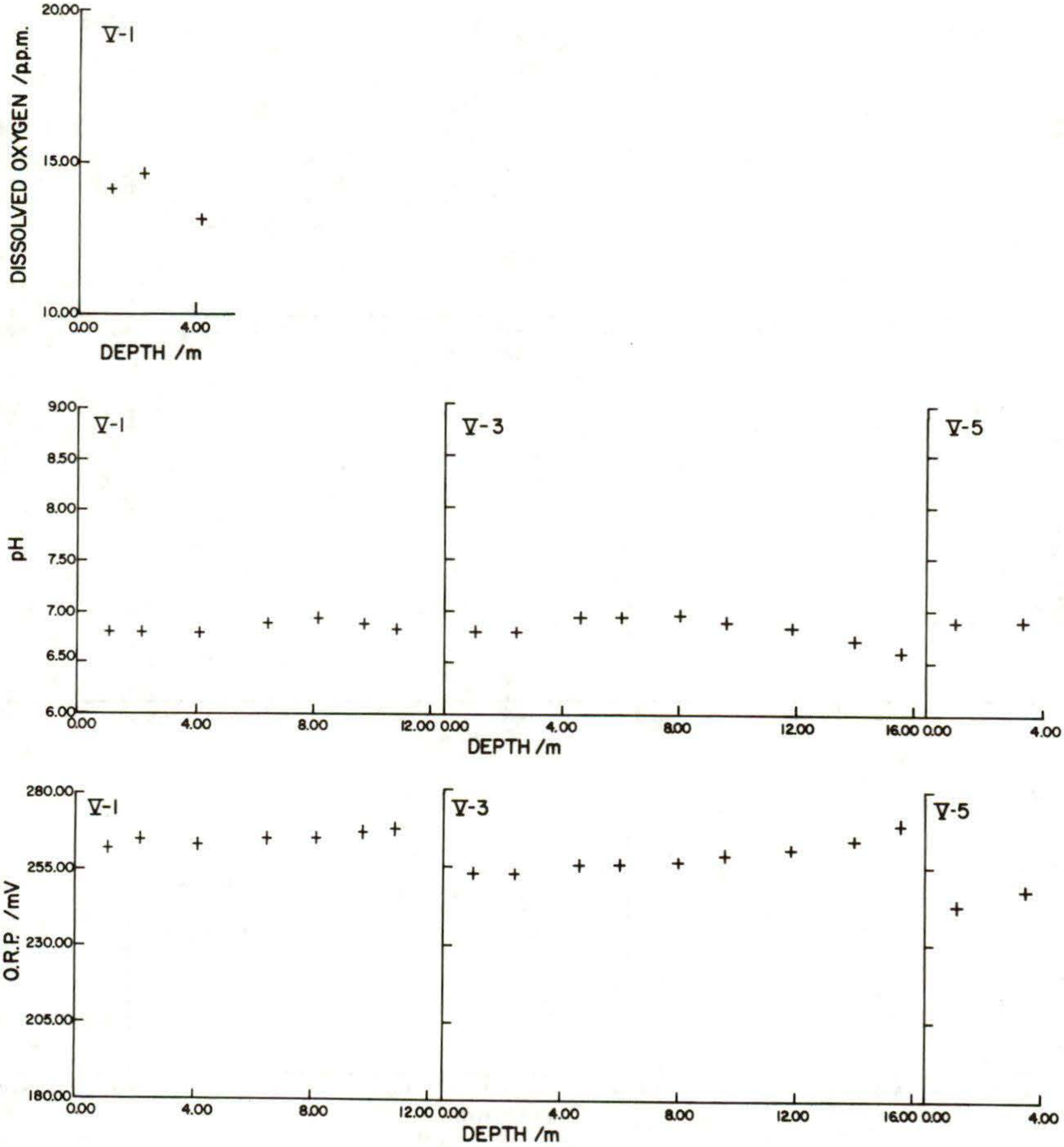

Figure 19. September, 1974, Water quality measurements: Dissolved oxygen/p.p.m. at Station V-1; pH and O.R.P./mV at Stations V-1, V-3 and V-5. (See Figure 1(a) for station locations.)

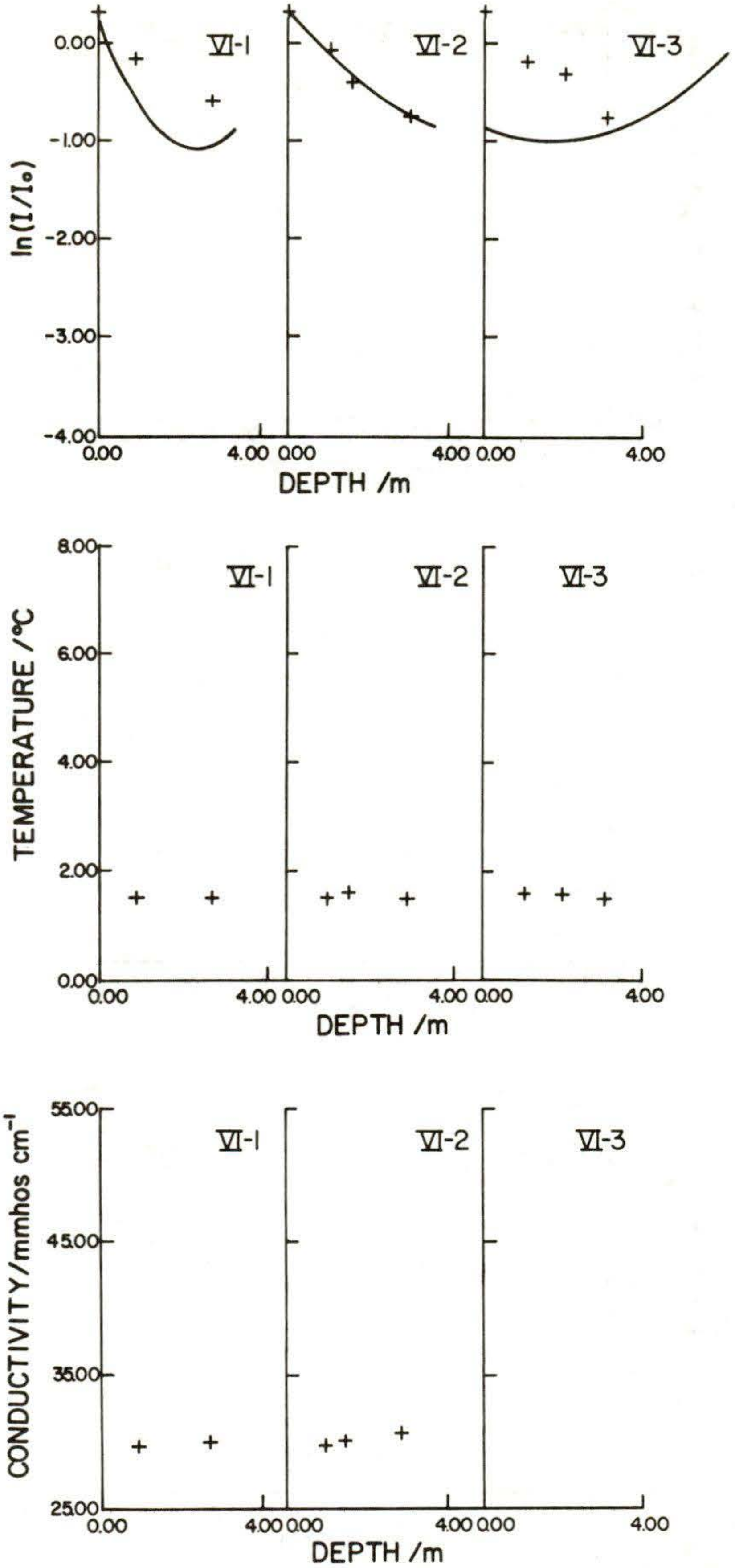

Figure 20. September, 1974, Water quality measurements: $\ell n(I/I_0)$, temperature, and conductivity at Stations V1-I, VI-2 and VI-3. (See Figure 1(a) for station locations.

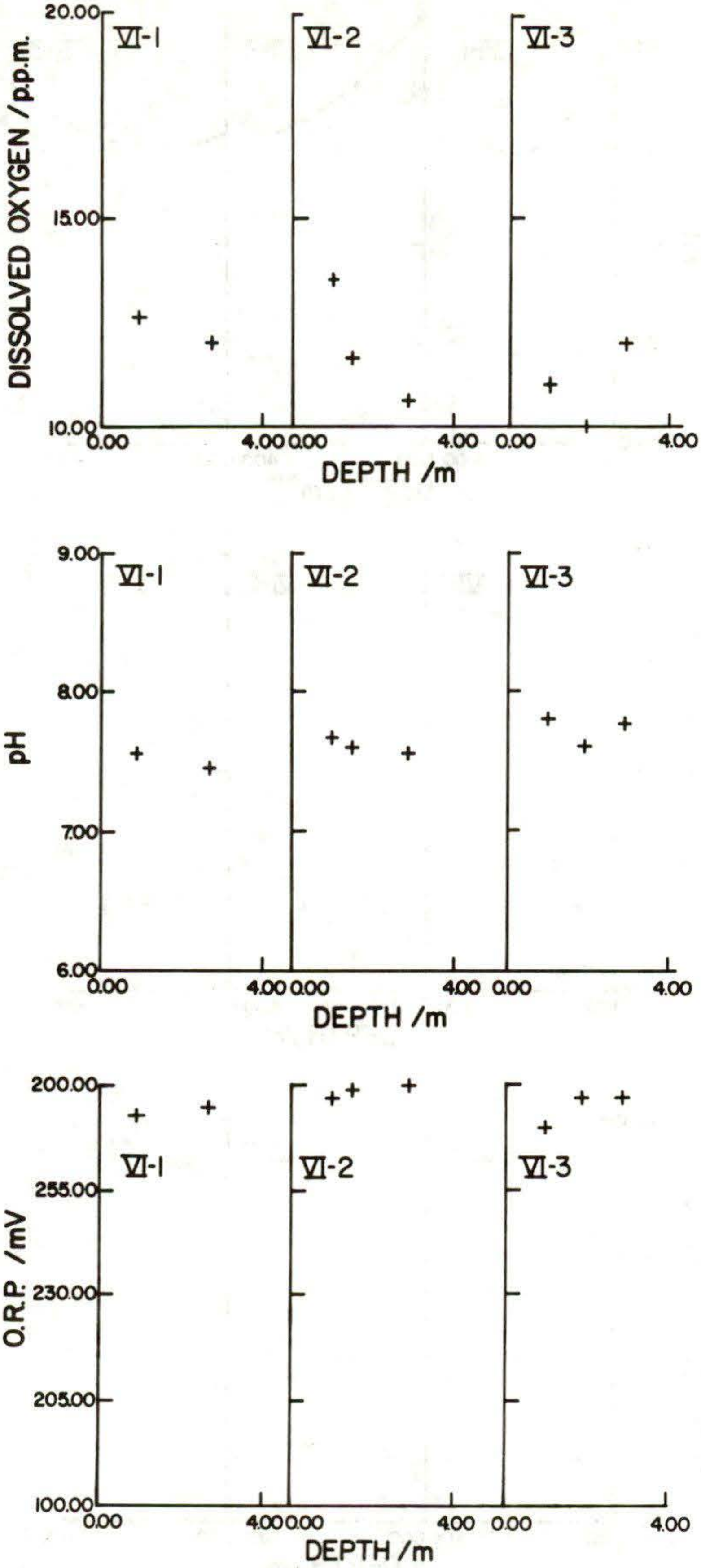

Figure 21. September, 1974, Water quality measurements: Dissolved oxygen/p.p.m., pH and O.R.P./mV at Stations VI-1, VI-2 and VI-3. (See Figure 1(a) for station locations.)

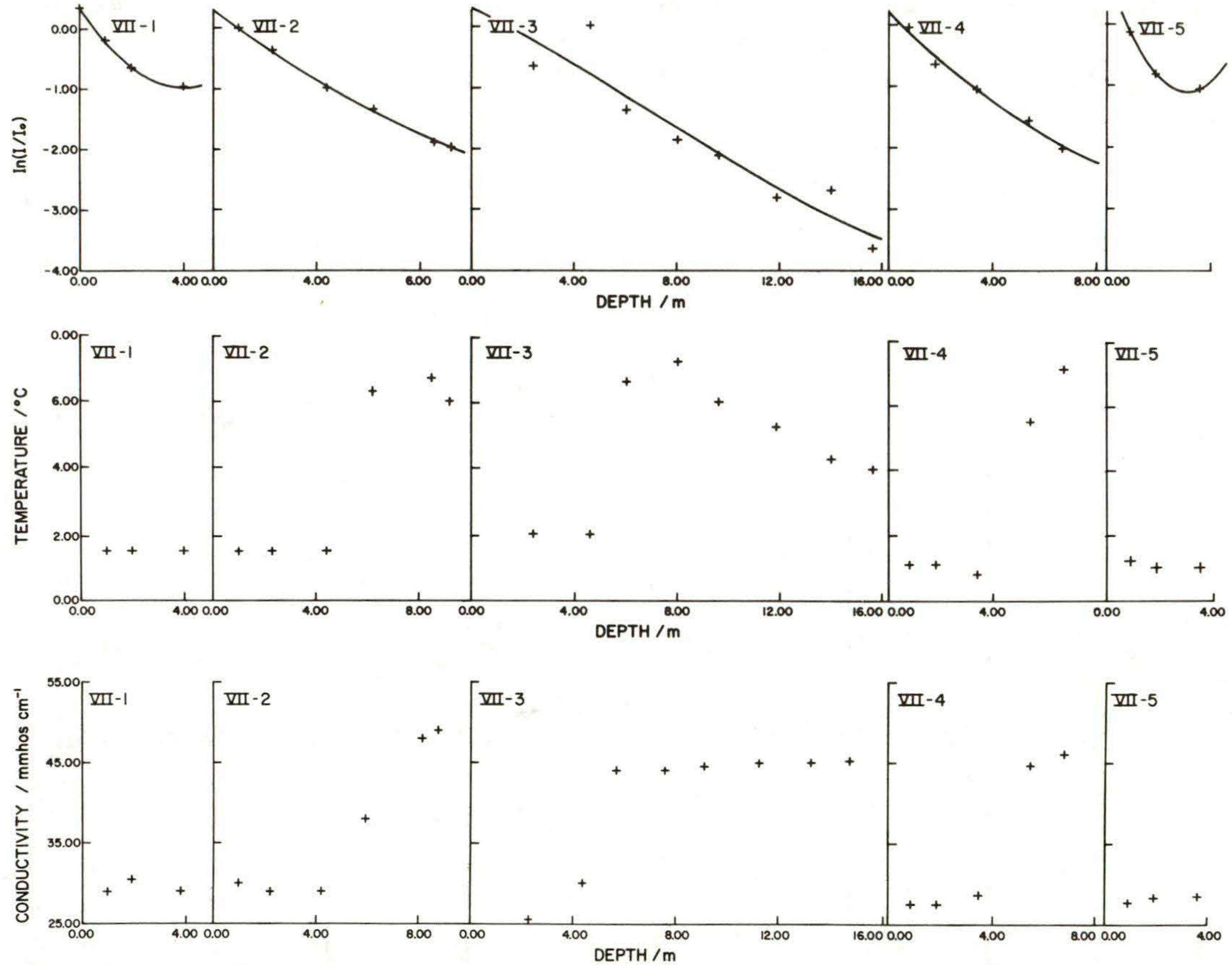

Figure 22. September, 1974, Water quality measurements: $\ell n(I/I_0)$, temperature and conductivity at Stations VII-1, VII-2, VII-3, VII-4 and VII-5. (See Figure 1(a) for station locations.)

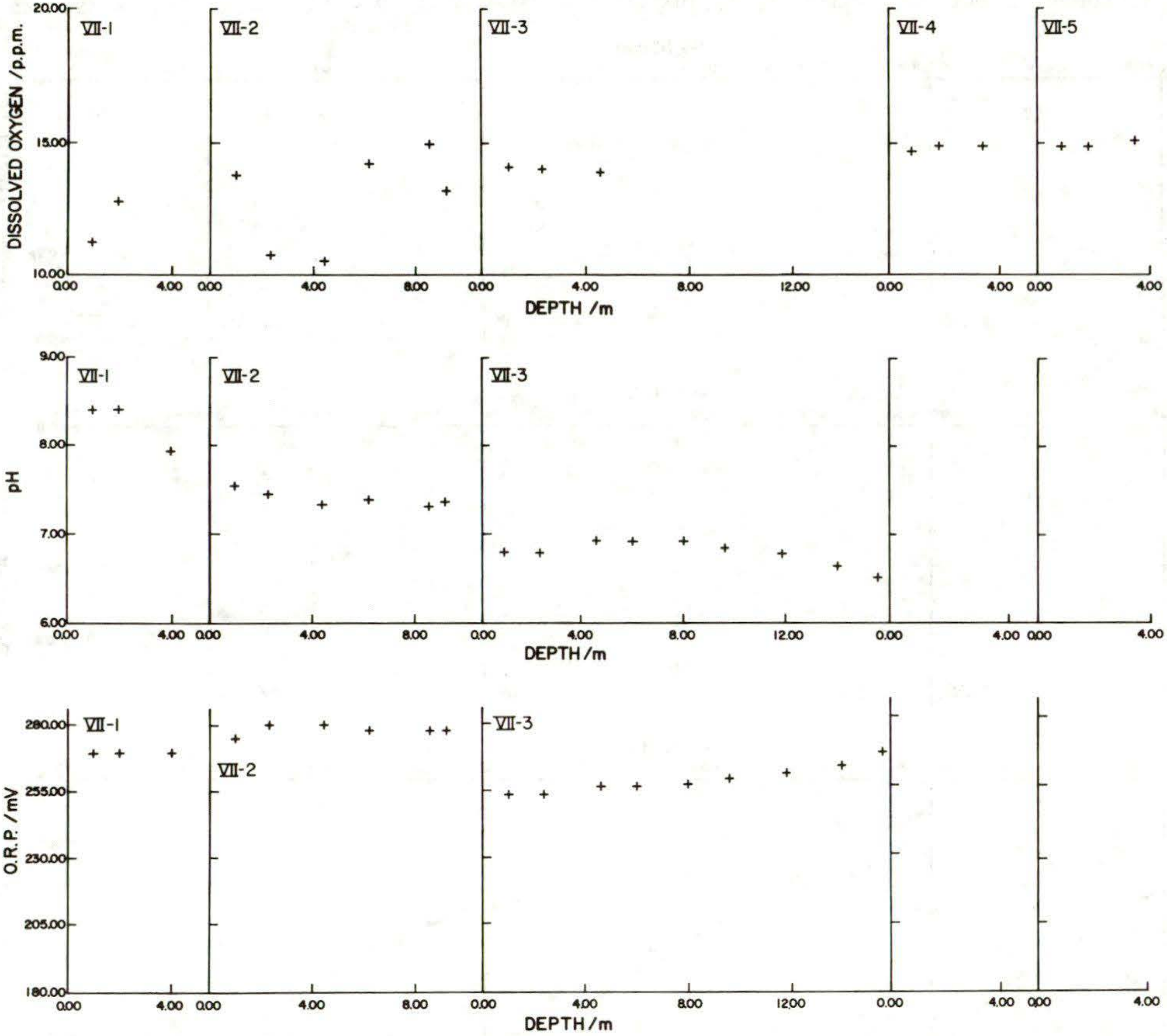

Figure 23. September, 1974, Water quality measurements: Dissolved oxygen/p.p.m., pH and O.R.P./mV at Stations VII-1, VII-2, VII-3, VII-4 and VII-5. (See Figure 1(a) for station locations.)

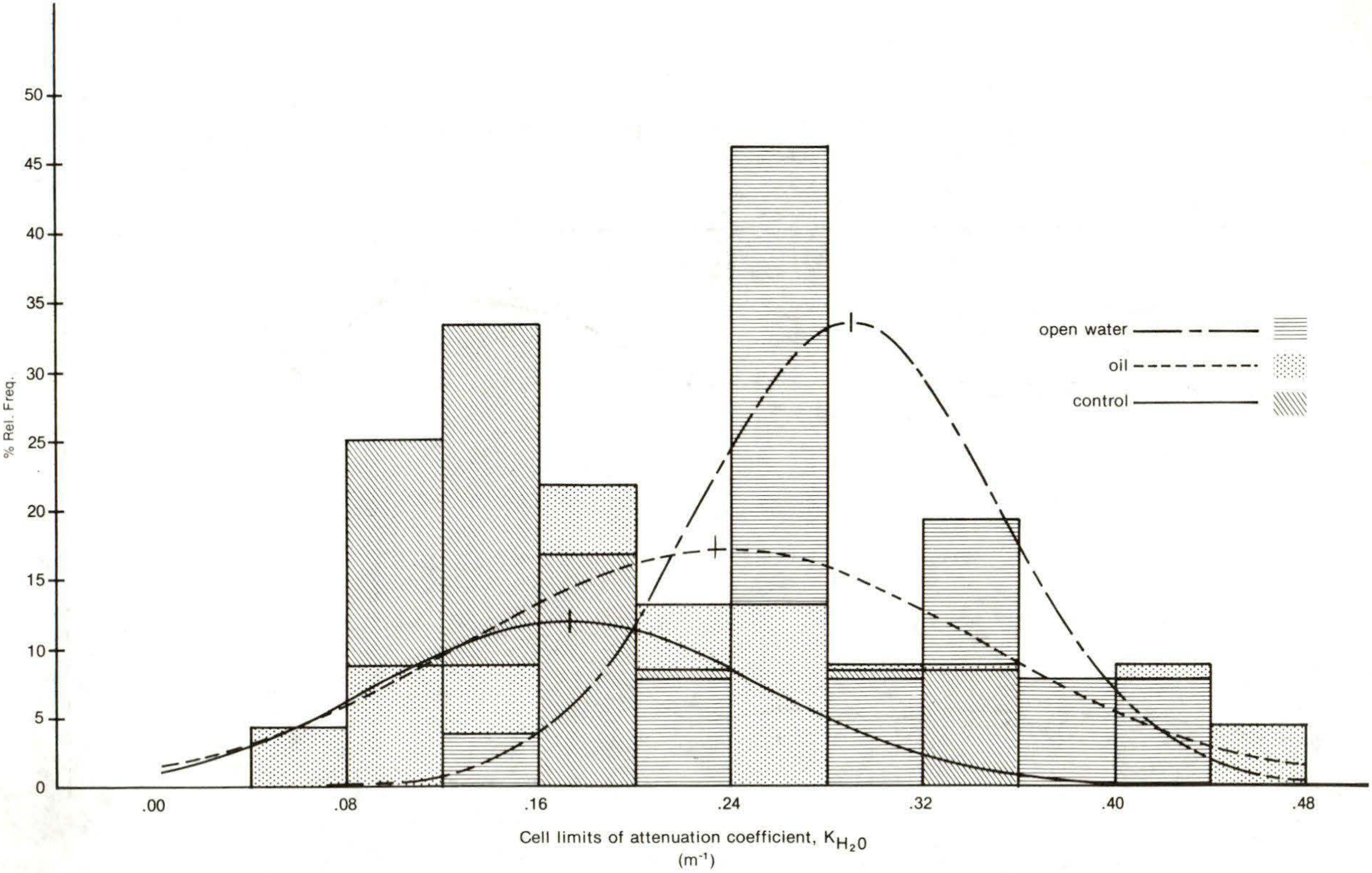

Figure 24. Histogram of diffuse attenuation coefficient data grouped into under-ice oil stations, under-ice control stations, and open water stations.

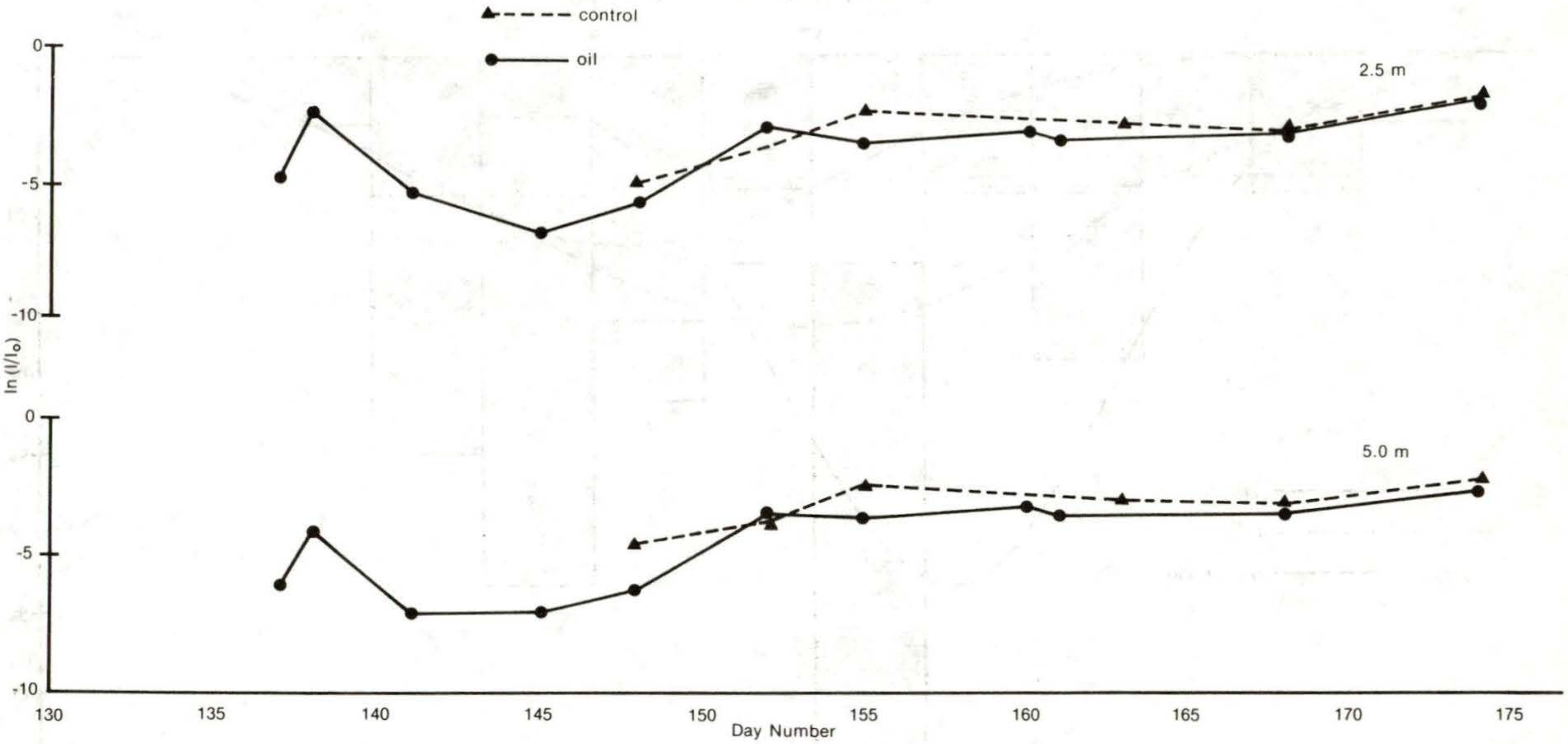

Figure 25. Mean of $\ell n(I/I_0)$ for control and oil stations as a function of time for 2.5 m and 5.0 m depths.

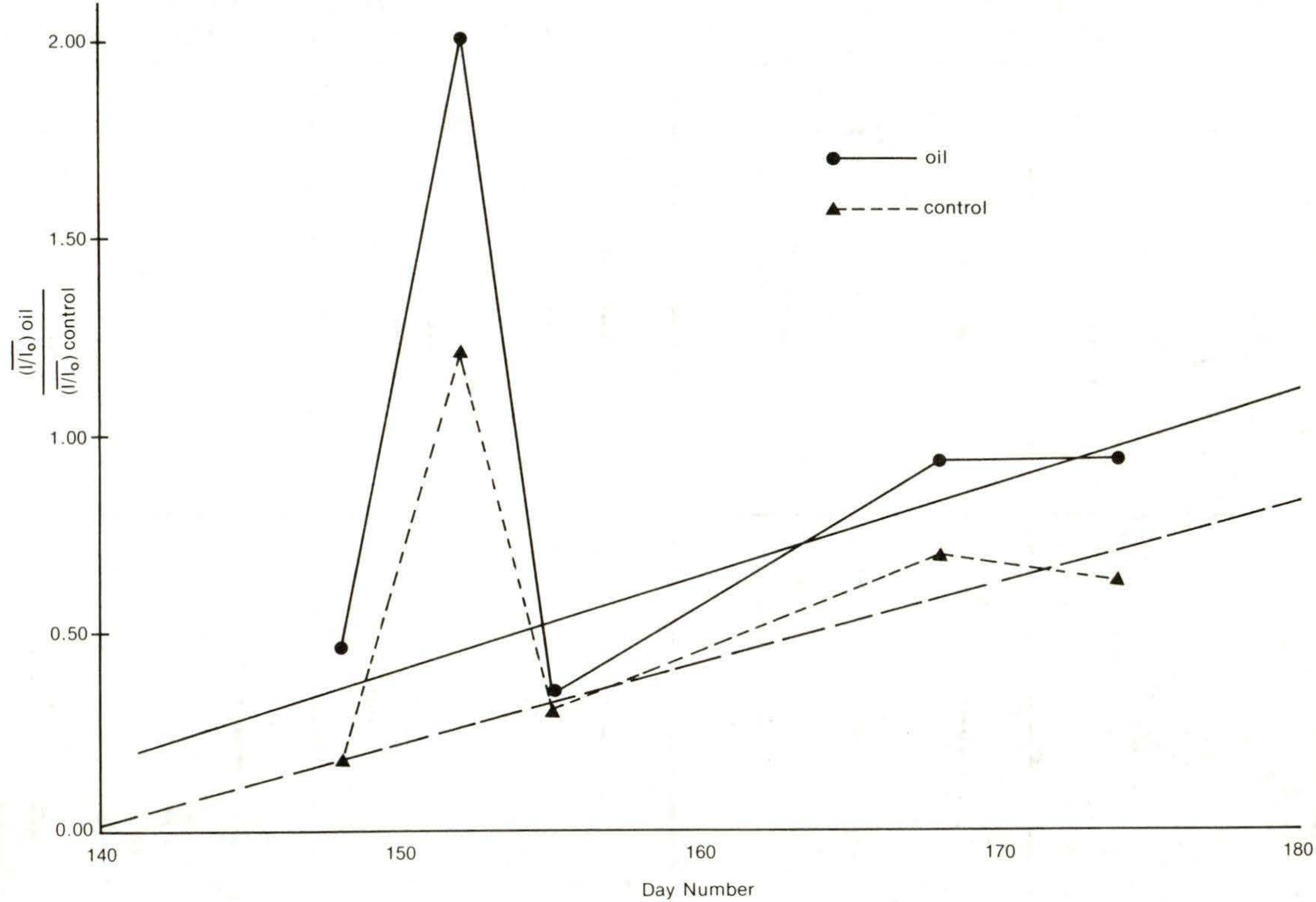

Figure 26. Ratio [oil (I/I_0) / control (I/I_0)] as a function of time for 2.5 m and 5.0 m depths.

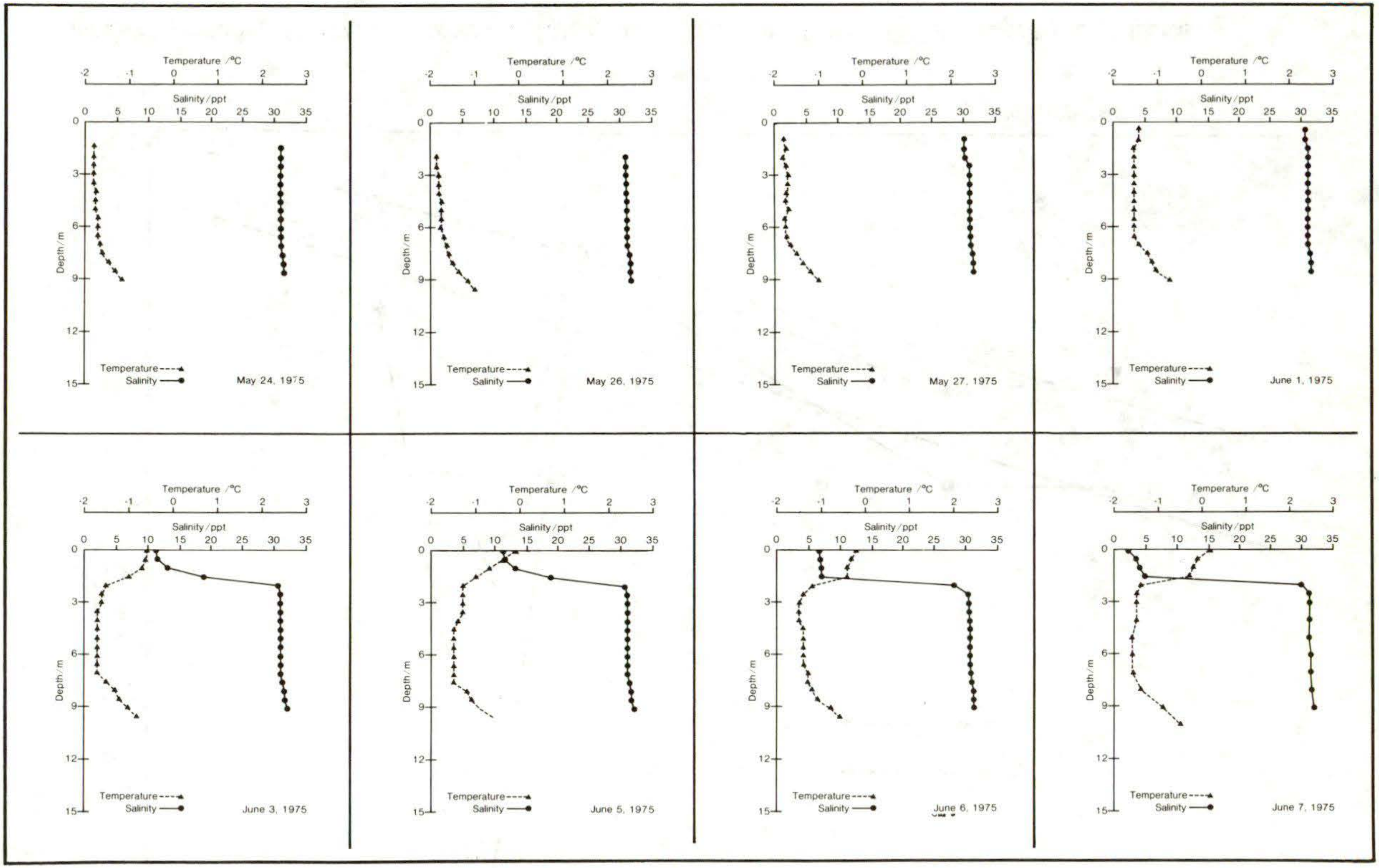

Figure 27. Temperature (°C) and salinity (p.p.t.) vs depth (m) profiles for station BH7 between May 24 and June 25, 1975.

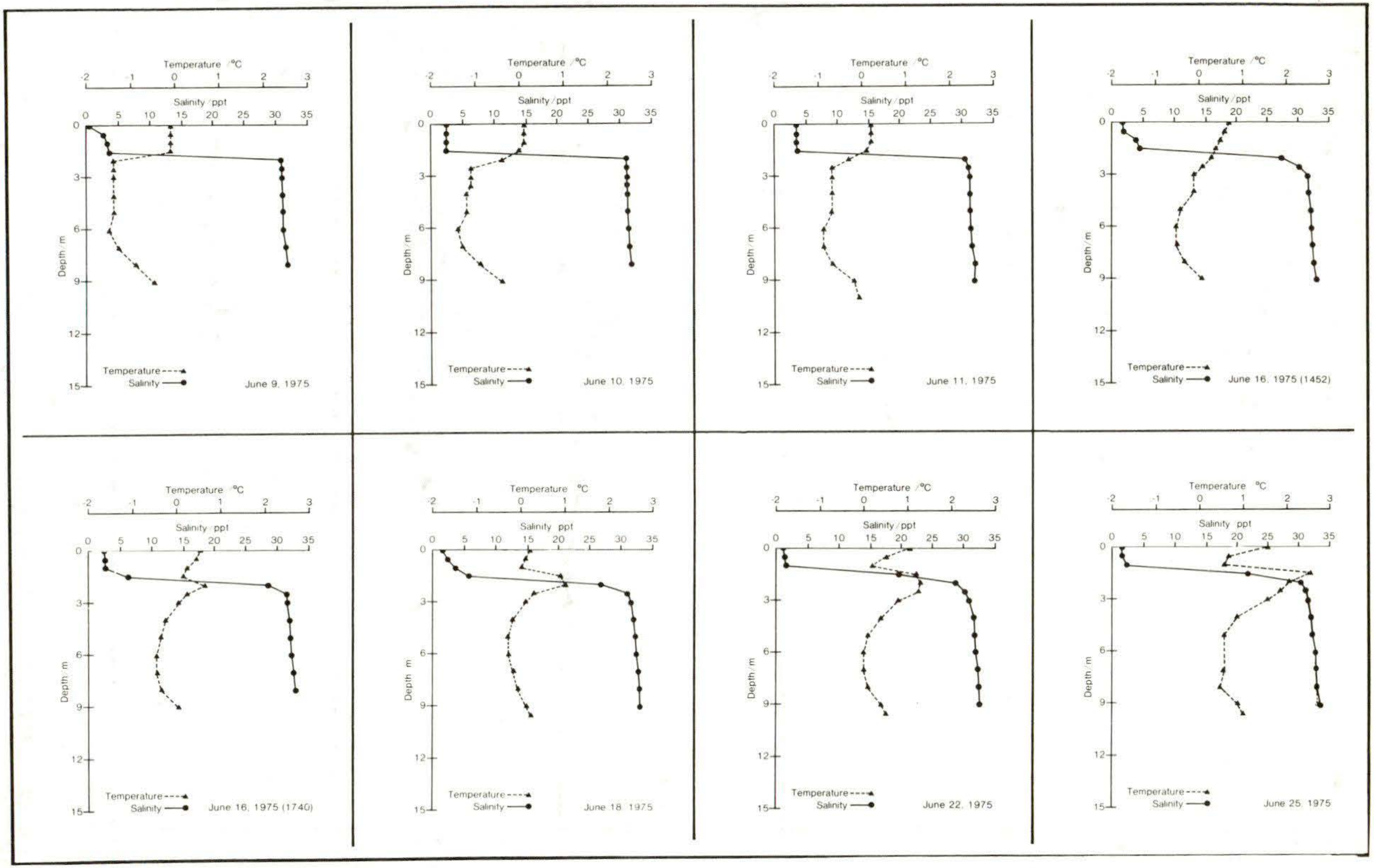

Figure 27. (Cont'd). Temperature (°C) and salinity (p.p.t.) vs depth (m) profiles for station BH7 between May 24 and June 25, 1975.

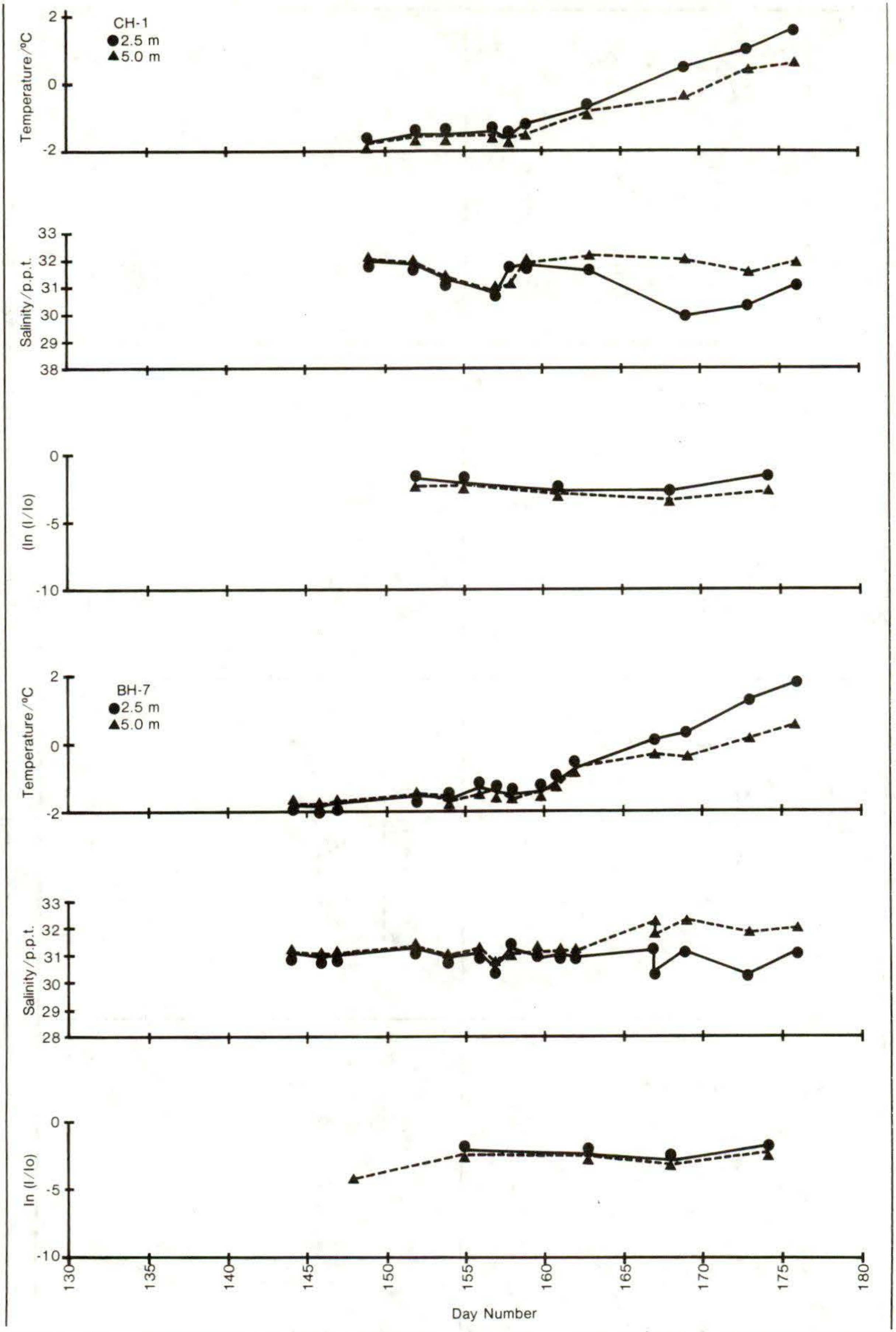

Figure 28. Temperature (°C), salinity (p.p.t., and $\ell n(I/I_0)$ plotted against time (day 0, January 1, 1975) for 2.5 m and 5.0 m depths. Station CH1 and Station BH7.

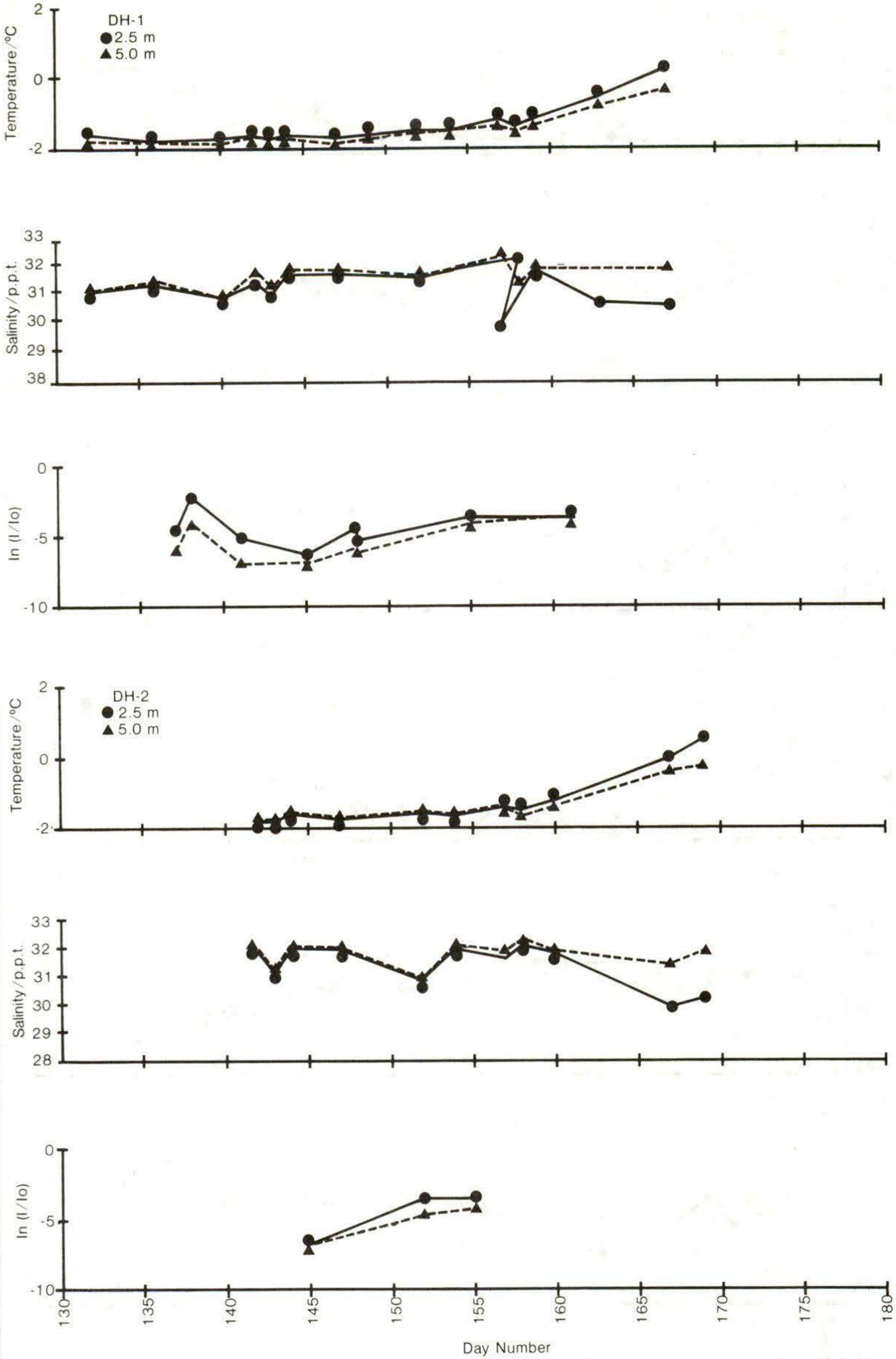

Figure 28 (Cont'd). Temperature (°C), salinity (p.p.t.), and $\ell n(I/I_0)$ plotted against time (day 0, January 1, 1975) for 2.5 m and 5.0 m depths. Station DH1 and Station DH2.

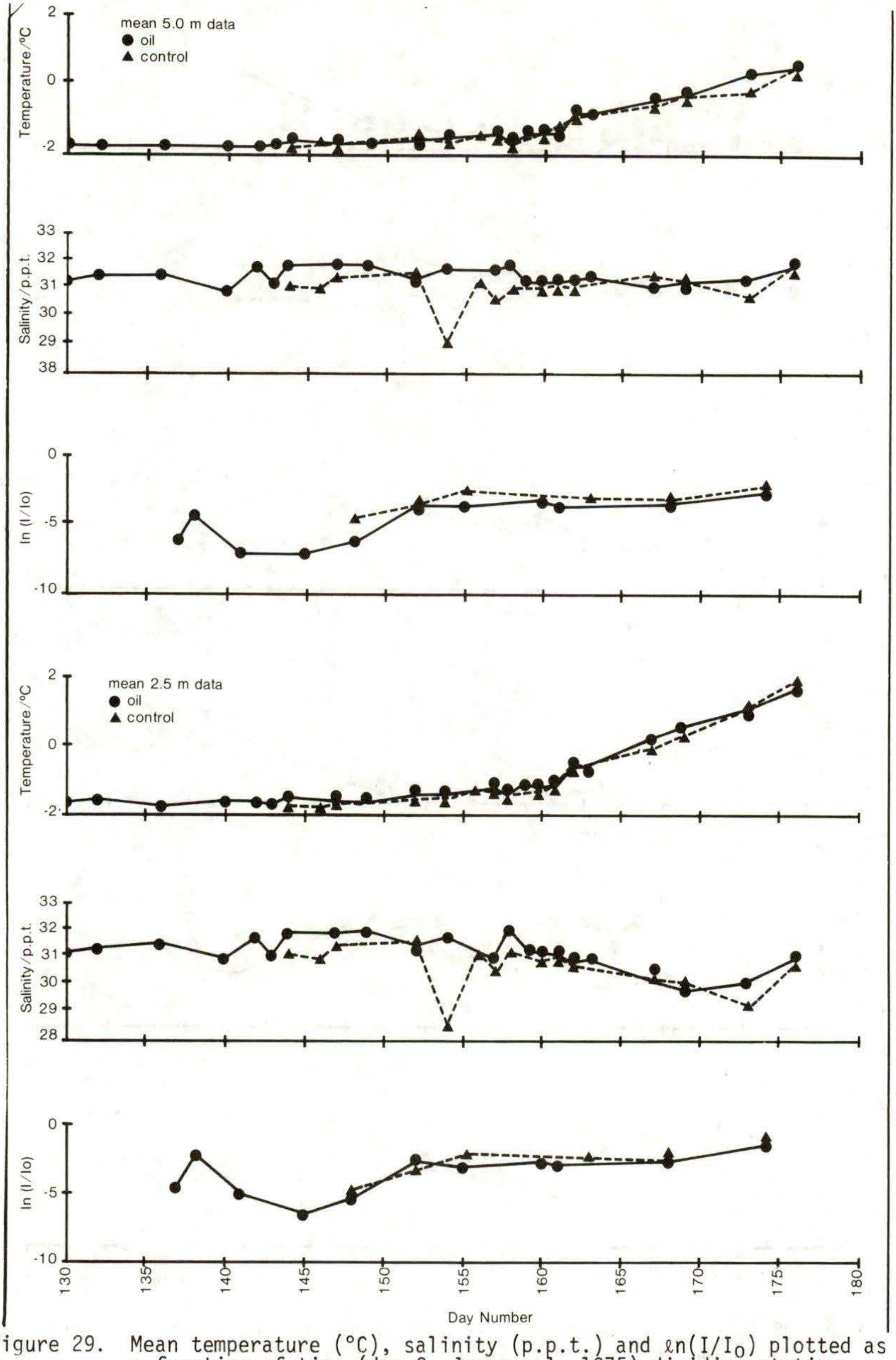

Figure 29. Mean temperature (°C), salinity (p.p.t.) and ℓn(I/I$_0$) plotted as a function of time (day 0, January 1, 1975) dividing stations into oil control groups at 5.0 and 2.5 m depths.

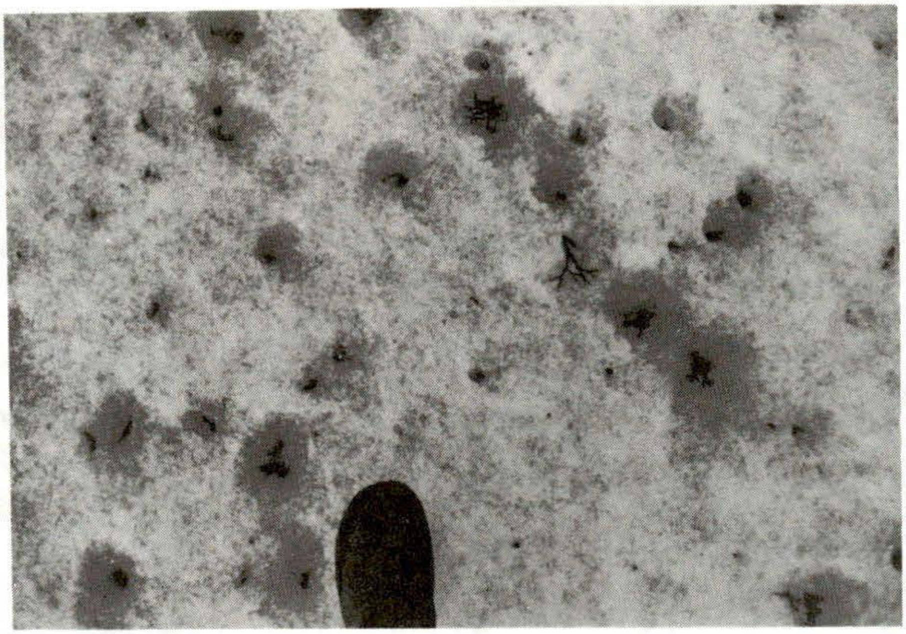

Figure 30(a). Photograph of algal melt pond, Balaena Bay, N.W.T. - algae in drained sea ice SE of east channel from cove, June 25, 1975.

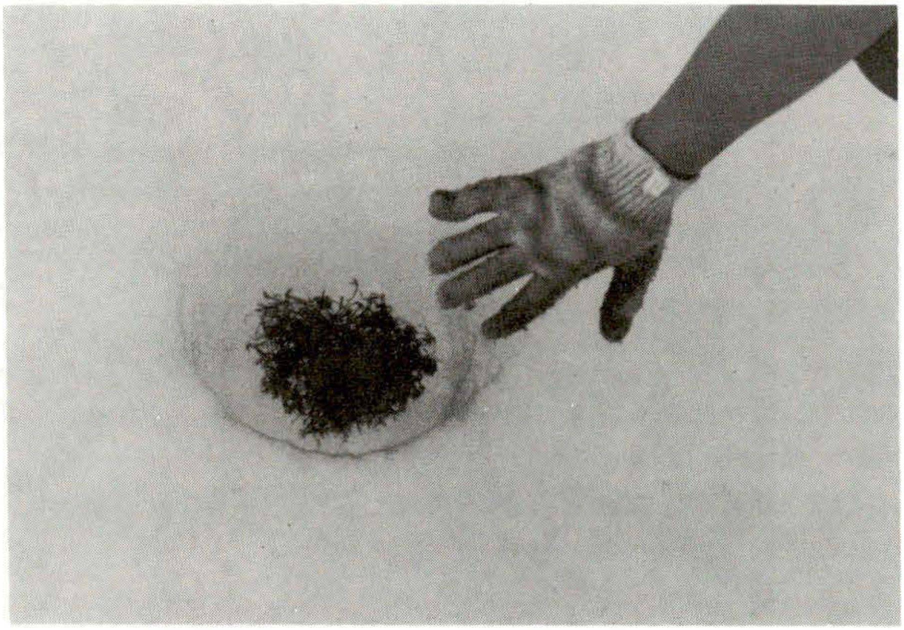

Figure 30(b). Photograph of algal melt pond, Balaena Bay, N.W.T. - algae in surface melt pond UA3, June 14, 1975.

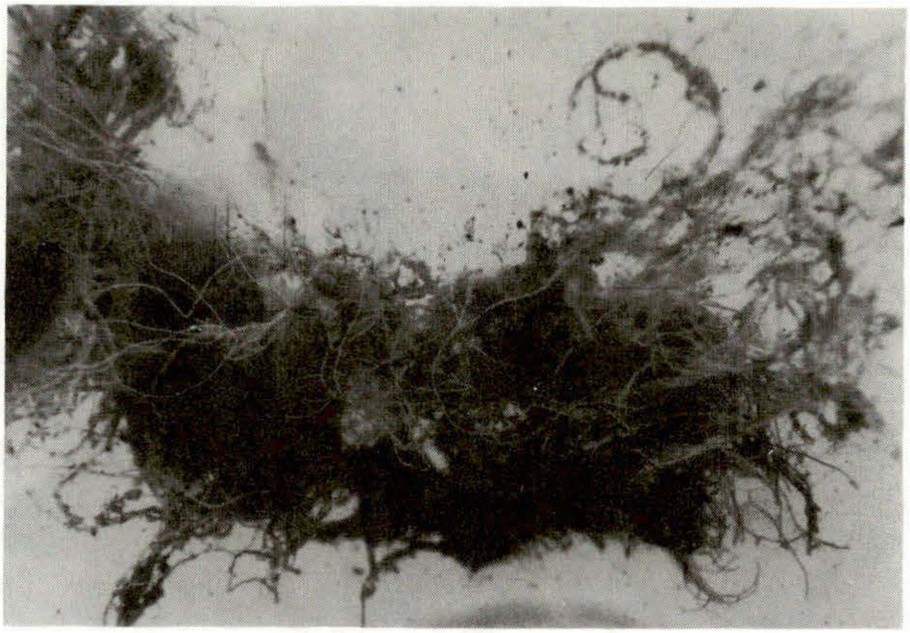

Figure 30(c). Photograph of algal melt pond, Balaena Bay, N.W.T. - green algae with epiphytic blue-green and diatom colonies in melt pond associated with soot, June 4, 1975.

Figure 30(d). Photograph of algal melt pond, Balaena Bay, N.W.T. - brown algae with epiphytes, June 16, 1975.

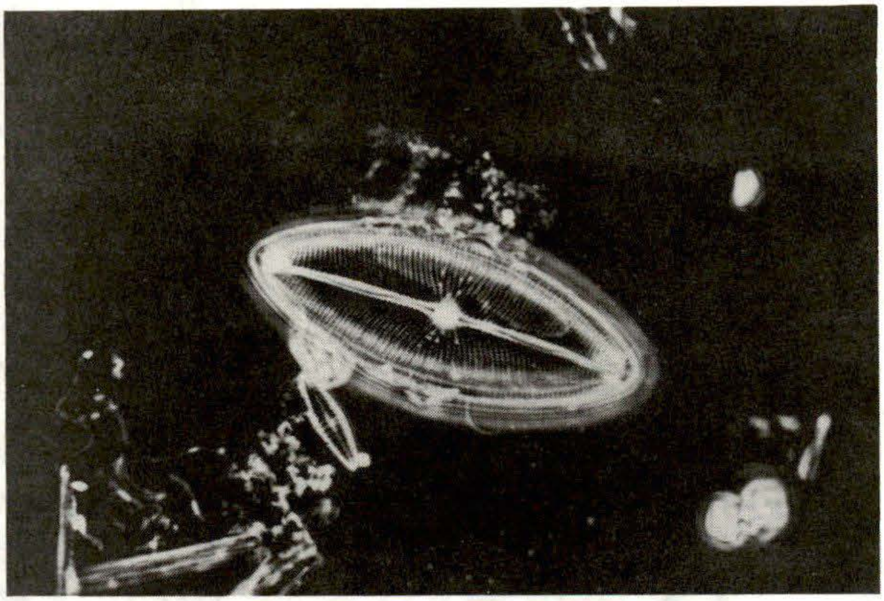

Figure 31(a). Photograph of Chrysophyta (diatoms) from Balaena Bay, N.W.T. *Navicula* (magnification x 630) approximate length, 20µm.

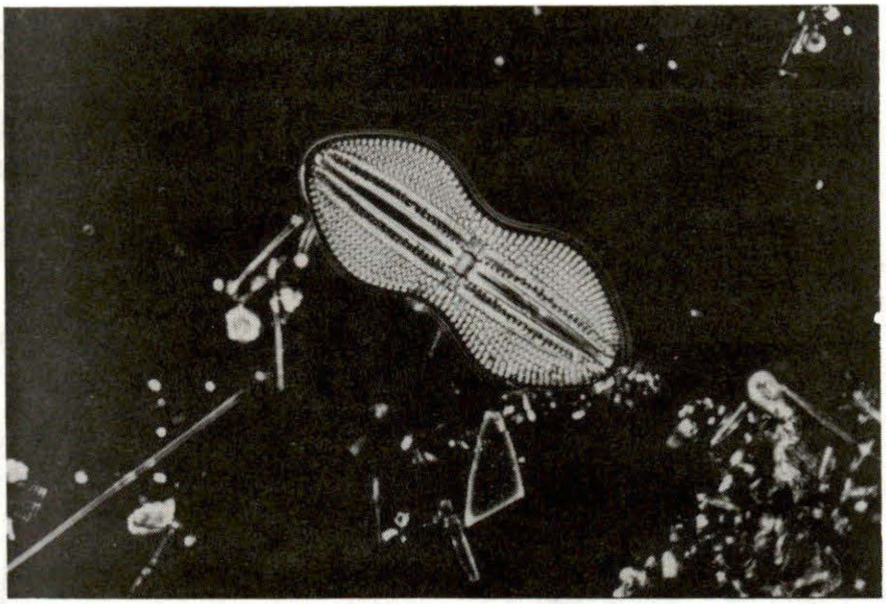

Figure 31(b). Photograph of Chrysophyta (diatoms) from Balaena Bay, N.W.T. *Diploneis* (magnification x 252) approximate length, 60µm.

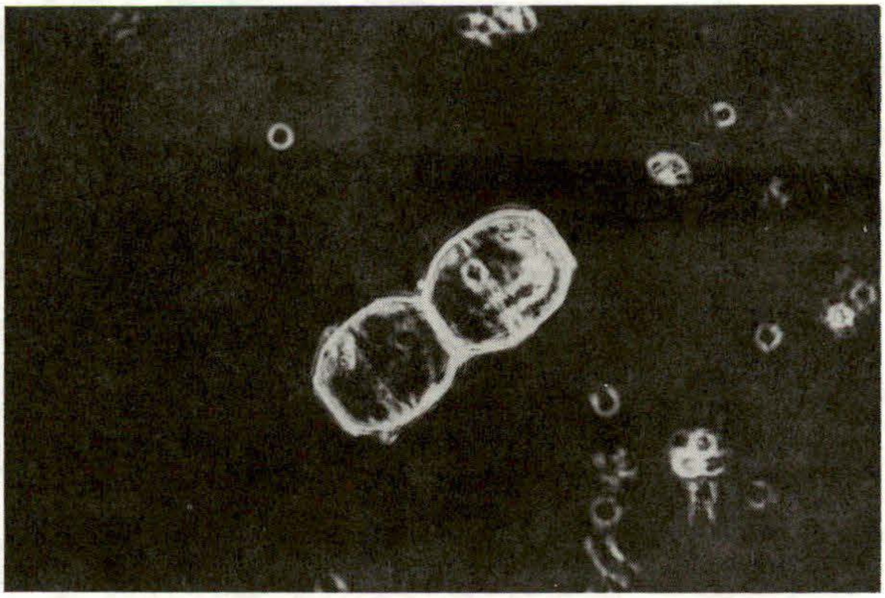

Figure 31(c). Photograph of Chrysophyta (diatoms) from Balaena Bay, N.W.T. *Melosira* (magnification x 630).

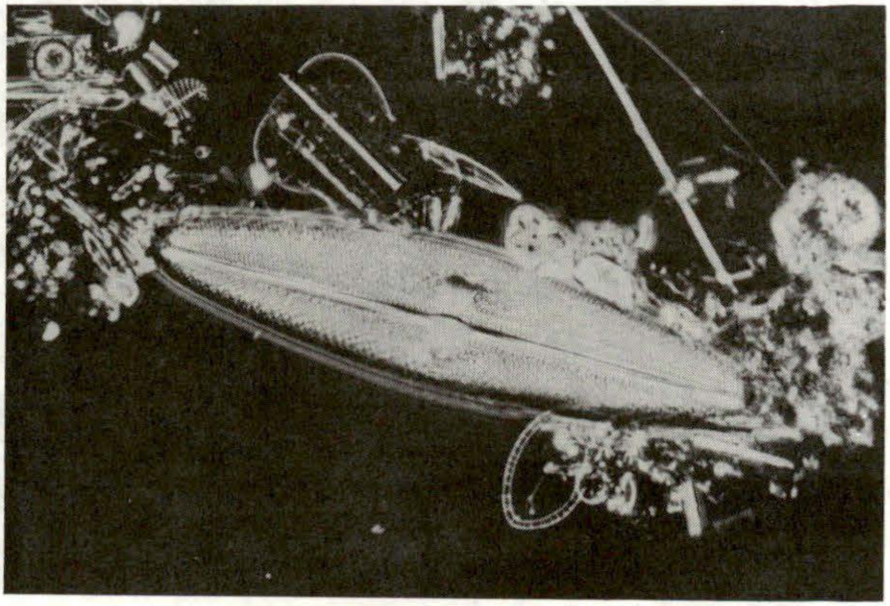

Figure 31(d). Photograph of Chrysophyta (diatoms) from Balaena Bay, N.W.T. *Trachyneis* (magnification x 630).

Figure 32(a). Photograph of clean-up procedure - burning of oil June 7, 1975.

Figure 32(b). Photograph of clean-up procedure - soot on ice under smoke.

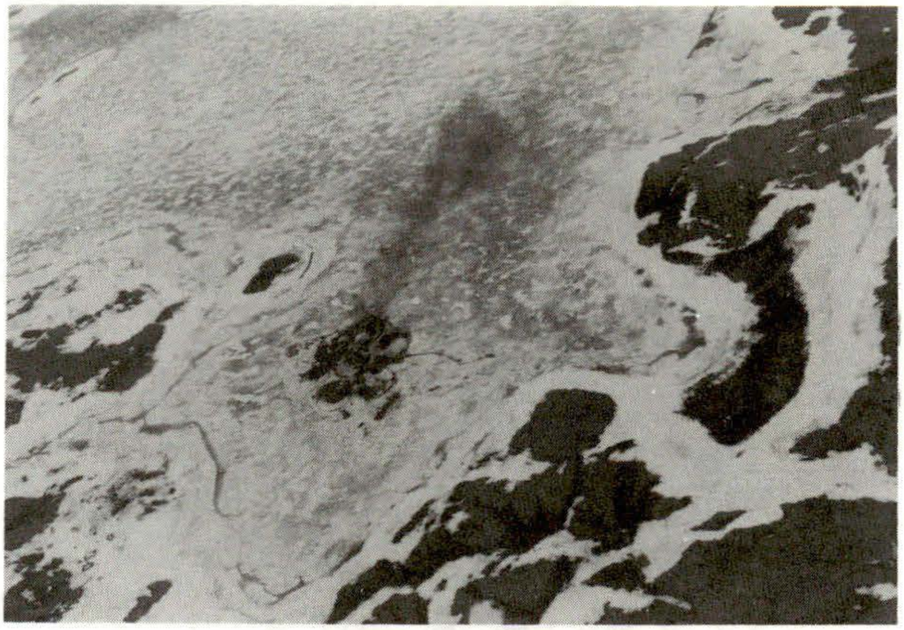

Figure 32(c). Photograph of clean-up procedure - distribution of airborne combustion products as seen from helicopter June 7, 1975.

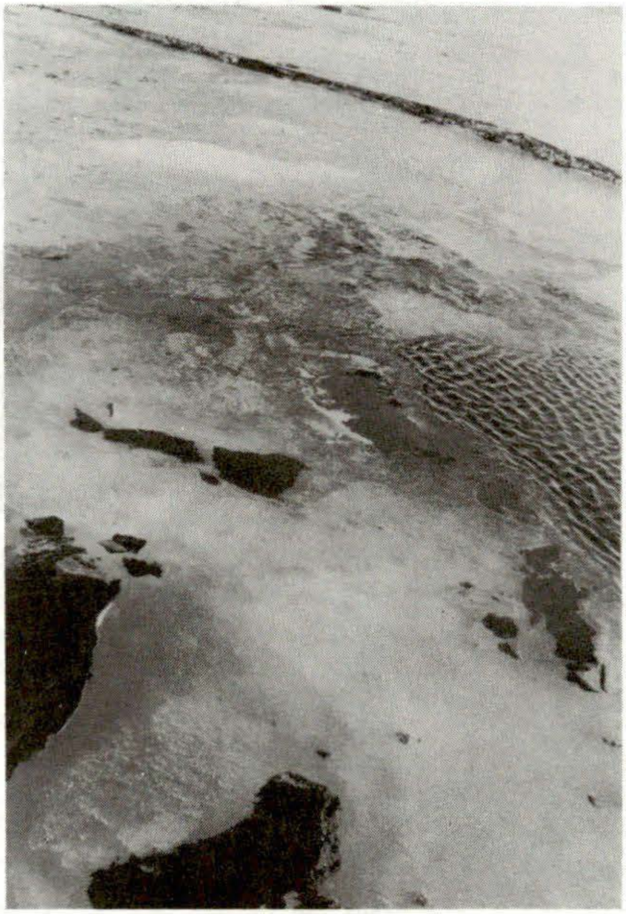

Figure 32(d). Photograph of clean-up procedure - Tar-like residue on the ice near NW2, June 26, 1975.

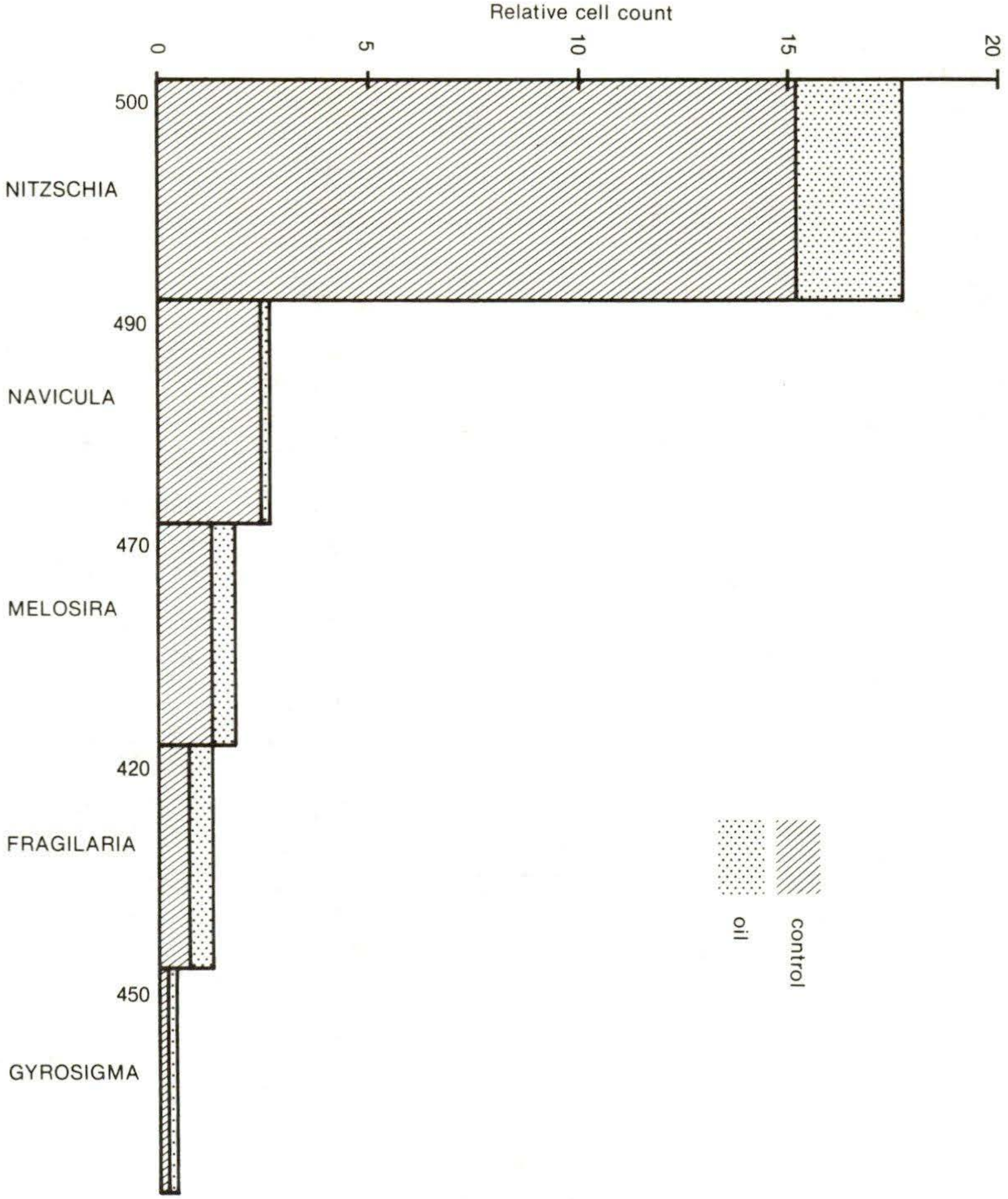

Figure 33. Dominant photoplankton genera plotted as mean cell abundance of control and oil stations.

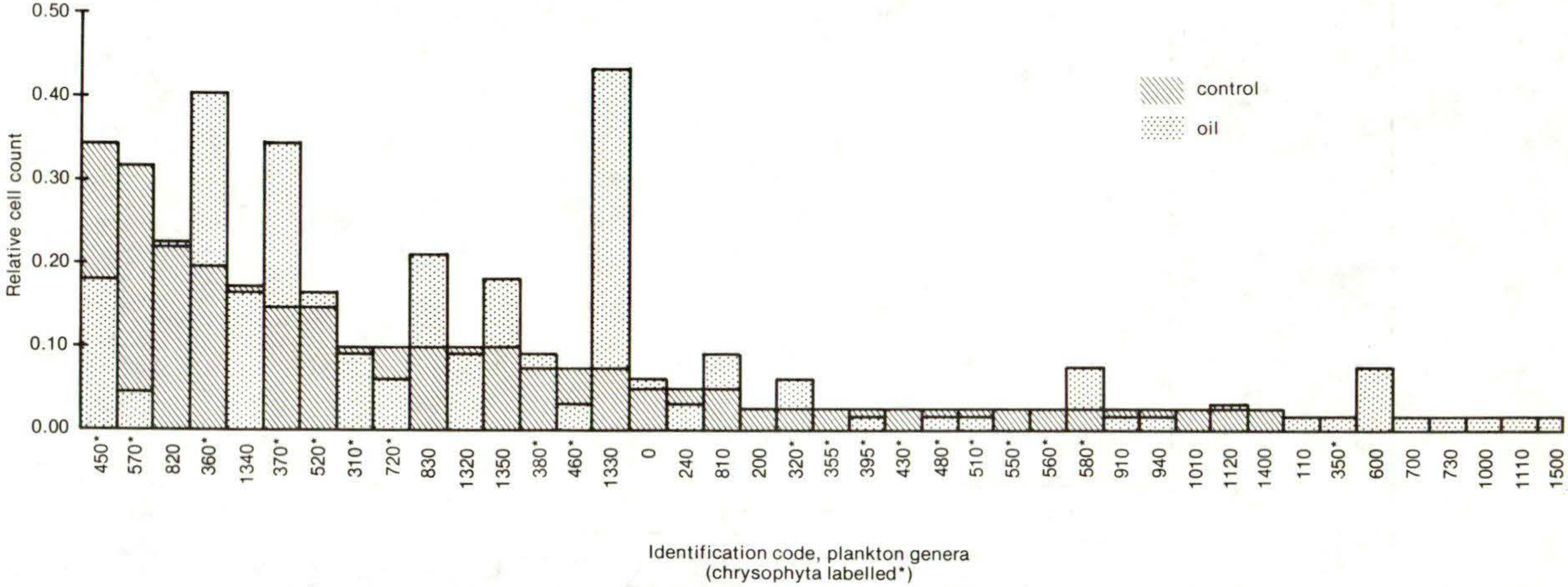

Figure 34. Relative cell count of less abundant plankton presented as mean of control and oil stations.

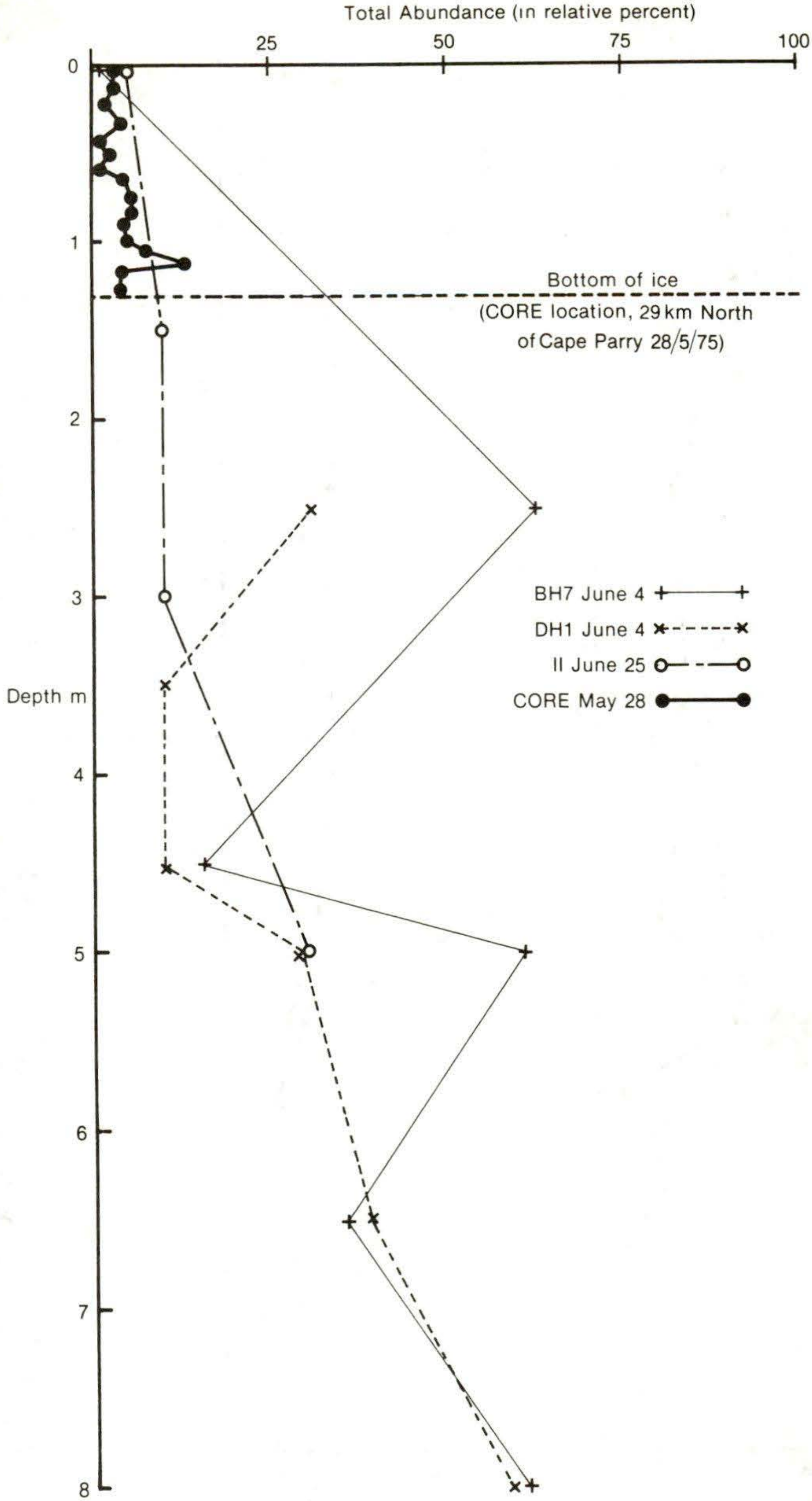

Figure 35. Plankton abundance in units of relative percent as a function of depth for an ice core, an oil station (DH1), and two control stations (BH7 and II).

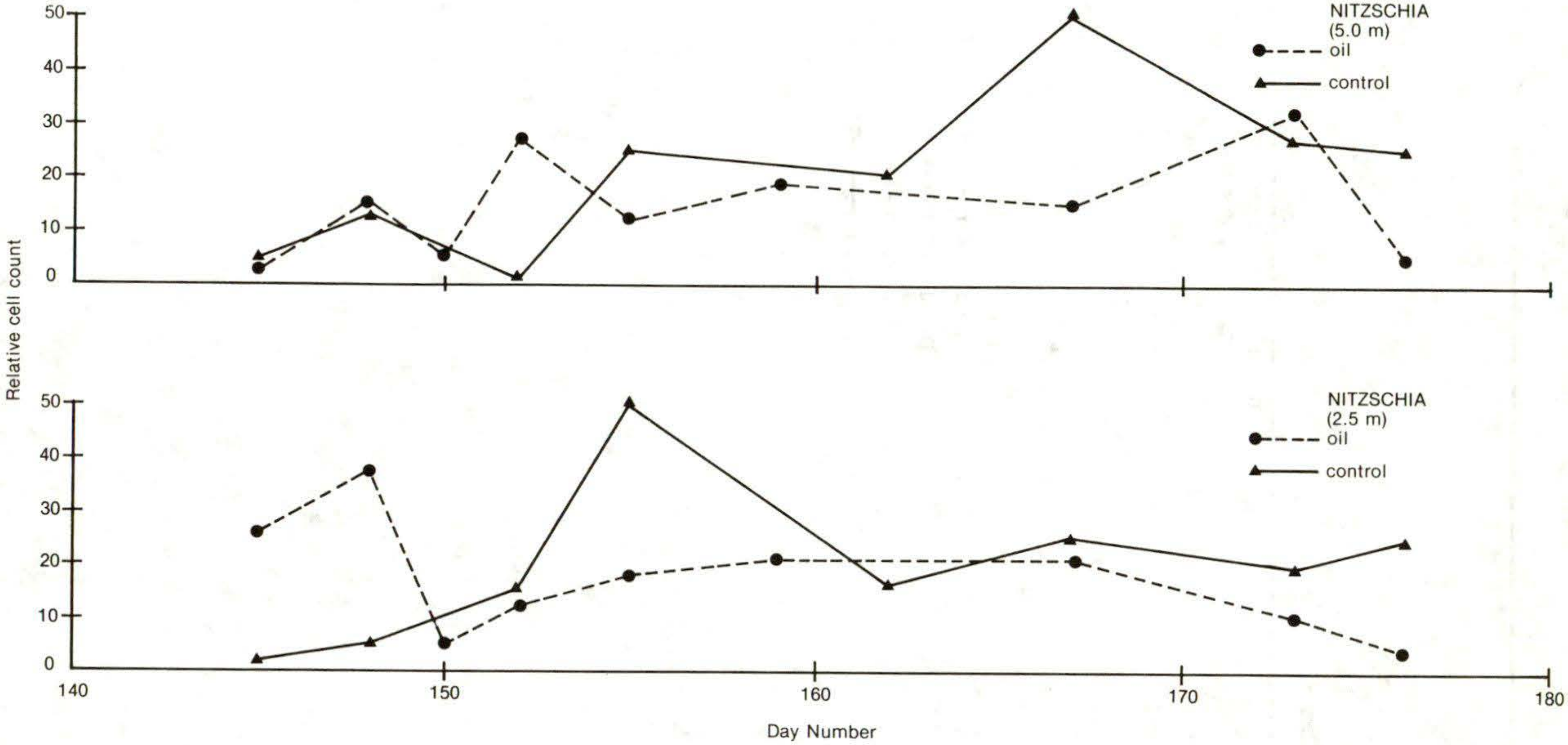

Figure 36. Relative cell count for *Nitzschia* at 5.0 m and 2.5 m depths as a function of time (day 0, is January 1, 1975) for the mean of all oil and the mean of all control stations.

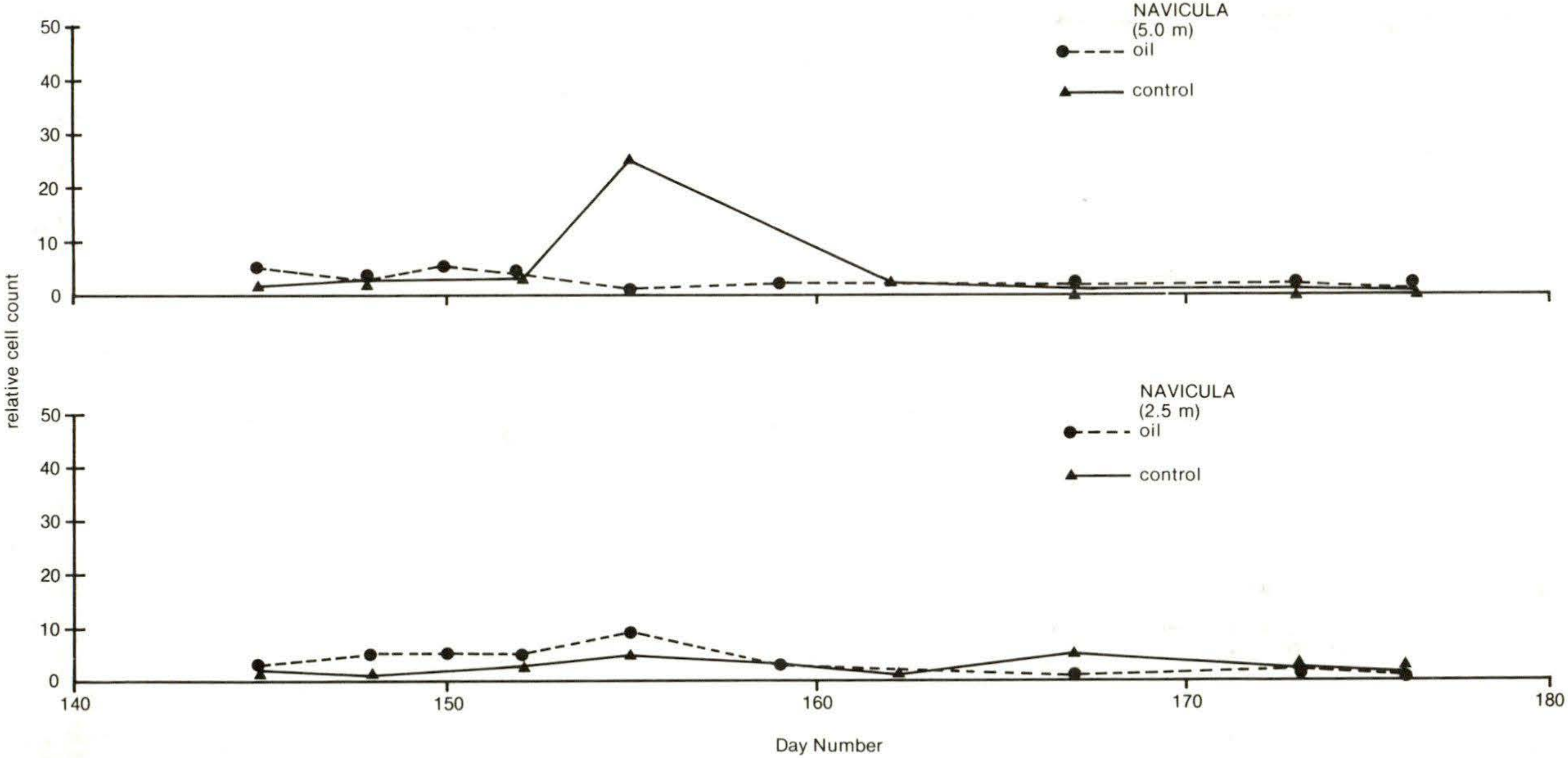

Figure 37. Relative cell count for *Navicula* at 5.0 m and 2.5 m depths as a function of time (day 0, is January 1, 1975) for the mean of all oil and the mean of all control stations.

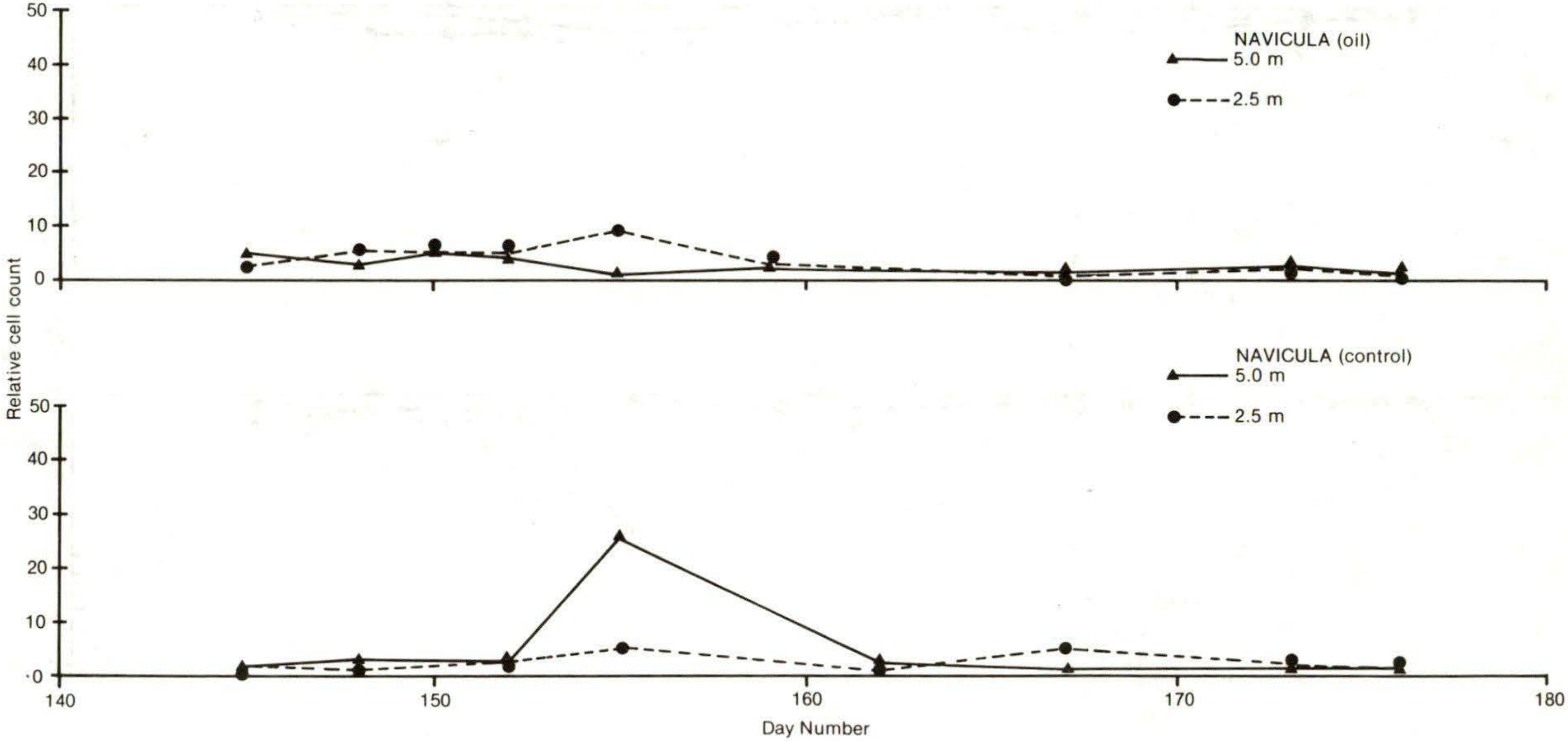

Figure 38. The relative cell counts for *Navicula* plotted against time but contrasting the 2.5 m - 5.0 m depths for the oil and for the control stations.

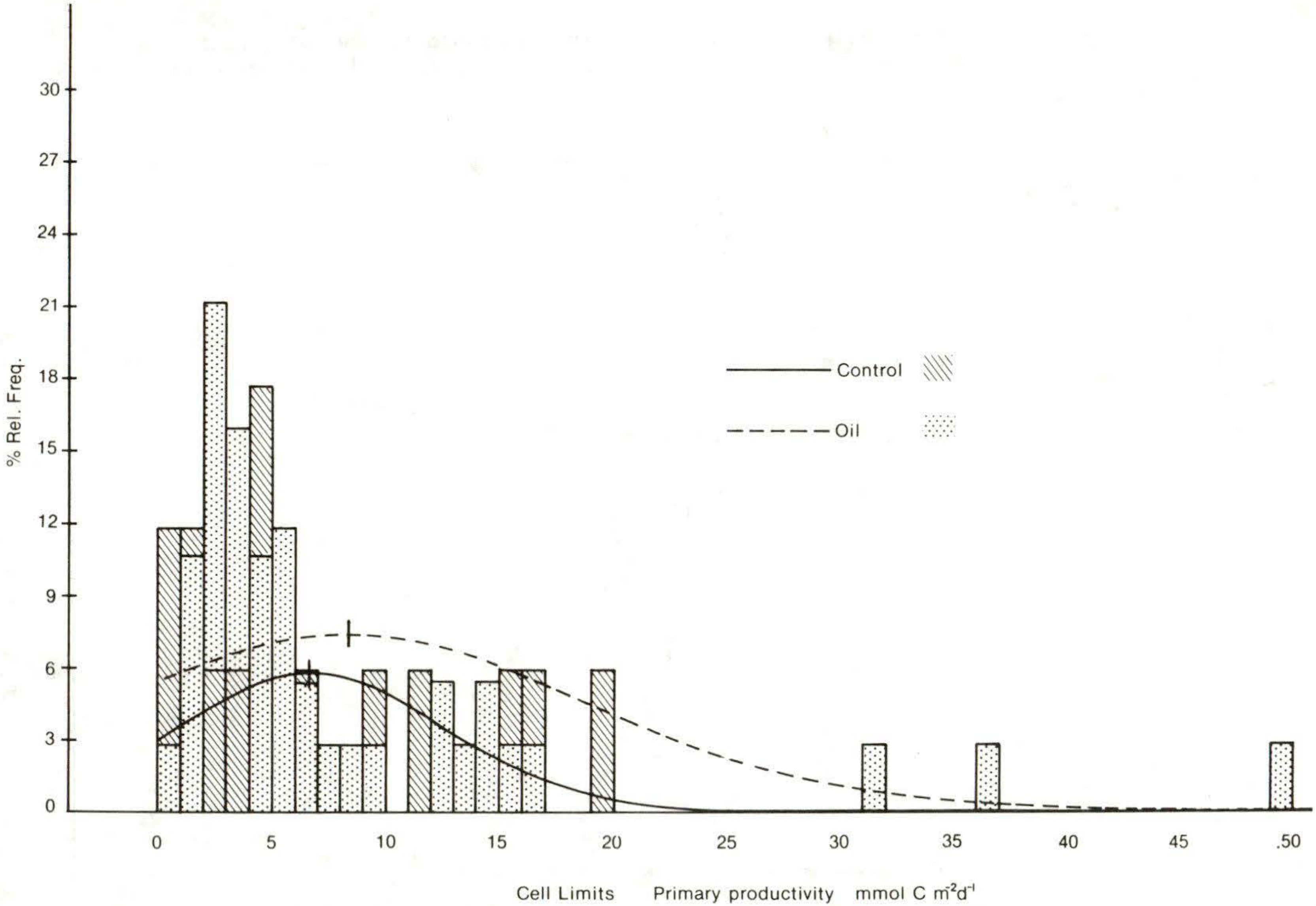

Figure 39. Histogram of net daily primary productivity of phytoplankton in Balaena Bay, N.W.T., during May and June, 1975, divided according to an oil group and a control group of stations.

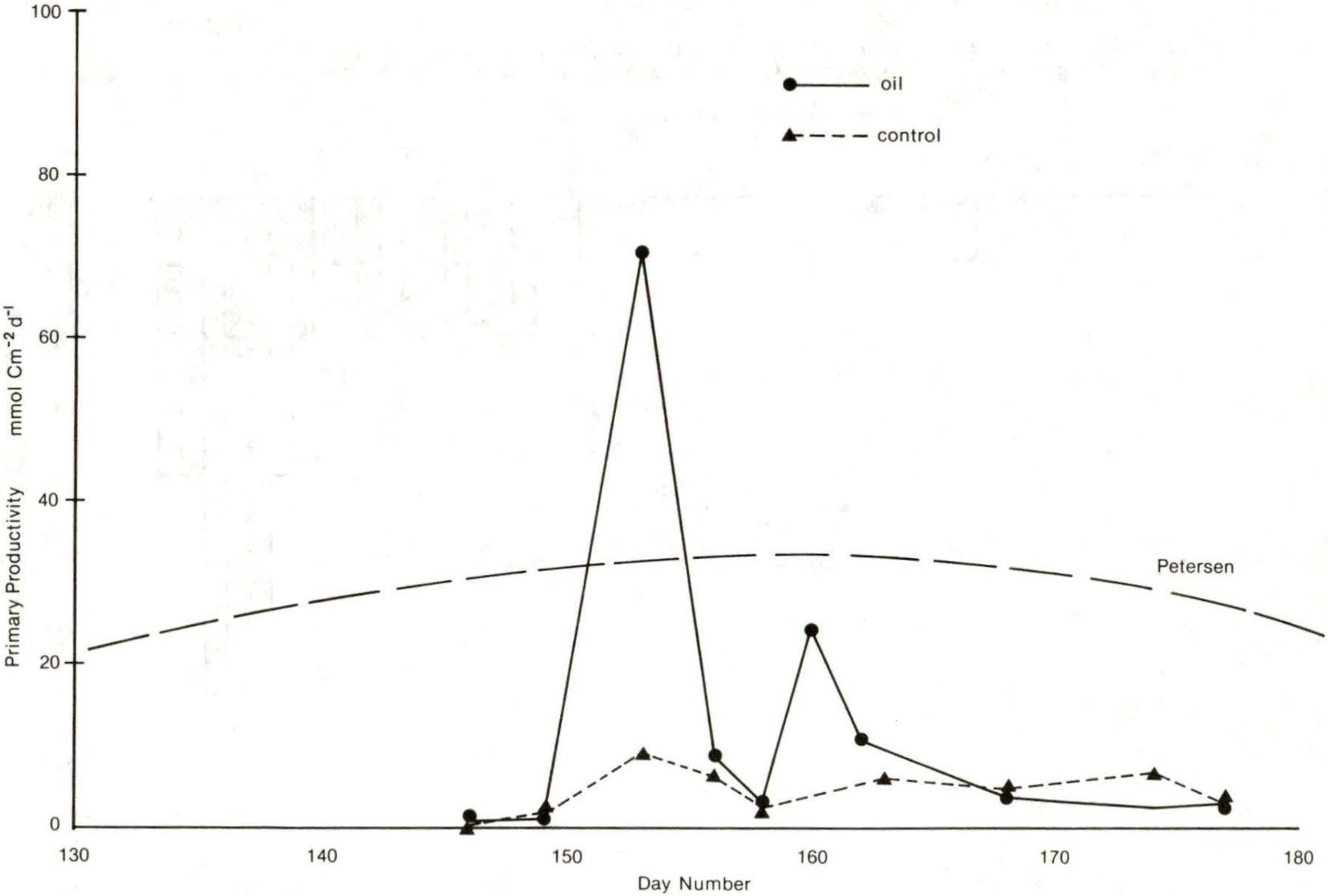

Figure 40. Net mean daily primary productivity of phytoplankton in Balaena Bay, N.W.T., for a control and an oil group of stations plotted as a function of time (day 0, January 1, 1975).