Environment Canada
Environnement Canada

Oil Spill at Deception Bay, Hudson Strait

R. O. Ramseier, G. S. Gantcheff
and L. Colby

SCIENTIFIC SERIES NO. 29

INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 1973

Environment Canada
Environnement Canada

Oil Spill at Deception Bay, Hudson Strait

R. O. Ramseier, G. S. Gantcheff*
and L. Colby**

*Natural Resources Management Company, Montreal.
**Polar Continental Shelf Project, Department of Energy, Mines and Resources.

SCIENTIFIC SERIES NO. 29

INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 1973

Cat. No.: En36-502/29

CONTRACT #02KXKL327-3-8060
THORN PRESS LIMITED

Contents

Illustrations

Tables

Tables (cont.)

CHAPTER 1

Introduction

Approximately 427,000 gallons of Arctic diesel oil and gasoline were spilled over permafrost and sea ice at Deception Bay, Quebec, sometime between June 6 and 8, 1970, when a tank farm was destroyed by a slush avalanche. Deception Bay (Figure 1) is located at the northern tip of Ungava, west of Sugluk. The bay is 9 nautical miles long and approximately 2.2 nautical miles wide. The depth varies between 60 and 180 feet. The spill occurred on the southwest shore (Figure 2) about 6.7 nautical miles from the mouth of the bay and about 3 miles from a camp operated by Asbestos Corporation of Montreal, owners of the tank farm. At the time of the spill the entire bay was covered with a continuous ice sheet approximately 54 inches thick. A well-developed tidal crack system separated the sea-ice cover from the shore-fast ice. The mean diurnal tide varies between 12 and 19 feet. The tidal currents average approximately 0.9 knots.

Eskimos passing the tank farm on June 8 found it destroyed and reported the fact to the camp. There were no eyewitnesses to the incident as the tank farm is not visible from the camp. It was last seen intact on June 5. Word of the spill reached the Department of Energy, Mines and Resources on June 9, at which time the Departmental Committee on Oil Pollution, under the direction of Drs. A.T. Prince, O.H. Løken and E.F. Roots, convened a group to investigate the spill and to provide advice to the Asbestos Corporation.

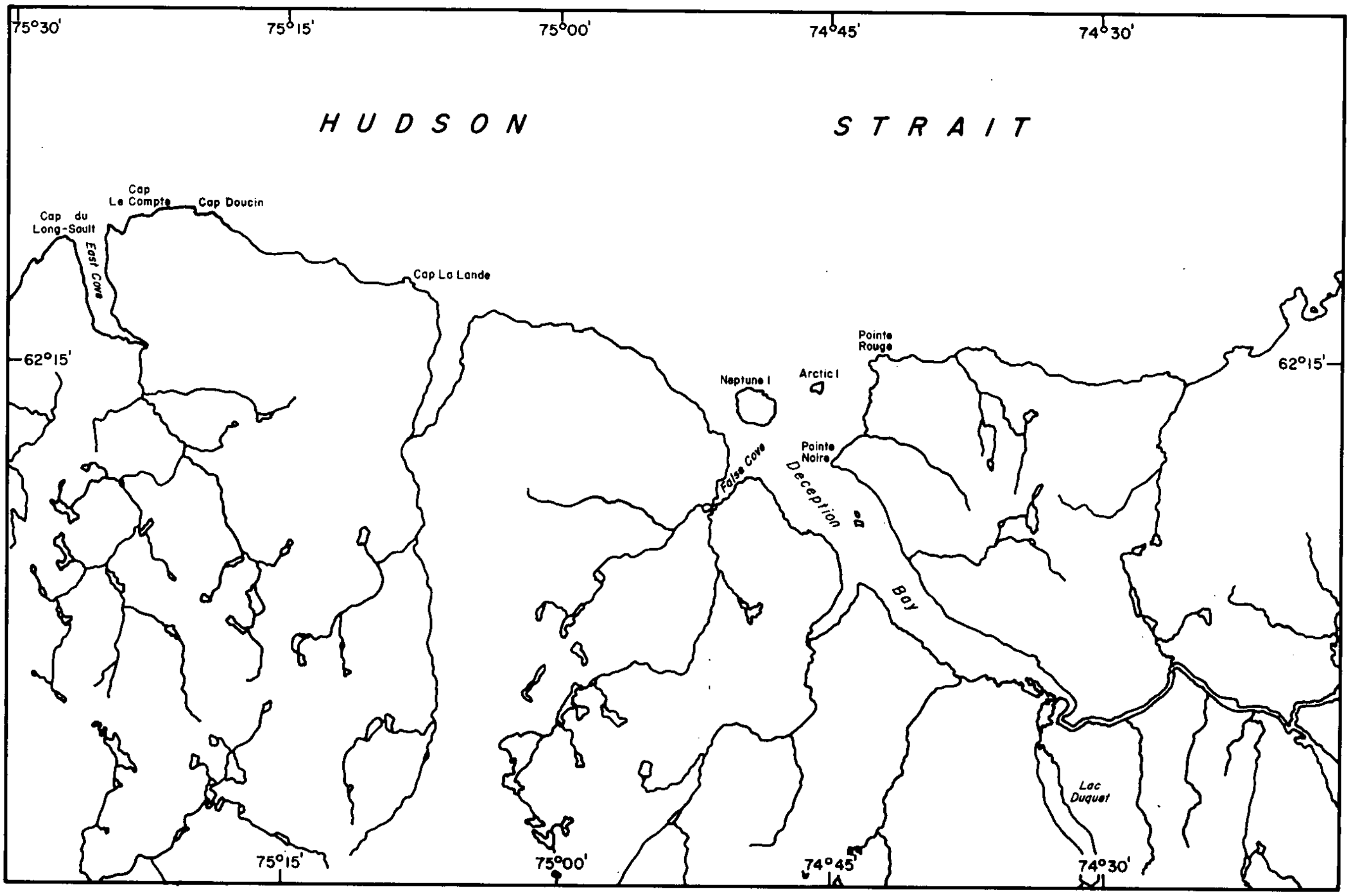


Figure 1. Area Map of Deception Bay, Hudson Strait.

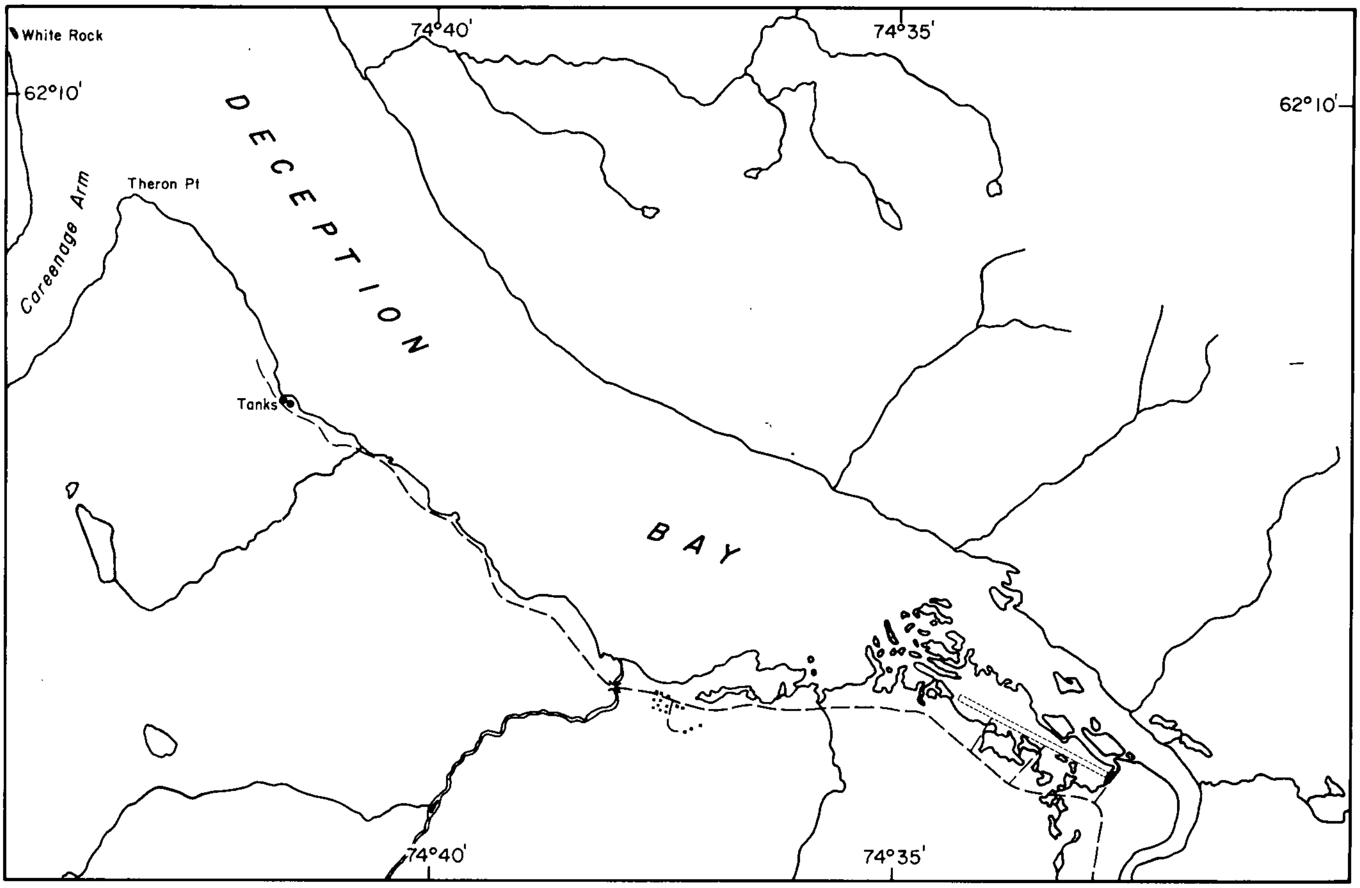


Figure 2. Detailed map of Deception Bay.

The group members, their association and disciplines were as follows:

Mr. Fred Barber, Marine Sciences Branch, On the scene coordinator and spokesman for the Federal team, clean-up specialist

Mr. René O. Ramseier, Inland Waters Branch, Glaciology Subdivision, Glaciologist

Mr. Lynne Colby, Polar Continental Shelf Project, Sea Ice Engineer.

Dr. George Gantcheff, under contract to Polar Continental Shelf Project from NAREMCO, Montreal. Pollution Engineer.

Mr. Raymond Bergeron, under contract to Polar Continental Shelf Project from NAREMCO, Montreal, Ecologist.

Dr. Collin Phillips, Under contract to the Glaciology Subdivision from the University of Toronto, Chemical Engineer.

The group arrived at Deception Bay on June 12 – joining Mr. Wybe Hoek, Marine Biologist, Department of Fisheries and Forestry, who was already at the site. Mr. Jim A. Code, Engineering Geologist, Geological Survey of Canada, joined the team on June 17.

The objectives of this team were:

(a) to discover the cause of the spill,
(b) to study the interaction of oil with ice and permafrost,
(c) to study the ecological effects of the spill
(d) to advise on the clean-up and disposal of the spilled oil.

Cause and Extent of Spill

2.1 PHYSIOGRAPHY AND GEOLOGY

(J.A. Code)

Deception Bay is situated on the northern edge of a physiographic region known as the Sugluk Plateau[1]. This barren plateau is bordered on the north by Hudson Strait, on the west by Hudson Bay, and on the south and east by a series of ridges called the Povungnituk Hills. The plateau is essentially an upland of Precambrian bedrock, varying in elevation inland from about 500 to 1,700 feet above sea level. The rock surface is partially covered by glacial drift and recent sediments which tend to accumulate at lower elevations. Bedrock consists of hard, metamorphic Precambrian rock, mainly gneisses. The region lies within the zone of continuous permafrost.

Inland from the western shore of Deception Bay, the ground level rises to elevations of 1,000 feet or more within a distance of about a mile. Marine terraces are present on the slopes, some of the material being reworked and transported to lower levels. Bedrock exhibits a fluted or ridged surface trending in a direction subparallel to the shoreline. Linear depressions separating the ridges serve to channel surface water to the main streams which, in turn, empty into the bay.

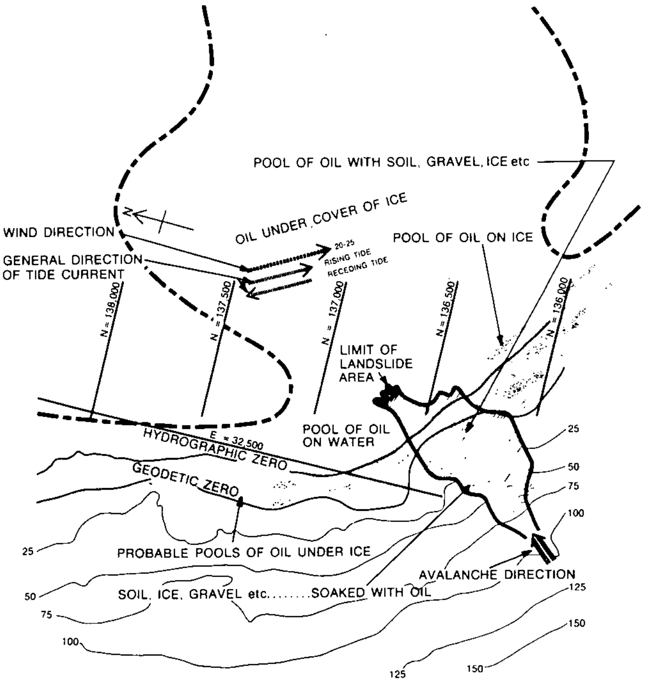


Figure 3. Areas affected by the spill.

The stream which empties into the bay at the site of the tank installation drains a portion of the adjacent upland (Figures 2 and 3). In the area of the slide the stream flows in a 25-foot deep gully which it has excavated from an accumulation of slopewash material. The stream gradient between the elevations of 475 feet and 250 feet is about 16 degrees. Below 250 feet it averages 7 degrees.

2.2 METEOROLOGICAL CONDITIONS

On-site evidence clearly indicated that the tank farm was destroyed by a slush avalanche. Based on the meteorological records (Figures 4 and 5) it was possible to determine approximately when the avalanche occurred. The tank farm was last seen intact on June 5; its destruction was reported on June 8. High temperatures were observed starting June 3 and ending in the early hours of June 7, causing rapid melting of the snow in the basin feeding the snow-filled gully. Wind velocities increased up to 60 to 70 miles per hour with gusts up to 80 miles per hour in the early hours of June 6. Thus accelerating the rate of melt. In addition, the wind direction changed from June 5 to June 6 by 180° to north-northeast becoming almost parallel with the gully, causing an increased amount of water to flow down the gully (Figure 3). The meltwater was readily absorbed by the snow-filled gully until the snow cover failed in tension from the additional forces exerted by the water. The probability of avalanching is indicated in Figure 5 for a period of 10 hours on June 6.

2.3 CHARACTERISTICS OF THE AVALANCHE

General avalanche theory would indicate no danger of a snow avalanche at the site at Deception Bay, since the slopes are too gentle (Figure 6). Figure 7, taken from the Handbook for Snow Avalanches, U.S. Forest Service[2], shows typical variations of slide activity with slope angle. As indicated in the diagram, gliding is extremely rare for an angle of 15°. The Handbook notes that slush runs do occur but are generally considered to be unimportant. In the

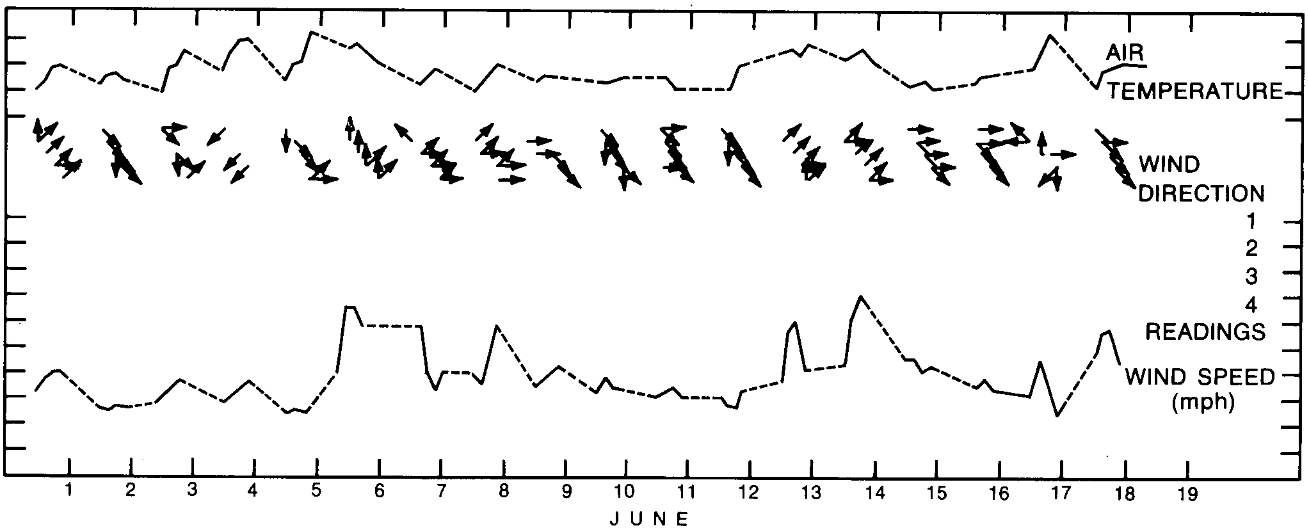


Figure 4. Meteorological records, June 1-19.

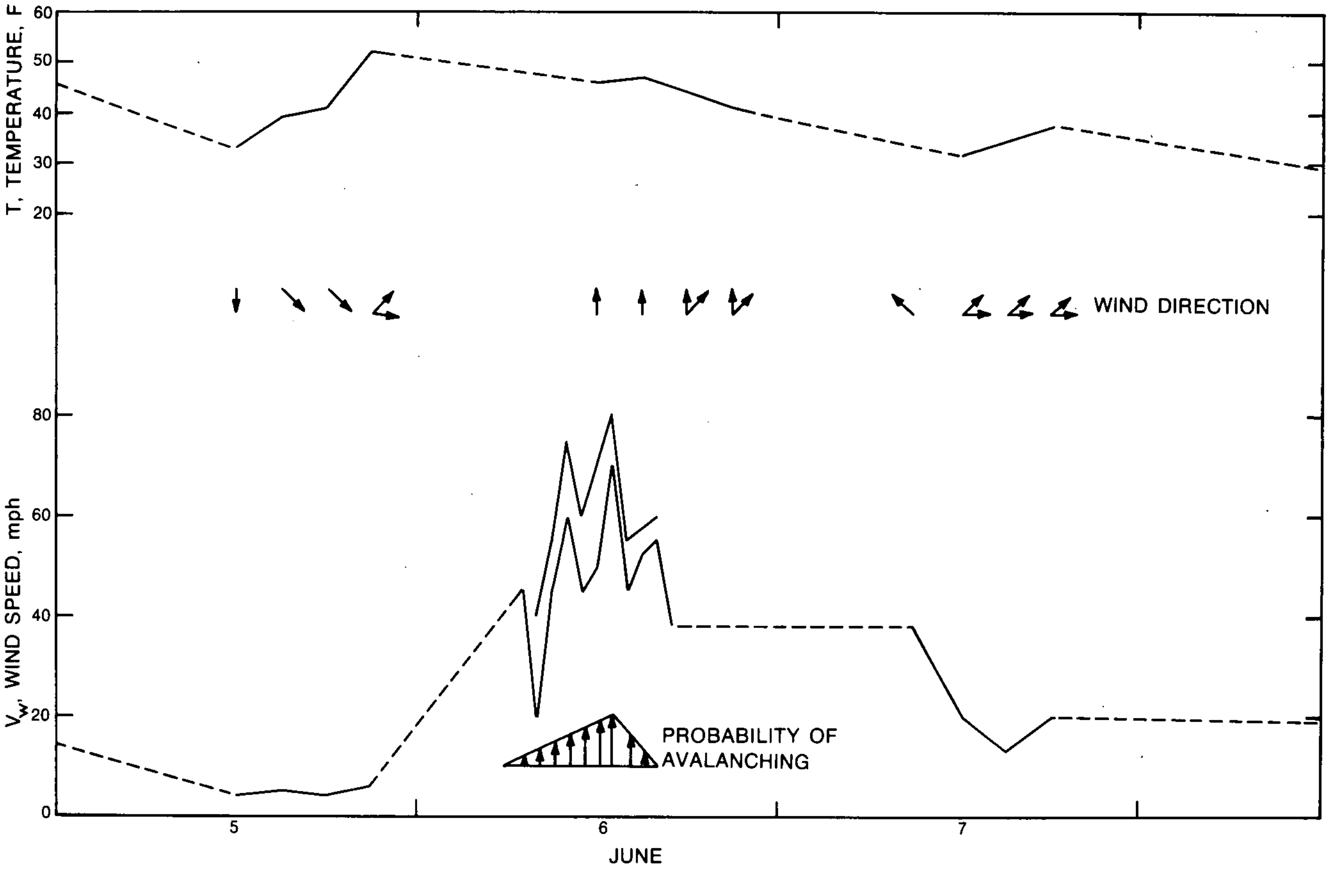


Figure 5. Probability of avalanching on June 6.

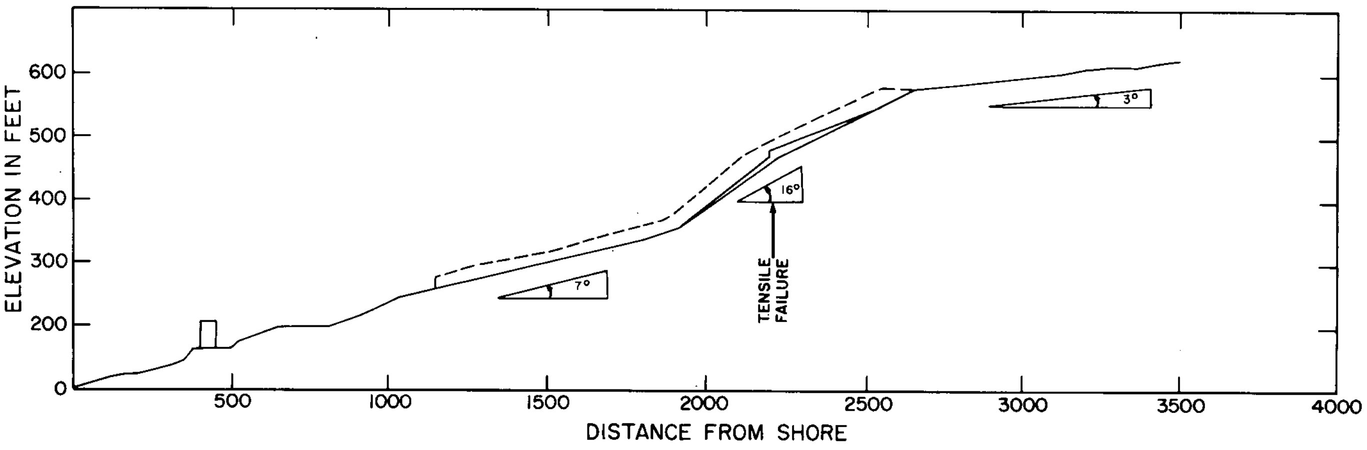


Figure 6. Slope of gully in avalanche zone.

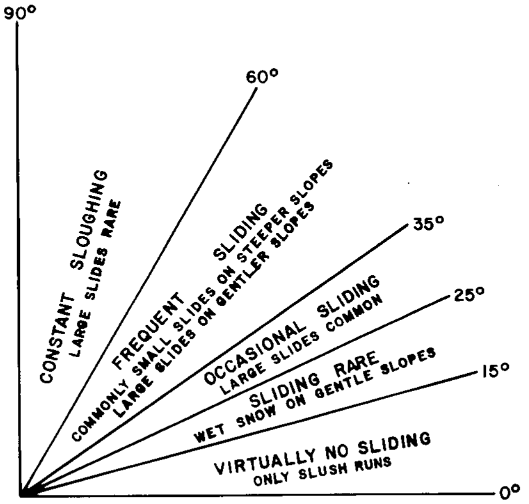


Figure 7. Typical variations of slide activity with slope angle.

Figure 8. Failure zone of avalanche.

present case (Figure 6) the slope in the failure zone is only 16° decreasing to an average of 7° after 300 feet.

Slush avalanches can originate on slopes as small as 2° according to Nobles[3]. Slush flows have been reported by Washburn and Goldthwait[4] as occurring in the spring following intensive thawing. They are probably most common in the Arctic but have also been reported as occurring in Norway[5] and in the Alpine countries of Europe. The major factors causing slush avalanches are:

(i) the presence of a snow-filled gully which may contain a frozen stream,

(ii) the production of more meltwater than can drain through snow.

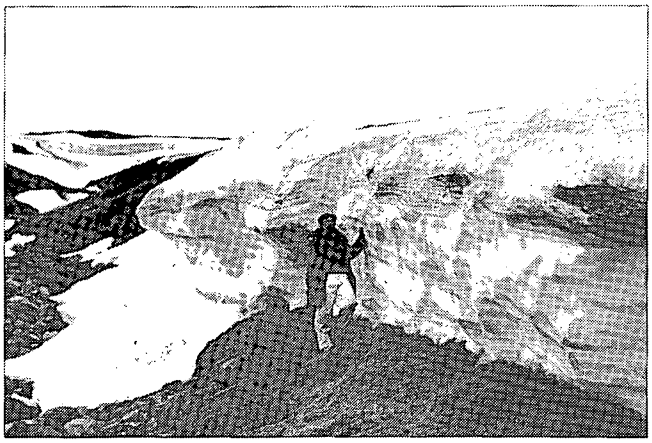


Figure 9. Thickness of snow left behind after avalanche descended.

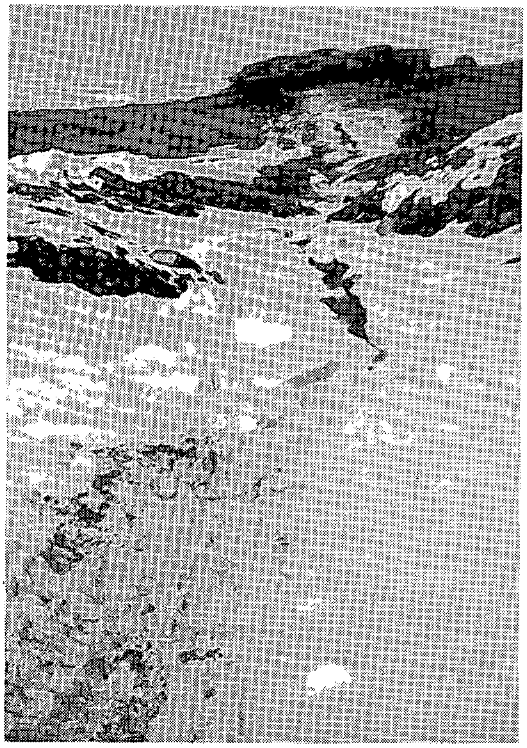


Figure 10. Downhill view of avalanche path.

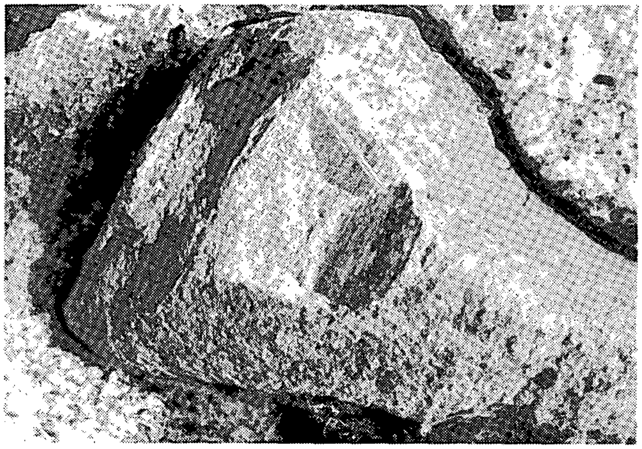


Figure 11. Single boulder with part chipped away.

Although this is the first such slush avalanche since the construction of the tank farm in 1958, the possibility of such an occurrence must be seriously considered when evaluating a potential construction site.

Based on a local survey made by Mr. Gransby, Site Engineer for FENCO, and the measurements made on snow thickness on June 12, the total amount of snow which descended on the tank farm was estimated at approximately 1.8 X 10^4 metric tons, excluding meltwater. Figures 8, 9 and 10 illustrate some of the features of the avalanche path. The partially water-saturated snow (Figure 6) picked up boulders (the biggest being about 1 X 2 X 5 feet) on both the 16° and the 7° slopes. Figure 11 shows one of these transported boulders. The slush avalanche descended about 300 feet to the 7° slope and continued for another 1000 feet onto the sea ice, overrunning the shore-fast ice.

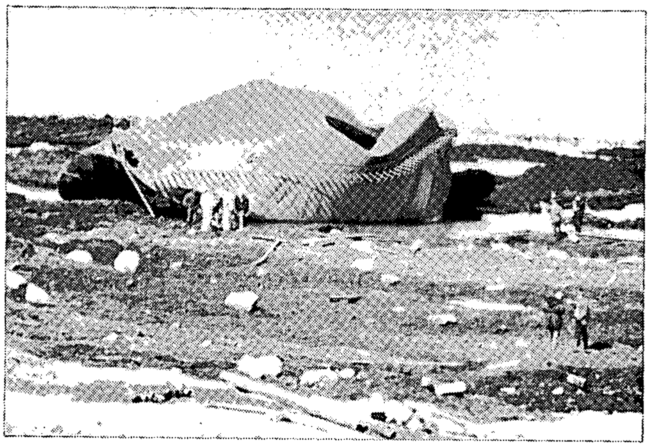


Figure 12. Debris carried down the slope.

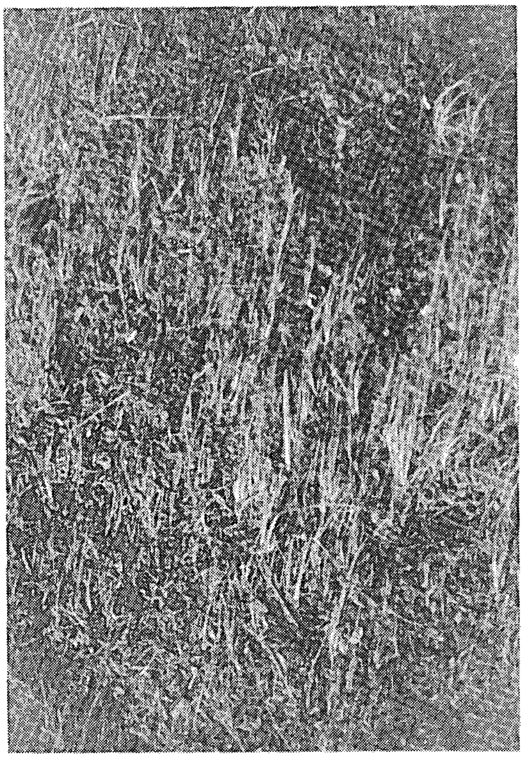


Figure 13. Flattened vegetation.

No estimate was made of the amount of debris carried down the slope. However, Figure 12 gives some feeling for the quantity involved and suggests that the transport of boulders by the slush avalanche in this particular case is probably a more important geological process than fluvial erosion. No unusual erosion of the ground in the avalanche path was observed. The vegetation had been flattened in a direction parallel to the avalanche path (Figure 13), either by the previously overlying snow or by the slush flowing over it. This was also true at the head of the gully where the slope was only about 3° (Figure 6). That no erosional marks were observed in the avalanche path would indicate that the quantity of free water was high, causing a torrent-like flow which prevented boulders from scarring the ground.

Rapp[5] has proposed calling such phenomena – torrent avalanches – to distinguish them from the more gentle slush avalanches described by Nobles[3] and Müller[6] on ice caps and glaciers respectively. The suggested terminology seems entirely appropriate to the present case.

2.4 TANK FARM

Table 1 provides pertinent data on the tank farm. Its arrangement before and after the spill is shown in Figure 14. The slush avalanche struck the farm in a broad front depositing seven to eight feet of snow covered by a two to three inch layer of fill from the road above the site (Figure 15).

Table 1. Basic Information on the Tank Farm

Tank Number	Capacity		Inventory June 15, 1970		Tank Status
	BBL	Gal.	Gal.	Content	
1	135,000	486,000	48,601	Arctic Diesel	Destroyed
2	4,000	144,000	57,927	Gasoline	Destroyed
3	1,500	44,000	36,896	Gasoline	Intact
4	1,500	44,000	920	Arctic Diesel	Destroyed
5	4,000	144,000	Empty	–	Destroyed
6	13,500	486,000	319,068	Arctic Diesel	Damaged

Total spill	426,516 ≈ 427,000*
Arctic Diesel	368,589 ≈ 369,000*
Gasoline	57,927 ≈ 58,000*

*The rounded off numbers will be used in the text.

The event can be reconstructed as follows:

Tank No. 1 containing one-tenth of its capacity hit tank No. 6 and damaged it (Figures 14, 16). Tank No. 6 was full enough to withstand the blow by No. 1 and the forces exerted by the slush avalanche. The small Tank No. 2, containing slightly less than its capacity, hit the equal-sized but empty Tank No. 5. The bottom of No. 2 slit open emptying its 58,000 gallons of gasoline over the fill. It came to rest on the original site of Tank No. 5. Tank No. 3, the smallest and almost full, withstood the forces exerted by the avalanche. However, No. 4, which was the same size but practically empty, was swept down by the avalanche even though it had the advantage of being somewhat in the lee of the avalanche. It came to rest in front of No. 5 as shown in Figure 16.

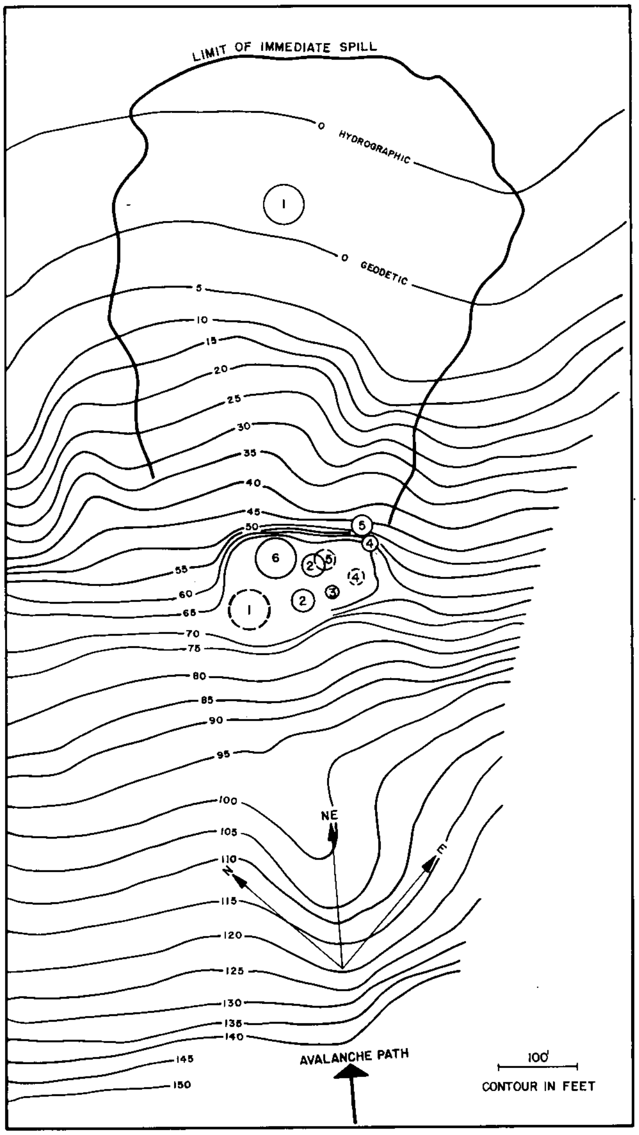


Figure 14. Tank arrangement.

2.5 AREAS AFFECTED BY THE SPILL

Figure 14 gives a general view of the areas affected by the spill: the permafrost below the tank farm, the shore-fast ice, the tidal crack network and the sea ice. The areas have been designated in such a way as to facilitate the oil budget analysis.

(i) *Permafrost*. A large quantity of snow and debris was deposited as the avalanche ran out onto the sea ice (Figure 15). A dirt layer from one to three inches thick covered the entire area. It originated predominantly from the fill on which the tank farm rested, with some fill from the road above the tank farm. Both the dirt layer and the snow itself were saturated with diesel oil (Figures 17 and 18). Figure 18 also shows some frost crystals which formed from the evaporation of gasoline. The surface layer on which the ice crystals formed was frozen hard. The ice crystals were somewhat yellowish in appearance.

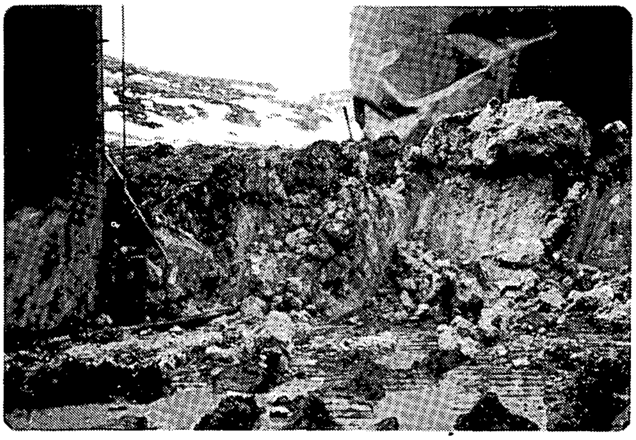


Figure 15. Layer of snow and dirt in front of tank 3 (left) and tank 6 (right).

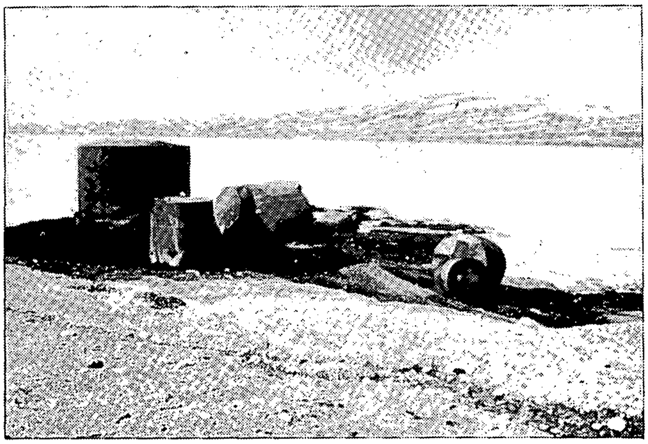


Figure 16. Destroyed tank farm.

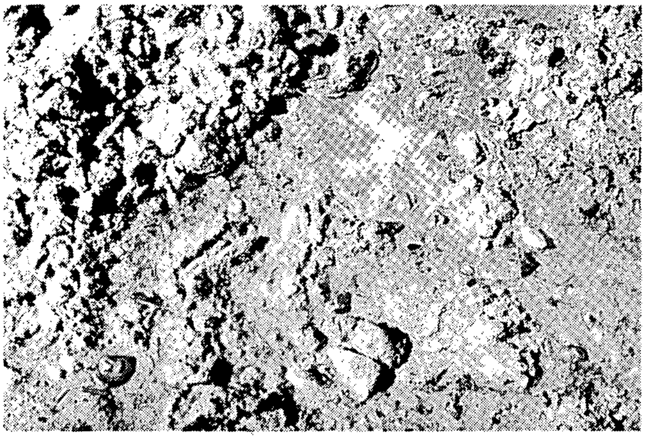


Figure 17. Oil in permafrost.

Figure 18. Oil in snow.

Figure 19. Shore fast ice.

(ii) *Shore-fast Ice.* The shore-fast ice extended from the shore to the tidal-crack network (Figure 19). A structural and textural analysis revealed that it was mostly porous snow ice with a grain size of 2-4 mm. Its origin was wind-blown snow. The tides, averaging 12 feet, made the surface and bottom of the shore-fast ice very irregular; and ideal place for absorption and pooling of oil.

(iii) *Tidal-Crack-Network.* The tidal cracks are clearly visible in Figure 19 between the smooth sea ice surface and the shore-fast ice. The spilled oil flowed up and down the crack system, and into the shore-fast ice, depending on the tide and prevailing wind.

(iv) *Sea Ice.* The sea ice extended over the rest of the bay, providing a wide relatively smooth surface on which the oil could be pushed by prevailing winds. The state of the surface was very unstable, depending on air temperature, tide and cloud cover. The ice, at the same temperature as the water, was very porous and had a whitish appearance due to its disintegration by solar radiation. Where meltwater was present the surface appeared blueish. On some occasions the sea ice over the entire bay was covered with meltwater. The ice thickness was about 54 inches and very regular. The ice-water interface was smooth and even. The water level was approximately 6 inches below the ice surface.

CHAPTER 3

Behaviour of the Oil

3.1 THEORETICAL ASPECTS – INTRODUCTION

Although the actual duration of the avalanche was brief, its effect on the area continued to evolve and change. Oil-soaked soil contributed to the evaporation of some of the pollutant. A natural draining process started, whose efficiency was increased through washing and leaching by the meltwater from the deposited snow on the site.

On the team's arrival, Tank Nos. 2 and 6 were feeding this system with oil and it appeared that equilibrium had not been reached. For this reason, and in the light of soil analysis made later, it was believed that the amount of oil in the soil on the days preceding our arrival was in the order of 6% by weight decreasing with time. When leaking from the two damaged tanks stopped, the rate of drainage, washing and leaching slowed. On June 16, the amount of oil in the soil was down to about $1^1/_2$%.

The properties of ice have a profound effect on the behaviour and subsequent fate of oil. It acts on the oil as a barrier, shock absorber, and shelter. The ice absorbs oil and basically alters evaporation efficiency. Oil will change the albedo of the ice, effecting its rate of melt. This allows the oil to sink into the ice surface to be further sheltered.

A knowledge of the effects of tides on oil in ice-infested waters is of great importance. They greatly influence its movement within the tidal-crack system and also its dispersal.

Oil in sea water presents a complex dynamic situation. The presence of ice somewhat simplifies the situation by limiting the parameters. On the other hand, by its own physical properties, ice complicates the analysis of the situation.

3.1.1 Behaviour of Oil on Ice: Spreading and Evaporation

When studying the rate and mechanism of the spreading of oil over ice one should consider the presence of three main factors: wind, state of ice surface and meltwater.

The effect of the wind is a very important, if not the most important factor affecting the spreading rate of oil over ice. In certain cases oil-spreading velocities reached 50 to 60 feet per minute. Spectacular as these figures might seem, they are still considerably lower than the spreading velocity observed over open water. Preliminary calculations indicate that the spreading of oil over ice by wind is only about one-third of that observed over open water. This can be explained by the fact that ice, particularly that observed on Deception Bay, did not have a smooth surface. Wind will strongly affect the evaporation rate by spreading the oil, thus increasing its evaporative surface. It also removes the faster vaporized hydrocarbon molecules, creating a gradient which will encourage the evaporation of other hydrocarbon molecules.

In the case of spreading of oil by pumping, the driving force is not the wind but the gravity-inertia, gravity viscous and surface tension-viscous forces of oil over the ice surface. The rate of pumping becomes the controlling factor. Several phenomena can be observed as oil spreads over ice. The oil is absorbed by the ice at a rate dependent on the porosity of the ice and the viscosity of the oil. As the oil's temperature decreases to that of the ice, its viscosity increases.

When oil has covered a given area and reached temporary equilibrium, several new processes take place. Oil will increase the albedo of the ice, increasing the absorption of solar heat. The temperature of the oil will rise, creating a temperature gradient between ice and oil. The oil will then heat the surrounding ice and cause further melting and sinking into the ice surface.

Theoretically, diesel oil evaporates quite rapidly. Then why had not the diesel oil evaporated almost 10 days after it was spilled? A chromatographic analysis of clean diesel, all which had been exposed several days in an open pool, showed a loss of only about 2-4% of its lightest fraction. There are several factors which may retard evaporation. First, the surface forces of both ice and water may effectively lock the oil molecules over their surface. If correct, this could account for only a very thin, almost monomolecular film. Also, in many cases the oil was sheltered by the ice, cutting down the evaporative rate. Although not enough data are available, it is strongly felt that a very important factor is the competition for energy by surrounding ice. Vapour pressure of most components of diesel oil (but for the lightest ones) is of the same order of magnitude or less than that of ice and water at 0°C.

Thus, as soon as the oil absorbs some energy, it quickly loses an important fraction of it to the adjoining ice and water, reaching temperature equilibrium.

This aspect can be examined in more detail. A process in which mass is exchanged between a liquid (or a soil) and a moving fluid is called *convection.* Natural convective flow is due to gravitational forces. A difference in density (due to a difference in temperature or concentration) is the main driving force.

Forced convection is presented by the well known Nusselt's equation:

$$\frac{h_c D}{k} = C\left(\frac{DV\rho}{\mu}\right)^b \left(\frac{C_p\mu}{k}\right)^d \qquad (1)$$

where $\frac{h_c D}{k}$ = Nusselt's number

$\frac{DV\rho}{\mu}$ = Reynolds number

$\frac{C_p\mu}{k}$ = Prantl number

and μ = viscosity, ρ = density, C_p = specific heat, k = thermal conductivity, h_c = surface coefficient of convection, V = velocity, D = diameter of the stream. The above equation can be transformed into an equation for free convection, i.e.

$$\frac{h_c L}{k} = C\left(\frac{g\beta\Delta T L^{3\,1\,2}}{\mu^2}\right)^{6/2} \left(\frac{C_p\mu}{k}\right)^d \qquad (2)$$

Here we recognize Nusselt's and Prantl number, the middle term being called Grashof's Modulus, where g = acceleration of gravity, β = coefficient of expansion, ΔT = temperature differential and L = evaporative surface.

With a given fluid, e.g., diesel oil, hexane or water, all characteristics of the liquid to be evaporated are fixed at any given temperature. Thus, the major factor governing increased efficiencies is T. This was found to have a very low value in Deception Bay.

The temperature difference between ice, water or oil on the ice and the surrounding air is low, seldom exceeding 10-15°C. Therefore, natural evaporation is limited. But this is not all. When oil warms up it establishes a temperature differential at the contact surface between ice and oil. The oil will keep a given temperature (most likely lower than that of air) by internal convection. At the ice-oil interface a conduction heat transfer process can be established simply by:

$$q = \frac{A\,k_m\,(T_1 - T_2)}{x} \qquad (3)$$

where q = amount of heat transferred, A = contact surface area, x = thickness of ice, k = thermal conductivity of ice.

In equation 3 we suppose that the oil is at a constant temperature, higher than that of ice. The two factors influencing the heat transfer process are the surface of exchange (in terms of unit volume of oil) and the temperature differential. To quantify further would require more complex equations, but one can see that as long as the transfer of energy into the oil equals the loss of energy to the ice, very little heating and evaporating of the oil can take place. At temperatures close to the melting point, the underlying ice has a better chance of melting than the oil above has of evaporating.

3.1.2 Behaviour of Oil in the Tidal-Crack System

The effect of the tides on the movement of oil on the sea is greatly reduced by the presence of ice which acts as a barrier to the oil. The tides in Deception Bay are particularly high and at certain times had a powerful effect on oil movement. Nevertheless, it is easy to imagine that these effects would have been greatly multiplied had not the ice been present.

Normally an oil slick will tend to follow the tidal currents. However, in ice infested waters two contravening factors are evident. First, ice booms are capable of partially or totally curtailing the movement of the oil. Second, wind counter to the tidal current not only can slow down the movement of the oil but can effectively entrain it in its own direction.

Since the water in the tidal-crack system is much less turbulent than on the open sea, its ability to emulsify and dissolve the oil is limited but not completely eliminated. There is evidence that oil has been dissolved and carried substantial distances from its origin. Some emulsification does occur through friction of the oil against ice caused by the tidal motion and by the wind on top of the sea ice. This was evidenced by the discovery of a few oil globules which had escaped to the open sea.

The amount of oil which dissolved in the water is extremely difficult to estimate. Most water samples analyzed proved to contain minute amounts of oil. The diffusion of dissolved or emulsified oil into the ocean could be represented by an idealized mathematical model for Fickian diffusion:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial y}\left(k\frac{\partial c}{\partial y}\right) = k\frac{\partial^2 c}{\partial y^2} \qquad (4)$$

c = oil concentration, y = a space coordinate, k = eddy diffusivity coefficient, t = time.

For a two-dimensional diffusion, considering a unit area in the dispersion column and writing a material balance we will have:

$$\frac{\partial c}{\partial t} + V_x\frac{\partial c}{\partial x} + V_y\frac{\partial c}{\partial y} = k\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right) - ac \qquad (5)$$

V_x and V_y are the velocities in the two directions (x and y) and a is a first order decay constant. Assuming steady state and unidirectional transport velocity in the x direction, we can make the following simplifying assumptions:

$$\frac{\partial c}{\partial t} = 0; \frac{\partial^2 c}{\partial x^2} \simeq 0; Vy = 0 \qquad (6)$$

The previous equation becomes:

$$V_x\frac{\partial c}{\partial x} + ac = k\frac{\partial^2 c}{\partial y^2} \qquad (7)$$

Many solutions to this equation have been proposed assuming different conditions. By plotting the results of many of the above solutions on a Log-Log paper, a straight line with an approximate equation is obtained.

$$k \approx 0.001\ell^{4/3} \qquad (8)$$

Here k is the eddy diffusivity coefficient in $ft^2/sec.$, while ℓ is the length of travel in feet. The length is between 2,000 and 5,000 feet and k is limited by 14 and 2,600.

These values are rather low in the case of ice-covered seas since the ice acts as a shock absorber reducing k and it also isolates the oil from the open sea.

3.1.3 Behaviour of Oil on Land

On-site observation showed that the soil around the tank farm retained an appreciable amount of oil but that this amount decreased with time. Let us briefly examine the factors influencing this displacement of the oil.

(1) *Draining.* The efficiency of draining depends on the slope of the land, porosity of the soil and underlying snow, and the amount of oil present. The slope from the tank farm down to the shore-fast ice was sufficient to allow oil to drain naturally through the soil, sand and snow.

(2) *Washing.* The meltwater from the snow deposited by the avalanche at the tank farm (Figure 15) washed oil down to the bay. Washing efficiency depends on soil and snow porosity, amount of oil present, and the amount of water percolating through the soil and snow.

(3) *Leaching.* This is the least efficient influence. It is controlled by the length of contact between oil and water as it passes through the soil. The slope in this instance has the negative effect of reducing this contact time.

(4) *Evaporation.* Some evaporation certainly occurred but it was limited by the protective cover of the soil and the gravity of the oil contravening the capillary action which would bring the oil to the surface to allow evaporation.

3.2 BIOLOGICAL OBSERVATIONS

(R. Bergeron)

Data obtained in this study were used to evaluate the immediate and short-term effect of oil pollution on marine and land environments.

3.2.1 Marine Environment

Ice, water and plankton samples were taken in the field and then microscopically examined in the laboratory immediately upon their receipt and re-examined one week later. Ice cores were obtained with a SIPRE auger and the stratum of each sample marked S (surface), M (medium), B (bottom), or C (composite). Water samples were taken through holes bored in the ice cover and their depths noted in the same way. (See Appendix 7, Map No. 11.) A plankton sample was obtained with the use of a plankton net set at a depth of 40 feet in the area between holes #2 and #3. The net was left for approximately 17 hours.

Microscopic observations revealed the amount of oil (ppm) as well as the type, abundance and condition of plankton in each sample, both immediately and after one week. Water and ice samples were grouped in three classes according to the amount of oil they contained. The abundance of the organic material was estimated by the thickness of deposit at the bottom of the collecting jar.

From Table 2 one can see that the ice and water samples on the whole contained very little organic material. However, it is more abundant in the surface water samples than it is in the bottom water samples. If we assume that organic material distribution was about the same over all of the sampled area, it would appear that oil had a slight decreasing effect on the abundance of organic material.

Table 2. Relationship of Abundance of Organic Material to Amount of Oil in Ice and Water Samples

Amount Organic Material	Number of Samples	Distribution of Samples by Oil Content*		
		First Class	Second Class	Third Class
Much	2	1	1	0
Sufficient	6	4	1	1
Little	14	7	6	1
Very little	44	14	19	11

*Oil ppm: First class 1; Second class 1 to 4; Third class 5.

There is very little difference in diversity between the number of plankton genera found in samples of first and second class oil content (see Table 3). However, it would appear that only a few genera could resist the high content of oil in the samples of the third class. Although Fragillaria, Melosira and Nitzschia were the only genera found in samples of 5 ppm, one cannot conclude that these algae are especially associated with oil-polluted waters. However, it is known that Melosira can tolerate a low dissolved oxygen concentration.

Table 3. Relationship of Diversity of Plankton's Genera and Presence of Oil

Genera in 1st class Samples (1 ppm)	Genera in 2nd class Samples (1-4 ppm)	Genera in 3rd class Samples (5 ppm)
*Fragillaria Gyrosigma Leptocylindricus *Melosira *Nitzschia Navicula Pleurosigma Rhyzosolenia Thalassiothrix	Amphiprora Biddulphia Coscinodiscus *Fragillaria Gyrosigma *Melosira Navicula *Nitzschia Pleurosigma Prorocentrum (Dimoflagelate) Unidentified diatom Unidentified algae	Fragillaria *Melosira *Nitzschia

*Genera most frequently found.

The relationship between the amount of oil and the abundance of algae in tested samples is shown in the following two tables (Tables 4 and 5). Table 6 indicates its condition in relation to the oil concentration.

Table 4. Abundance of Phytoplankton* In Ice and Water Samples

Quantity of Phytoplankton	Number of Times Found in Samples
Many	5
Common	7
Few	24
Rare	55
Nothing observed	20

*Estimated according to number of organisms seen in the microscopic field (20/4 magnification).

Table 5. Occurrence of Phytoplankton in Relation to Oil Concentration in Ice and Water Samples

Quantity of Phytoplankton	Number of Times Found in Samples Belonging to:		
	1st	2nd	3rd class
Many	1	4	0
Common	6	1	0
Few	8	16	0
Rare	23	24	8
Nothing observed	9	4	7

Table 6. Condition of Phytoplankton in Relation to Oil Concentration

Oil Content	Occurrence of Algae in "Good" Condition*	Occurrence of Algae in "Poor" Condition**	Ratio Good/Poor
First class	19	10	1.9
Second class	23	13	1.8
Third class	1	6	0.17

*"Good" – no special alterations observed in the cells or in the chains of the cells.

**"Poor" – alterations observed on the algae consisting of broken chains, broken cells or lack of normal structures in the cells.

Phytoplankton are most abundant in samples with 1-4 oil ppm and are very scarce in samples with more than 5 ppm oil.

Zooplankton were found in only three samples, each of low oil concentration (holes #1, 2 and 51).

An analysis of the plankton obtained by a plankton net at a depth of 40 feet revealed many diatoms of the genus Coscinodiscus and few of the genera Fragillaria, Melosira and Nitzschia. All zooplankton found in this sample were in excellent condition. No conclusions can be drawn on the effect of oil on these plankton since there was probably no oil present in the water at that depth.

3.2.2 Land Environment

Soil and plant samples were taken for evaluation in the laboratory and a field survey was made for any animals or birds affected by the oil spill.

Four 15′ X 15′ quadrats were traced in the spill area and soil and plant samples were taken in each quadrat. Plant samples were also taken from an area unaffected by the spill for the purpose of comparison. Plants were then identified and the soil examined microscopically. These data are presented in Appendix 3.

The effect of the oil spill on plant life could only be determined by a long-term ecological study. The plants observed in the present study seemed unaffected by oil. Many were torn and uprooted by the avalanche. From the time of collection to laboratory inspection 10 days later some (mainly the shrubs Salix and Vaccinium) had produced new sprouts.

As can be seen in Table 3.2 in Appendix 3, no living organisms or remains of dead organisms were found in the microscopic examination of soil samples. However, it should be noted that no bacterial cultures were made.

During the field survey one dead lemming was found. It was completely covered by oil which seemed to have caused its death. It can be assumed that other lemmings were affected by the spill but in such a restricted area this could have little ecological significance.

Eight dead birds were also found: a tern, four plovers and three sandpipers. Four were found on June 12, three on June 16 and one on June 18. Their bodies were intact but completely covered with oil. Robert W. Holcomb (*Science,* Vol. 166) describes the effect of oil on birds as follows:

> "The most visible victims of ocean oil are sea birds. . . It is believed that most deaths are the result of disease such as pneumonia, which attack the birds after they are weakened by the physical effects of the oil (feather matting, loss of buoyancy, flying difficulty and others)."

It can be assumed that more birds were killed after the field survey was carried out. Geese and ducks are not normally observed on Deception Bay. However, according to Wybe Hoek, the bay could be frequented by murres, in which case further losses could occur.

There was no indication that fish were affected by the oil spill. However, the sea and shore-fast ice did restrict our observations considerably. The presence of oil in water could, for instance, impede fish respiration, reduce plankton's abundance and thus reduce the amount of oxygen and food available, limit the activity of fish and promote disease. Therefore, the impending arrival of Arctic char (Salvenius alpinus) was of considerable concern. It seems, however, that the small area contaminated by oil could easily be bypassed by the char. A few specimens of sea weed (Fucus) were found in oil-filled pools. Many of these were literally burned by the oil.

In conclusion, considering the small size of the area contaminated by oil, this spill does not seem to have disturbed to any great extent the biotic marine and land environment.

3.3 CHEMICAL OBSERVATIONS

The properties of gasoline have not been considered since no samples of this material were recovered. The diesel oil collected from a storage tank had a boiling range between 150°C and 280°C. The oil retrieved from pools in the bay had a boiling range of 165°C to 284°C. By comparing these distillation ranges one could conclude that about 3-4% of the lighter portion had evaporated or had been dissolved from the spilled oil. The higher end point might be accounted for by the presence of some salts in the oil retrieved from the sea. There is also a slight increase in the specific gravity of the oil collected in the field.

Seventy samples of water and ice were analyzed for the following properties: pH, colour, turbidity, dissolved oil, or oil in the form of a film or layer. The results of these tests are presented in Appendix 1 and Map 11. On inspection of the map one sees that the oil concentration decreases with increasing distance from the spill site and tidal network. Of some interest are the water and ice samples from location 301 and 302 where the oil had been pumped onto the ice surface. They were saturated with dissolved oil and also contained free oil. The soil samples lost some of their oil from June 12 ($3^1/_2$%) to June 16 ($1^1/_2$%). Based on these figures and the observations made earlier it is felt that immediately after the slide, the concentration of oil in the soil was 4-5% by weight.

It should also be mentioned that some contamination could well have occurred in the sampling procedure due to the presence of oil on the water and ice surface and the possible contamination of the drilling auger.

3.4 DAILY OBSERVATIONS OF OIL DISTRIBUTION

June 12, 1970 (see map No. 4, Appendix 7). Most of the area below the tank farm was soaked with oil. Some open pools were observed on the debris of the tank farm platform. A few ponds of almost clean oil were observed along the tidal crack. In general, oil could be seen at distances not exceeding 700-800 feet southeast of the tank farm and not more than 200-300 feet in the opposite direction.

The ice surface seemed free of oil. The winds were mainly southeasterly, confining most of the oil to the southeastern shore.

June 13, 1970 (see Map No. 5). The situation on the 13th was drastically altered. The temperature was much milder, contributing to surface melting of the ice. The winds were mainly northeasterly and considerably stronger than the previous day. The oil pools were spread along the tidal cracks in both southeasterly and northwesterly directions.

During tidal inflow most of the pools tended to move in a southeasterly direction, while during tidal outflow they moved in a northwesterly direction. The wind sweeping across the bay carried oil droplets over the ice surface spreading them at considerable distances, even as far as the other side of the bay. Small spherical potholes (less than one inch diameter) were created and filled with oil and wide irregular water ponds were covered with a thin film of oil.

The wind not only carried oil droplets but also some loose ice crystals which fell on the oil and in certain cases rapidly sank into the oil. In other cases (especially when they fell into cracks or small potholes) the ice fragments accumulated and formed a protective cover (see Map No. 5).

June 14, 1970. The situation closely resembled that of the previous day. The wind remained in a northeasterly direction and increased its velocity by the end of the day to about 50 miles per hour. The spreading process continued. The tidal movement of the oil became more efficient. The pools of oil close to the tidal cracks spread and could be classified as follows:

(a) pools of clean oil of varying depths (3-20 inches). Some of these pools extended 300 feet in length and 10-35 feet in width;

(b) pools of oil of 1-3 inches in depth, either on meltwater pools or in direct contact with the sea;

(c) pools of oil with a depth between 1/4 and 1 inch on meltwater pools or in direct contact with the sea;

(d) pools of water covered with a thin film of oil.

It was noticed that several new cracks appeared in the tidal crack system. Oil was found in many of these new cracks.

June 15, 1970 (see Map No. 6). The temperature dropped to the freezing point, the wind velocity diminished, and the wind direction changed to east-southeast.

During the night most of the meltwater drained through the sea ice leaving a hard porous crust. Some of the oil pooled on the sea ice was absorbed in the ice surface. New cracks appeared in the tidal-crack system while some of the old cracks disappeared. It now became apparent that most of the oil was stored in and under the shore-fast ice, i.e., the intertidal region. Tunnels three to four feet high were discovered under the shore-fast ice. These contained large pools of oil and gasoline.

June 16, 1970 (see Maps No. 7 and No. 9). The milder sunny weather started melting some of the ice surface causing meltwater pools to form, some of which were covered with oil. Oil was found in small open ponds, in holes partially or completely covered with loose ice, and in holes covered with sheets of ice of various thicknesses. Map No. 7 depicts the situation in front of the tank farm.

During this period limited pumping of oil and water was started. The mixture was spread over the ice. Map No. 9 indicates the situation at the end of the day. By this time open pools were located (with few exceptions) on the southeast side of the spill close to the main tidal crack. The pumping operation produced a very irregular slick which went 500-600 feet across the bay ice. It is interesting to note that the slick was formed in a direction opposite to the direction of the wind. During the night of the 16th the temperature dropped below freezing.

June 17, 1970 (see Maps No. 7 and No. 10). The temperature went from freezing during the night up to 52°C by 1800 hours. Early in the morning the surface of the bay ice resembled that of June 13, except for the presence of a few thin oil slicks on the sea ice in front of the tank farm. As the day progressed more slicks of oil appeared. They were still much fewer than those observed on June 16.

The pumping operation continued. The oil slick produced by the two pumps was now more than a thousand feet across (Map No. 10).

A closer examination of this slick revealed that at times one of the pumps was emulsifying the oil. This emulsion was absorbed in the porous ice surface.

June 18, 1970 (see Maps No. 8 and No. 10). Some new slicks appeared due to melting. The pumping operation (magnified by the changing wind direction) continued to spread the slick. No major changes from the previous day's condition was observed.

CHAPTER 4

Oil Budget

This inventory of spilled oil was made on June 15, nine days after the spill occurred.

(i) Oil retrieved by oil skimmer, pumped into drums, and collected in a mobile tanker.
5,000 gallons

(ii) Oil visible in open pools along tidal crack network. Length, width and depth of pools were measured. The depth of the oil could easily be measured by using a meter tape and immersed to the oil-water interface. Another method was to float small ice pieces which would accumulate at the water-oil interface. The oil thickness could then easily be measured using a tape.
50,000 gallons

(iii) Oil in soil and snow. The total surface area affected was about 140,000 square feet with an average soil depth of 0.25 ft. Taking an average density of 120 lbs/ft^3, the total weight of the soil is 4.2×10^6 lbs. The weight of fill on which the tank farm sat was 2.4×10^7 lbs. The average snow depth under the soil was approximately two feet; a total weight of 8.4×10^6 lbs. The soil contained 2% of oil by weight; or approximately
45,000 gallons

The snow contained 5% of oil by weight; approximately
34,000 gallons

(iv) Oil observed in shore-fast ice. The area of shore-fast ice that contained oil was approximately 3,000 feet by 100 feet. To establish the amount of oil absorbed in the porous structure of the snow ice, several five-inch diameter holes were drilled approximately three feet deep. The cores were retrieved and the holes were allowed to fill with water and oil. On the average a two-inch thick oil layer was found on top of the water. Assuming the drainage area of this hole to be one square foot in area and on the average three feet deep, the total amount of oil trapped in the pores would be
42,000 gallons

(v) Oil in water. From the results obtained in Chapter 3, the average quantity of oil in water was taken as 1 ppm covering an area of 6,000 X 14,000 feet with an average depth of 60 feet. The actual area under study was 2,000 X 6,000 feet. The increase was taken to compensate for the freshwater intake above the spill area in the upper part of the bay which increased the amount of oil removed by tidal flushing.
30,000 gallons

Although a reasonable value for the concentration of oil in the water can be obtained, the effect of tidal flushing is difficult to assess. According to Kenney *et al.*[9] in a study on the effect of tidal flushing in Cook Inlet, Alaska, the amount of oil removed would amount to 3%, which is negligible. The same authors also observed that biodegredation was much more effective than tidal flushing. We were not able to undertake any such study but this is certainly an area which should be pursued in the light of the Alaskan study.

(vi) Loss of oil components by evaporation. From the gas chromatographic analysis (Chapter 3) the amount lost is estimated at about 4% of the Arctic diesel and possibly all of the gasoline.

Arctic Diesel:	15,000 gallons
Gasoline:	58,000 gallons

(vii) Oil under shore-fast ice. At low tide, holes were observed in the shore-fast ice large enough to allow a man to enter the labyrinth of chambers below. Upon entering the subglacial chambers two items of importance were observed:

1) fuel odors were strong enough to make breathing difficult;

Table 7. Oil Mass Budget

i) Oil reclaimed	5,000 gallons
ii) Oil in open pools	50,000 gallons
iii) Oil in soil and snow	79,000 gallons
iv) Oil absorbed in shore-fast ice	42,000 gallons
v) Oil loss by evaporation (gasoline)	58,000 gallons
Oil loss by evaporation (Arctic diesel)	15,000 gallons
vi) Oil in water	30,000 gallons
vii) Oil under shore-fast ice	75,000 gallons
Total oil accounted for	354,000 gallons
Total oil spill	427,000 gallons
Oil unaccounted for	73,000 gallons

2) the water pools on the beach affected by the tide were covered by an oil layer averaging one inch in thickness.
   The upper surface of the shore ice was extremely uneven. Assuming the total 300,000 square foot area of shore-fast ice to be similar to the area observed, 50% of the shore-fast ice would have a one inch layer of oil beneath it; making a total of
   75,000 gallons

Table 7 summarizes the oil mass budget. From a total spill of 427,000 gallons, approximately 354,000 gallons can be accounted for. The various categories have been listed in term of confidence in the calculated and estimated amounts. The 73,000 gallons which have not been accounted for could easily be assumed to be included in (vi) and (vii). The oil which was swept across the sea ice by moderately high winds was not accounted for since the quantity involved was estimated to be less than the smallest quantity in Table 7.

Prevention, Containment and Cleaning

As we have seen in the previous chapters the problems associated with an oil spill in ice-infested waters are unique. The points to be considered in a spill are: prevention, detection, containment, clean-up and disposal. Generally one can say, based on the experience gained in this spill, prevention, detection and disposal of reclaimed oil presents a difficult problem in the Arctic whereas containment and clean-up are very much facilitated by the presence of ice.

5.1 PREVENTION

In the present case this oil spill could have been prevented if the site had been more carefully chosen. However, it should be recognized that slush avalanches are little known and have not caused any material damage of any consequence. From the viewpoint of classical avalanche theory the site was certainly safe. Future site selection should be made on a more conservative basis.

5.2 DETECTION

Early detection of any accident is a very important factor in the whole program of oil pollution prevention in the Arctic. Although the cold climate is an advantage in slowing down the physical processes of oil deterioration, the remoteness and difficult climatic conditions are a disadvantage when trying to reach the site of an oil spill to take advantage of a favourable disposal method such as burning. Places such as the tank farm at Deception Bay should have an automatic alarm system connected to the main camp which would also include a level indicator for the amount of fuel left in the tanks.

5.3 CONTAINMENT

Containment presents no major problem due to the presence of ice and winds. At certain times of the year the ice can be used as a working platform. Where the ice is broken up or in the area along the tidal crack, as in the present case, artificial barriers could be implaced to prevent further spreading. Chemical barriers and air curtains seem to have an advantage over mechanical barriers because of the dynamic ice situation.

5.4 CLEAN-UP AND DISPOSAL

Procedures of clean-up used in harbors or open waters are of very limited or no use in ice-infested waters. New methods should be developed for Arctic conditions. In the present case three methods were tried with various degrees of success: reclaiming the oil by pumping, spreading the oil to promote evaporation, and selective burning on the site.

(i) *Reclaiming Oil.* In the early stages of the spill an oil skimmer was used with a pumping capacity of 100 gal. min^{-1}. The principle is very sound since one can move from pool to pool. However, the disposal of the reclaimed oil was a more difficult problem to solve. The oil had to be pumped into 45-gallon drums which in turn had to be carried over difficult terrain to the nearest road to be emptied into a tank car. No other storage facilities were available.

This presented an immediate problem of disposal. Some solutions considered were: spraying the local road system, burning the oil in a gravel pit, using the oil for burning the garbage, and reclaiming the oil for heating fuel for the camp. The first two solutions could have easily been achieved if the reclaiming method could have been improved, e.g., pumping the reclaimed oil directly from the pools to the tank car on the road. However, these ideas were abandoned due to the difficulties encountered.

(ii) *Evaporation of the Oil.* Arctic diesel (with a pour point of -40°C) evaporates rather quickly if the oil is spread over a large surface. Calculations based on laboratory tests[7] indicate that oil would evaporate at 0°C and a wind velocity of 10 knots from a free surface at a rate of approximately 50,000 gal. mile^{-2} day^{-1}. Unfortunately the oil was quickly absorbed by the porus surface ice, preventing effective evaporation. Since the surface area of pools was rather small the amount of oil evaporated was insignificant.

(iii) *Burning.* Burning has been tried at one time or another in most major oil spills with varying degrees of success, most of the time with negative results. To assess the possibility of burning, two 10

X 10-foot test pools five inches deep were cut into the surface of the sea ice.

Test 1. Approximately 35 gallons of reclaimed oil was poured into the pool. The fuel was ignited by burning diesel-soaked rag wicks. Under calm conditions, the burning was very vigorous and produced substantial smoke. The duration of the burn was approximately three to four minutes. The residue amounted to less than 1% of the initial amount burned.

Test 2. In this case about 45 gallons were poured into the pool and allowed to remain for one hour. The wind was at 30 knots at the time of the burn. A burning wick was placed downwind. Due to the force of the wind the fire was not able to spread upwind. The upwind edge of the pool was then ignited and the flames spread quickly across the entire surface. The total burn lasted about 25 minutes. The oil on the pool surface burned quickly but some of the edges of the pool continued burning. It became apparent that the porous edge of the surface ice acted as an efficient wick. This was also reflected in the small amount of residue left, amounting to less than in the first test. Thereafter, most of the oil was successfully burned[8]. On-site selective burning was possible because of the presence of ice acting as an effective barrier and the wind which collected the oil in a thick enough layer to be ignited.

Post-Operation Activities

On June 26, after the oil had been burned, an overflight of the spill area was carried out by the Department of Transport. Infrared imagery was taken using the following wavelengths: 3-5 microns, 8-14 microns and ultraviolet. No conclusion as to the presence of oil could be drawn from the pictures in the infrared range. Unfortunately the camera failed to function in the ultraviolet range, which was the range most likely to yield conclusive results. Ground observations made at the same time as the flight revealed pockets of oil in the shore-fast ice and small amounts in the tidal crack system.

One month later, on July 25, the site was revisited by a team from the Fisheries Research Board in Montreal. Grainger and Wacasey (1970) reached the following conclusions in their report of the visit:

"(1) About seven weeks after the spill occurred, evidence of oil was found in the intertidal region along nearly 900 metres of beach, and in the substrate below low tide as far as 150 metres off shore.

(2) Approximately 90 per cent of the biota in the subtidal slide area (15,000m^2) was destroyed by the physical effects of the slide. Barring long-term effects of the oil, this area could recover within a short period of time.

(3) As much as 50 per cent of certain bivalves could have been killed by oil in inshore subtidal areas. This would account for 17 per cent of the total biota.

(4) At most 5 per cent of the polychaete fauna (mostly mud ingesters) could have died from the effects of oil.

(5) Fucus and Mytilus were the intertidal species most affected by the spill and its aftermath, and both appear to have been much more severely harmed by heat (evidently from the burning of oil from the sea ice surface in June) than by oil.

(6) There were no observed effects of oil upon the plankton.

(7) No assessment can be made on the long-term effects of the oil. The area should be sampled again in the summer of 1971.

(8) Overall damage was slight and localized."

CHAPTER 7

Conclusions and Recommendations

From our point of view the most important conclusion to be drawn from this study is the existence of important fundamental differences in the general behaviour, spreading and dispersion mechanisms of oil in ice-infested waters as compared to oil in ice-free water. In the present case the ice was static except for its rise and fall due to the tides. This was a great advantage in solving the major problem of containment. Prevailing winds were also advantageous since they drove the oil towards the natural ice booms where it could easily be pumped and then burned.

A second very important conclusion is the need for development of equipment and standard procedures for the prevention, monitoring, detection, containment, clean-up and study of oil spills in the Arctic. The procedures currently used to deal with pollution in open waters could easily be modified and adapted for use in ice-infested regions.

The third conclusion concerns the site selection for any kind of structure in the Arctic. More care should be taken in the selection of sites since many phenomena occurring in remote regions are not of general knowledge. Engineers and scientists should be consulted in the site selection and planning stage.

A fourth conclusion is that some basic and applied research must be undertaken. The results of this research should provide a better understanding of and ability to control the behaviour of oil in sub-zero climates. This would in turn permit a faster and more effective prevention of any damage in the Arctic.

Finally, the use of multidisciplinary research team has worked out very well in synthesizing the problem at hand and has helped enormously in clarifying which problems should be studied in further detail and in what priority.

References

1. G.S.C. Map 1254A.
2. Snow Avalanches. 1961. A Handbook for Forecasting and Control Measures. Forest Service, U.S. Department of Agriculture, *Agriculture Handbook Nr. 194.*
3. Nobles, L.H. 1965. Slush Avalanches in Northern Greenland and the Classification of Rapid Mass Movements. Int. Symposium on Scientific Aspects of Snow and Ice Avalanches, Davos, Switzerland. *Publication Nr. 69*, Int. Assoc. Scientific Hydrol., pp. 267-272.
4. Washburn, A.L. and R.P. Goldthwait. 1958. Slush Flows (Alaska). *Bull. Geol. Soc. Amer.*, Vol. 69: 1657-1658.
5. Rapp, A. 1960. Recent Development of Mountain Slopes in Karkevagge and Surroundings, Northern Scandinavia. *Geogr. Ann.*, Vol. XLII: 71-200.
6. Müller, F. 1962. Zonation in the Accumulation Area of the Glaciers of Axel Heiberg Island, N.W.T. Canada. *J. Glaciology*, Vol. 4: pp. 302-310.
7. Grainger, E.H. and J.W. Wacasey. 1970. Report on a visit to Deception Bay to examine the biological effects of the oil spill of early June 1970. Fisheries Research Board of Canada, Ste. Anne de Bellevue, Que.
8. Ramseier, R.O. 1971. Oil Pollution in Ice-infested Waters. Int. Symposium on Identification and Measurements of Environmental Pollutants, Ottawa.
9. Kinney, P.J. *et al.* 1969. Kinetics of Dissipation and Biodegradation of Crude Oil in Alaska's Cook Inlet. Proceedings of Joint Conference on Prevention and Control of Oil Spills, New York, December 15-17, 1969, pp. 335-340.
10. J.A. Fay. 1969. "The Spread of Oil on a Calm Sea" in *Oil on the Sea*, D.P. Hoult, ed., Plenum Press, New York.

Appendices

Laboratory Data of Water and Ice Samples

The hole numbers are indicated on Map No. 11. The abbreviations used in Table Ia are as follows:

W – water
I – ice
S – surface
M – medium
B – bottom
C – composite
} Stratum

The colour is expressed by figures equivalent to the colouration of a number of ppm of potassium chromate ($KCrO_4$) in distilled water. The turbidity is expressed in terms of the equivalent turbidity produced by a solution of silver nitrate (in ppm) precipitated by addition of an excess of chloride ions. The dispersed oil is expressed in ppm. The odour is expressed by the use of 1, 2, 3, 4 and 5, meaning odour ranging from very, very slight to very, very strong. The free oil in the form of films and layers is expressed in weight percentages.

Abundance of Organic Material

VL – very little: traces of deposit (around $^1/_2$ mm or less)
L – little: deposit from $^1/_2$ to 1 mm
S – sufficient: deposit from 1 mm to 2 mm
M – much: deposit greater than 2 mm

Unidentified Material

This unidentified material is usually a mixture of:

(1) fibrous material,
(2) long segmented or unsegmented non-chlorophyllian filaments (probably mold),
(3) residue (chlorophyllian or not) of destroyed cells,
(4) vegetal spores.

Abundance of Each Type of Organism

(1) rare: from 1 to 5 organisms in the field – R
(2) few: from 6 to 10 – F
(3) common: from 11 to 20 – C
(4) many: more than 20 – M

Plankton Condition

I. – Zooplankton has been classified simply as Dead (D) or Alive (A).

II. – Phytoplankton has been classified as Good (G) or Poor (P).

Table 1.1 Laboratory Data of Water and Ice Samples

Hale	Type	Stratum	pH	Colour	Turbidity	Dissolved Oil	Odour	Free Oil	Abundance	Unidentified Material	Organic Material							
											Composition							
											Zooplankton				Phytoplankton			
											Type	Abundance	Condition as seen from:		Type	Abundance	Condition as seen from:	
													Field obs.	Lab. obs.			Field obs.	Lab. obs.
		S	8.0	0.10	0	–	–	–	L	+ (Fibres)	Nematode	R	A	–	Fragillaria sp.	C	G	G
															Melosira sp.	F	G	G
1	W														Navicula sp.	R	G	G
		B	8.0	0.50	1	2	1	–	VL	+	–				Nitzchia sp.	R	G	G
															Coscinodiscus	R	G	G
		S	6.3	1	2	–	1	–	VL	+ (Fibres)	Nematode	R	A		Fragillaria sp.	C	G	G
2	W														Melosira sp.	R	G	G
															Girosigma sp.	R		
		B	7.4	0.50	0	1	1	–	VL		†							
		S	6.7	75	50	–	4	–	VL	+ (Cells, fibres)					Melosira sp.	R	P	P
3	W														Nitzschia sp.	R	G	G
		B	4.9	200	1	2	5	–	VL		†							
		S	4.3	1	5	4	2	–	M	+ (Fibres)	Nematode	R		observed on a formal sample	Melosira sp.	M	G	G
															Fragillaria sp.	F	G	G
															Nitzschia frigida	F	G	G
															Nitzschia sp.	F		
4	W														unidentified diatoms	R		
															Gyrosigma sp.	R		
															Navicula sp.	R		
															Amphiprora hyperborea	R	G	
		B	6.0	2	10	T	2	–	VL	+ (Cells)					Melosira sp.	R	P	P
		S	6.7	0.75	4	T	1	–	S	+	Amphipods	R	D	D	Nitzschia frigida	F	P	P
															Melosira sp.	R	P	P
															Gyrosigma sp.	R	G	G
5	W	M	7.2	1	1	3	3	–	VL	+					Nitzschia frigida	M	P	P
															Melosira sp.	M	G	G
		B	8.0	0.75	1	2	1	–	VL	+					Melosira sp.	F	P	P
															Nitzschia sp.	F	G	G

+indicates presence of unidentified material *sp. denotes species †nothing observed.

Table 1.1 (Cont'd) Laboratory Data of Water and Ice Samples

Hale	Type	Stratum	pH	Colour	Turbidity	Dissolved Oil	Odour	Free Oil	Abundance	Unidentified Material	Organic Material							
											Composition							
											Zooplankton				Phytoplankton			
											Type	Abundance	Condition as seen from:		Type	Abundance	Condition as seen from:	
													Field obs.	Lab. obs.			Field obs.	Lab. obs.
		S	7.2	0.60	4	2	2	–	S	+ (Fibres & cells)	Rotifer (Euchlanis)	R	D	D	Fragillaria sp.	F	G	G
															Nitzschia frigida	F	G	G
															Pleurosigma	R		
															Navicula sp.	R		
															Unidentified diatoms II	R	G	G
															Melosira sp.	R	G	G
6	W	M	7.6	1	1	2	1	–	VL	+					Melosira sp.	F	P	P
		B	7.8	0.50	1	3	2	–	VL	+					Nitzschia frigida	F	G	G
		S	7.5	0.25	2	1	–	–	L	+					Unidentified algae III	M		
6	I	M	7.3	0.50	2	1	–	–	L	+					Nitzschia frigida	F	G	G
		B	7.6	0.50	1	1	–	–	VL		†							
		S	7.0	0.75	3	1	–	–	L	+ (Fibres)					Biddulphia sp.	C	G	G
															Nitzschia frigida	F	G	G
															Melosira sp.	R	P	P
															Unidentified algae III	R	G	G
7	W	B	7.2	0.75	3	2	1	–	VL	+ Rare					Melosira sp.	R	P	P
7	I	C	7.1	0.2	2	1	1	–	VL	+ (Fibres)					Fragillaria sp.	F	P	P
8	W	S	6.5	0.75	3	1	–	–	VL	+ (Fibres & cells)					Fragillaria sp.	R	P	P
															Nitzschia sp.	R	P	P
		B	7.3	0.50	2	3	2	–	VL	+ (Fibres)	†							
8	I	C	7.2	0.50	10	1	–	–	VL		†							
		S	6.9	0.10	2	2	3	–	L	+ (Fibres)					Nitzschia frigida	F	G	G
															Melosira sp.	R	P	P
															Nitzschia sp.	R	G	G
															Fragillaria sp.	R	P	P
9	W	B	7.5	0.25	2	2	2	–	VL	+ (Fibres)					Nitzschia sp.	R	G	G

+indicates presence of unidentified material

*sp. denotes species

†nothing observed.

Table 1.1 (Cont'd) Laboratory Data of Water and Ice Samples

Hale	Type	Stratum	pH	Colour	Turbidity	Dissolved Oil	Odour	Free Oil	Abundance	Unidentified Material	Organic Material							
											Composition							
											Zooplankton				redo: Phytoplankton			
											Type	Abundance	Condition as seen from:		Type	Abundance	Condition as seen from:	
													Field obs.	Lab obs.			Field obs.	Lab obs.
9	I	C	7.2	0.10	2	2	2	–	VL	+					Nitzschia sp. Fragillaria sp.	R R	G P	G P
10	W	S	6.7	0.75	8	1	1	–	L	+ (Fibres)					Melosira sp. Nitzschia frigida Fragillaria sp.	F F R	G G P	G G P
		B	7.6	0.50	2	–	–	–	VL	+	†							
10	I	C	–	0.75	2	3	2	–	VL	+					Dinoflagellate (Prorocentrum) Fragillaria sp.	F R	L P	L P
51	W	S	6.7	1	2	T	–	–	L	+ (Remains of cells)					Nitzschia frigida Thalassiothrix nitzschioïdes	F F	G G	G G
		M	7.3	0.75	2	2	2	–	VL	+ (Fibres)	†							
		B	7.4	0.25	1	T	–	–	VL	+	†							
51	I	S	6.9	0.25	2	2	2	–	VL	+					Navicula sp.	R		
		M	6.8	0.10	1	T	–	–	VL	+								
		B	7.4	0.10	1	T	1	–	S	+ (Fibres)	Ciliate (Vorticella)	R		A	Nitzschia sp. Navicula sp. Pleurosigma sp. Fragillaria sp. Rhizosolenia sp.	C F R R R	G G G	G G G
52	W	S	6.3	0.25	1	T	1	–	L	+ (Fibres)					Thalassiothrix ?	R	G	G
		B	7.1	0.10	1	T	–	–	VL	+ (Fibres)	†							

+indicates presence of unidentified material *sp. denotes species †nothing observed.

Table 1.1 (Cont'd) Laboratory Data of Water and Ice Samples

Hale	Type	Stratum	pH	Colour	Turbidity	Dissolved Oil	Odour	Free Oil	Abundance	Unidentified Material	Organic Material							
											Composition							
											Zooplankton				Phytoplankton			
											Type	Abundance	Condition as seen from:		Type	Abundance	Condition as seen from:	
													Field obs.	Lab. obs.			Field obs.	Lab. obs.
52	I	C	6.9	0.05	2	T	1	–	L	+ (Fibres)					Leptocylindrus ?	C	G	G
															Thalassiothrix sp.	R		
53	W	S	6.5	0.75	1	T	1	–	S	+ (Fibres)					Thalassiothrix sp.	C	G	G
															Melosira sp.	C	G	G
		B	7.5	0.50	3	1	1	–	VL	+	†							
53	I	C	7.2	0.10	1	T	1	–	M	+					Thalassiothrix sp.	M	G	G
															Fragillaria sp.	F	P	P
54	W	S	7.3	0.50	2	1	1	–	L	+ (Fibres & cells)					Nitzschia sp.	R	P	P
		M	7.9	0.25	1	1	1	–	VL	+ (Fibres)					Melosira sp.	R	P	P
		B	8.2	0.25	0	T	–	–	VL	+					Melosira sp.	R	P	P
54	I	S	7.6	0.05	3	T	1	–	VL	+ (Fibres)	†							
		M	7.5	0	2	T	–	–	VL	+ (Fibres)	†							
		B	7.4	0.05	4	T	–	–	L	+					Fragillaria sp.	F	P	P
															Nitzschia sp.	R		
55	W	S	7.3	0.25	1	T	–	–	S	+					Nitzschia sp.	R	G	G
															Navicula sp.	R		
															Pleurosigma sp.	R		
		M	7.8	0.25	1	T	–	–	VL	+	†							
		B	7.8	0.25	1	T	–	–	VL	+	†							
55	I	S	7.7	0.25	1	–	1	–	L	+ (Fibres)					Leptocylindrus danicus	F	G	G
															Melosira sp.	R	P	P
		M	7.5	0.05	1	–	1	–	VL	+ (Fibres)					Diatoms	R		
		B	7.3	0.10	1	–	–	–	L	+					Pleurosigma	R		
															Fragillaria	R		
															Navicula	R		

+indicates presence of unidentified material *sp. denotes species †nothing observed.

Table 1.1 (Cont'd) Laboratory Data of Water and Ice Samples

Hale	Type	Stratum	pH	Colour	Turbidity	Dissolved Oil	Odour	Free Oil	Abundance	Unidentified Material	Organic Material							
											Composition							
											Zooplankton				redo: Phytoplankton			
											Type	Abun-dance	Condition as seen from:		Type	Abun-dance	Condition as seen from:	
													Field obs.	Lab. obs.			Field obs.	Lab. obs.
P_0	W	S	6.4	0.75	3	15	4	–	VL	+					Melosira sp. Nitzschia sp.	R R	P P	P P
P_0	I	T	6.3	1	10	Saturated	5	1% oil	VL	+ (Cells)					Melosira sp.	R	P	P
P_1	W	S	6.3	0.72	10	10	5	–	L	+					Nitzschia sp. Diatoms sp.	R R	P	P
P_1	I	T	6.4	0.25	15	Saturated	4	0.5%	VL	+					Melosira sp.	R	P	P
P_2	W	S	5.4	0.50	6	25	2	–	VL	+	†							
		B	5.4	0.50	3	Saturated	5	1% oil	S	+ (Cells)					Nitzschia sp.	R	G	G
P_2	I	B	5.7	0.50	4	Saturated	5	1.5%	VL	+	†							
P_3																		
P_4	W	S	7.3	0.25	10	10	3	–	VL	+ (Fibres & cells)					Fragillaria sp.	R	P	P
P_4	I	C	5.6	0.10	1	10	2	–	VL	+ (Fibres)	†							
301	W	S	6.3	0.75	1	Saturated	6	–	VL	+ (Cells)	†							
	I	T	5.2	0.50	5	Saturated	5	5%	VL		†							
302	W	S	6.8	1	50	Saturated	5	$^1/_4$%	VL	+ (Cells)	†							
	I	T	5.2	0.50	8	Saturated	5	2.5%	VL		†							

+indicates presence of unidentified material   *sp. denotes species   †nothing observed.

Table 1.1 (Cont'd) Laboratory Data of Water and Ice Samples

Hale	Type	Stratum	pH	Colour	Turbidity	Dissolved Oil	Odour	Free Oil	Abundance	Unidentified Material	Organic Material							
											Composition							
											Zooplankton				redo: Phytoplankton			
											Type	Abun-dance	Condition as seen from:		Type	Abun-dance	Condition as seen from:	
													Field obs.	Lab. obs.			Field obs.	Lab. obs.
Results of a second water sampling in holes 1, 2, 3, 4 (June 16)																		
1		S							VL	+ (Fibres)	†							
2		S							S	+ (Fibres destroyed cells)					Melosira sp. Nitzschia sp.	R R	P G	P G
3		S							VL	+	†							
4		S							VL	+ (Destroyed cells)					Melosira sp.	R	P	P
Fresh water			7.4	2	1	–	–	–										
Sea water			7.6	0.25	1	–	–	–										
Clean Diesel			–	0.75	0	–	–	–										
Diesel from sea			–	75 to 100	0	–	–	–										

+indicates presence of unidentified material

*sp. denotes species

†nothing observed.

APPENDIX 2

Analysis of Oil

Table 2.1 Boiling Points and Solubility of Oil

Volume cm^3	Storage Tank Temperature °C	Bay °C	Mutual Solubility of Diesel Oil and Water	
			NAREMCO	Imperial Oil*
1	150	165		
5	169	190	Oil in water >25 ppm	10-30 ppm
10	175	195		
20	185	203	Water in oil >50 ppm	50-150 ppm
30	193	209		
40	200	216		
50	211	223		
60	222	231		
70	233	240		
80	246	251		
90	260	265		
95	271	274		
Dry	280	284		
Colour	0.75	75-100		
Turbidity	0	0		
Specific gravity	0.7925	0.800		

*personal communication – Mr. Leslye Orr

Table 2.2 Oil Content in Soil Samples

Sample	Approximate Composition %	Bulk Density g·cm^{-3}	Oil Content %Weight
A*	50 sand§ 50 top soil‡	1.48	1.5
B	100 top soil	1.6	4.1
C	80 sand 20 soil	1.55	3.7
D	65 sand 35 soil	1.3	1.2
E	85 sand 15 soil	1.4	4.6
F	100 sand	1.45	2.0
C-1†	85 sand 15 soil	1.65	1.5
D-1	70 sand 30 soil	1.5	1.2
F-1	100 sand	1.55	1.3
F-2	90 sand 10 soil	1.5	2.1

*Samples A-F were collected on June 12 at ≈2000

†Samples C-1 to F-2 were collected on June 16 at ≈ 1600

§For extraction stones bigger than one third of an inch were removed from the sand.

‡Top soil usually contained debris of roots, plants, etc.

Table 2.3 Results of Soil Samples Observations

Sample	Stratum	Organisms Found by Eye Observation	Organisms Found by Microscope Observation
A	Surface (6″ to 8″)	None	None
B	Surface	None	None
C	Surface	None	None
D	Surface	None	None
E	Surface	None	None
F	Surface	None	None

Composition of the Plankton Sample Collected on June 18, 1970

Table 3.1 Composition of the Plankton Sample Collected on June 18

Components	Type	Abundance	Condition (Field Observation)
Unidentified Material	Mostly fibers	Common	
Phytoplankton	Coscinodiscus sp.†	Common (dominant)	Good
	Melosira sp.	Few	Usually good
	Fragillaria sp.	Rare	
	Nitzschia sp.	Rare	
Zooplankton*	A. Amphipods		
	(1) Parathemisto sp.	Rare	Good (alive)
	B. Copepods	Few	Good (alive)
	(1) Cyclopoida		
	– Oithonina sp.	Rare	Good (alive)
	(2) Calanoida		
	– Paracalanus sp.	Few	Good (alive)
	– Acartia sp.	Rare	Good (alive)
	– Isias sp.	Rare	Good (alive)

*Because of lack of time, the exact genus of each zooplankton representative could not be ascertained. Listed genera are possible genera.

†sp. denotes species

Table 3.2 Results of Quadrats Observation

Quadrat	General Aspect of Soil	Plants Collected (mostly remains)
I	sand mixed with ice and oil	sedge (curex sp.*) grasses (Graminacae) club-moss (Lycopodium sp.) shrubs (Salix sp.) shrubs (Vaccinium sp.)
II	sand mixed with ice, rocks and oil	lichens mosses grasses (Graminacae)
III	sand mixed with oil	mosses grasses (Graminacae) shrub (Salix sp.)
IV	sand mixed with oil	shrub (Salix sp.) shrub (Vaccinium sp.)
V Unaffected Area	mossy spongious soil	lichens mosses sedges (Curex sp.) Grasses (Graminacae) shrubs (Salix sp.) shrubs (Vaccinium sp.)

*sp. denotes species

Table 3.3 Results of Ecological Survey

Class	Common Name	Scientific Name	Number
I. Mammal			1
	a) Hudson Bay Collared Lemming	Dicrostonyx hudsonius	(1)
II. Birds			8
	a) Semipalmated Plover	Charadrius semipalmatus	(4)
	b) Semipalmated Sandpiper	Ereunetes pusillus	(2)
	c) White-rumped Sandpiper	Erolia fusciollis	(1)
	d) Sandwich Tern	Thalasseus sandvicensis	(1)
III. Fish			1
	a) Sculpin	–	(1)
		TOTAL	10

N.B. A sea weed of the genus Fucus was also collected during field survey.

Ice and Water Samples

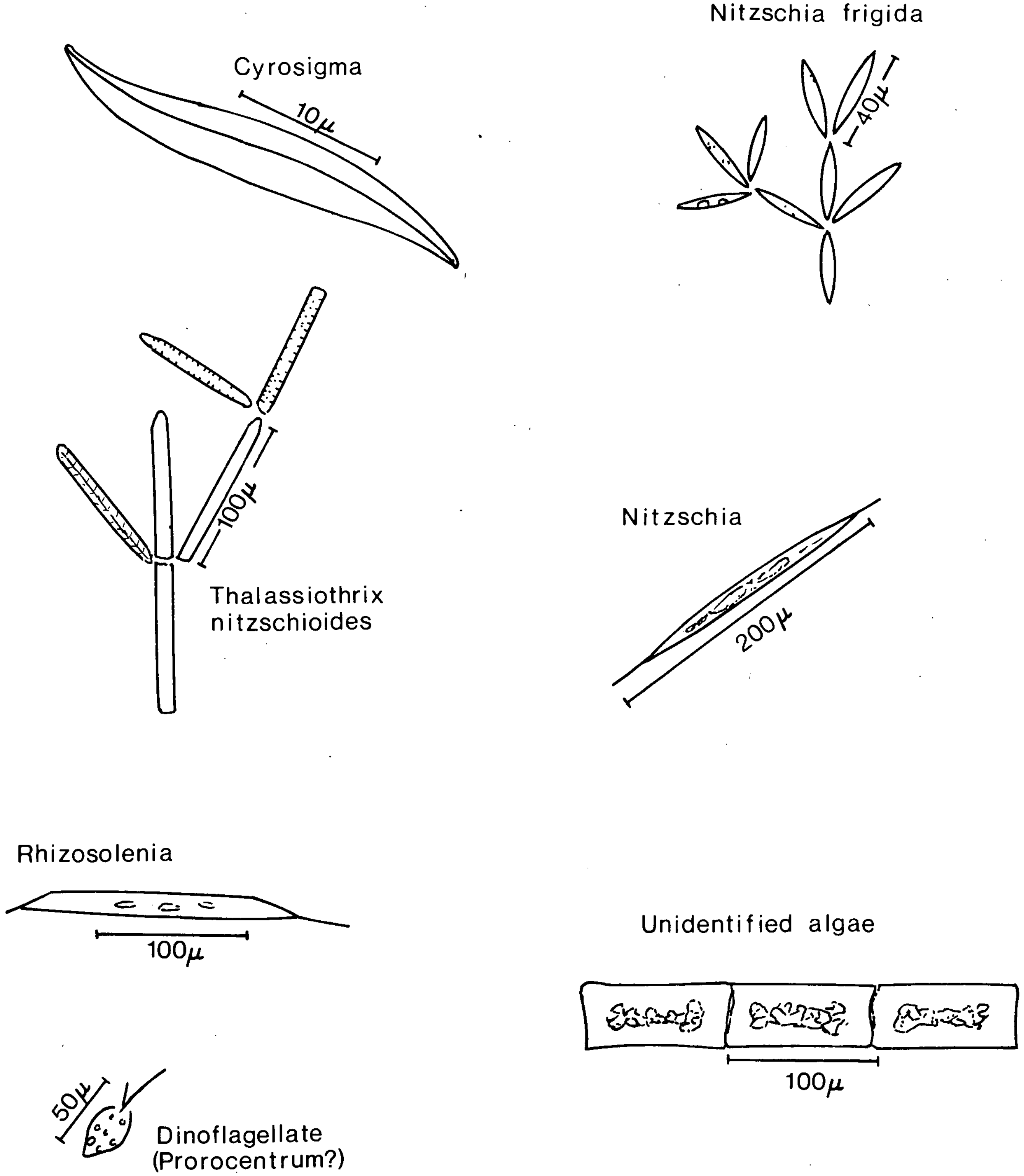


Figure 4.1 Phytoplankton.

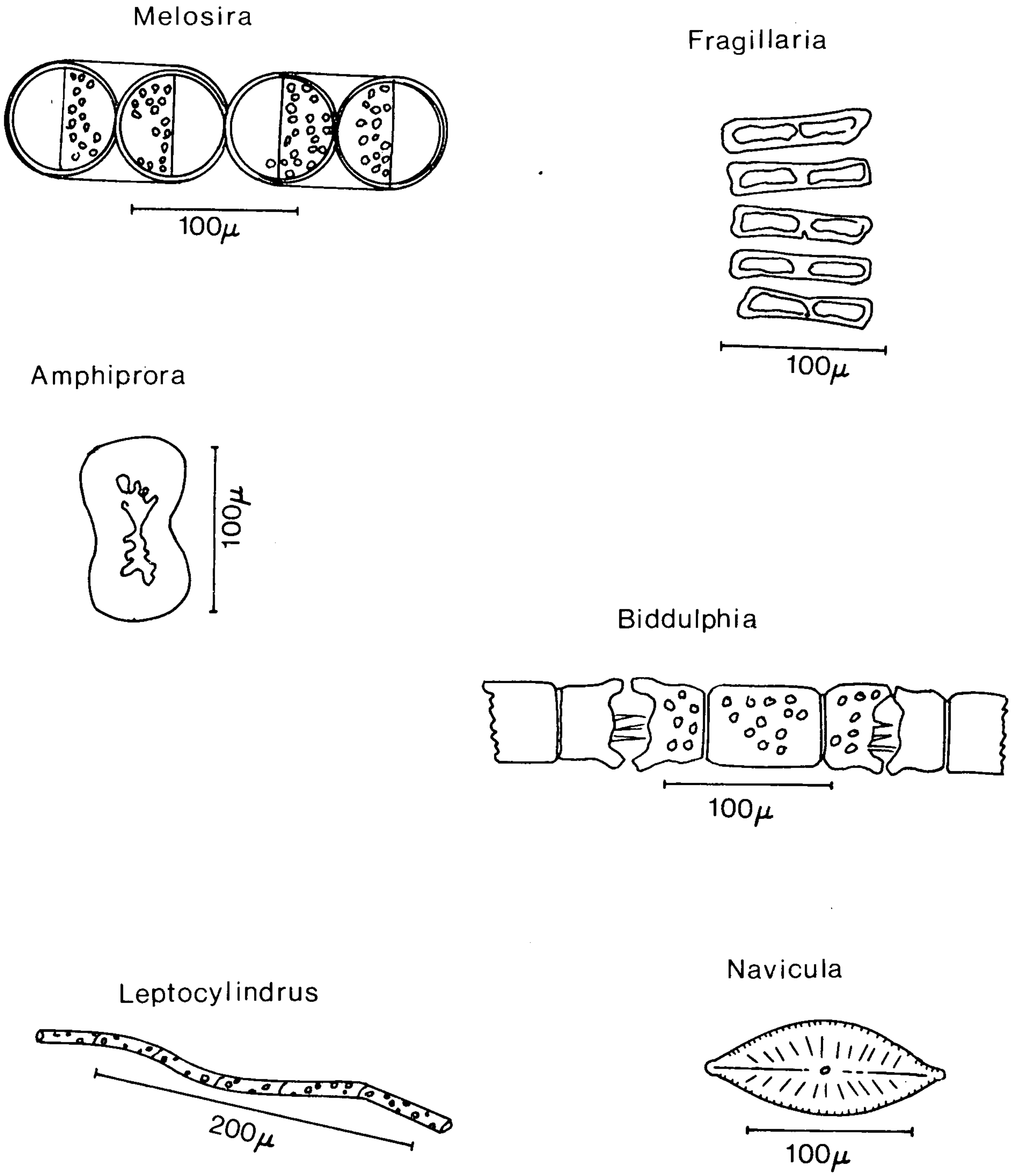


Figure 4.2 Phytoplankton.

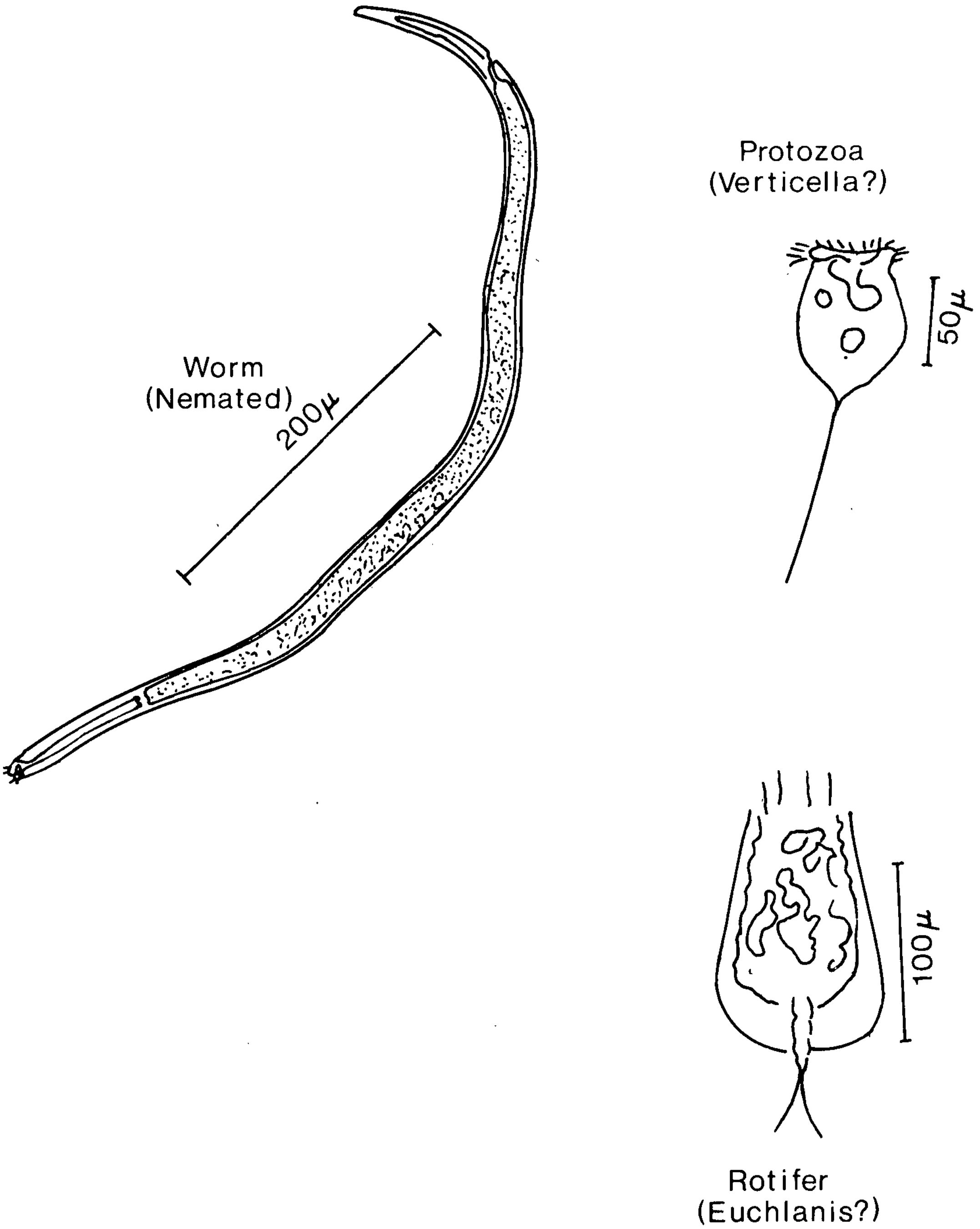


Figure 4.3 Zooplankton.

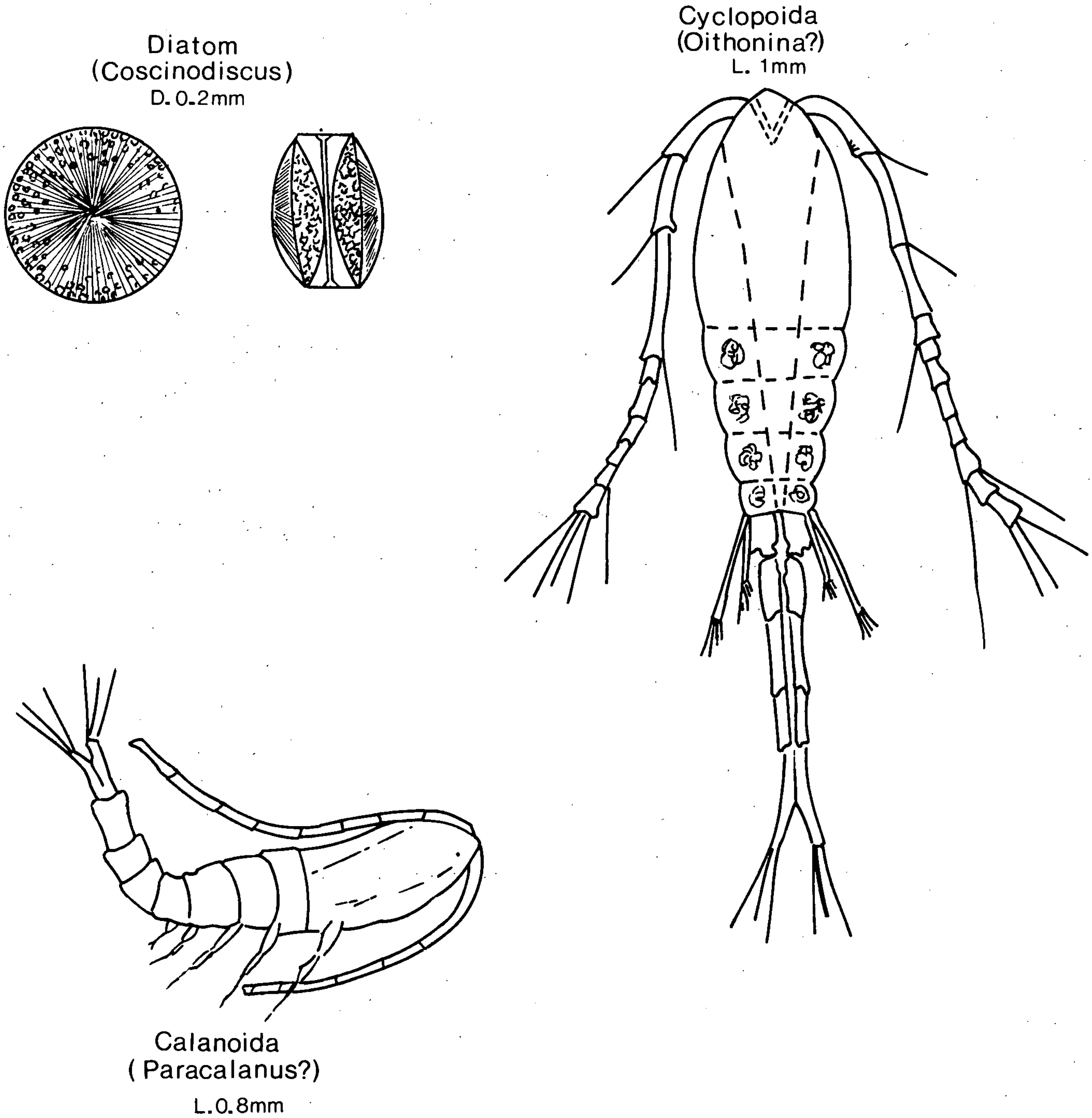
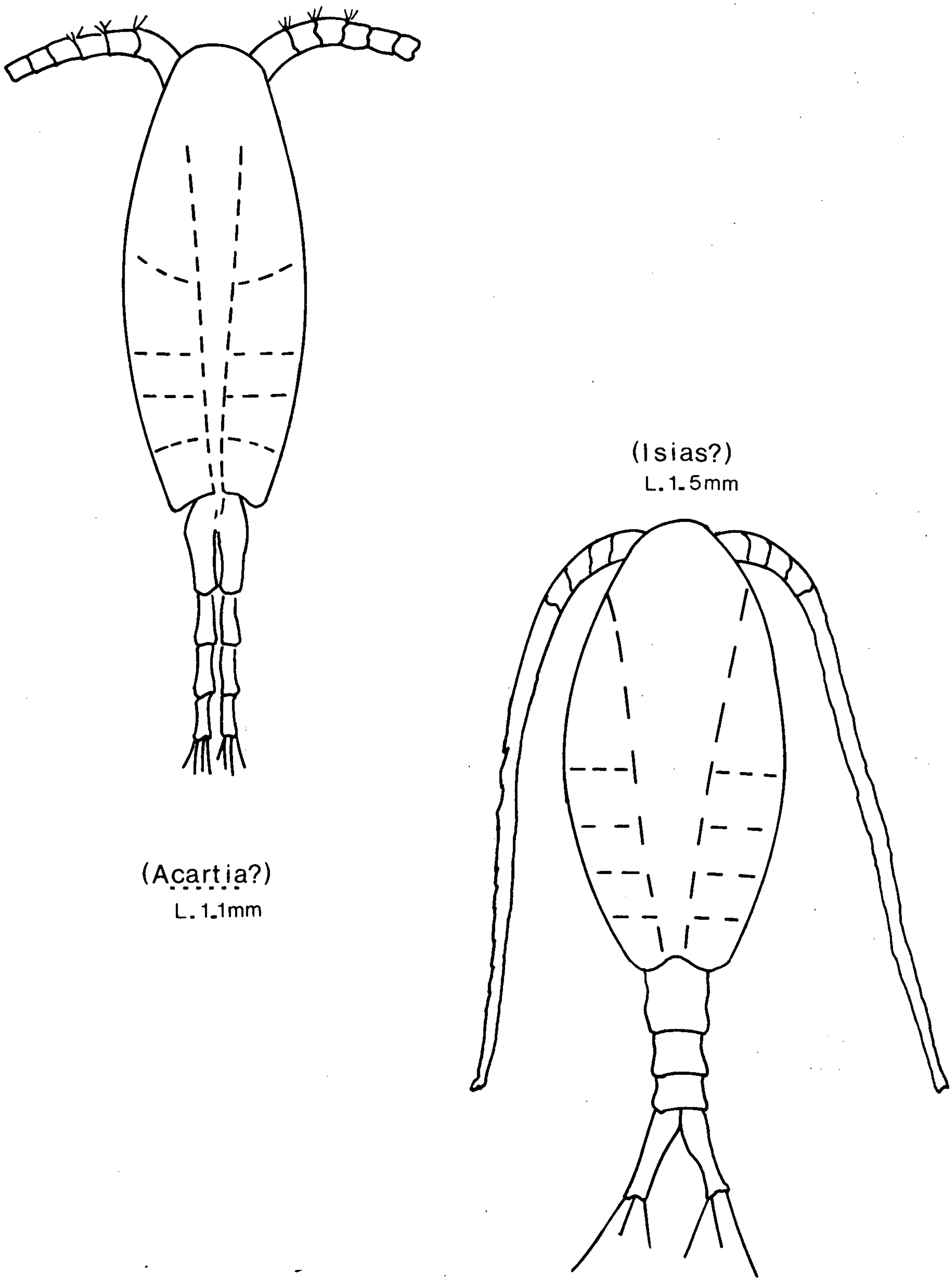


Figure 4.4 Plankton collected with the plankton net.



Calanoid copepods
(Calanoida)

Figure 4.5 Plankton collected with the plankton net.

Examination of the Biological Effects of the Oil Spill at Deception Bay

On or about June 6, 1970 a snowslide moved 4 and punctured the fifth of 6 fuel storage tanks at Deception Bay (62°08.2'N, 74°40.8'W), an inlet off Hudson Strait on the north shore of Quebec. Only a single small tank was left intact. Estimated loss at the time was 58,000 gallons of gasoline and 367,000 gallons of arctic diesel fuel. How much of the total 425,000 gallons was absorbed by the snow and debris below the tank site, how much was spilled onto the surface of the sea ice (at that time solidly covering the bay) and subsequently burned, and how much entered the sea through cracks in the sea ice evidently is not known.

The original location of the fuel tanks was about 20 metres above mean sea level, only a short distance east of a stream (see map – Figure 5.1) which ran down a narrow ravine in the general direction of the tanks, and flowed into the bay a few metres north of the tanks. It was down this ravine and along most of its length parallel to the stream that the slide moved, overrunning the tanks which were near the centre of the slide path, and spreading over the beach below the tanks and over the shore-fast ice immediately below the tanks, taking one of them onto the sea ice (see map). At the time of this visit, starting on 25 July, the

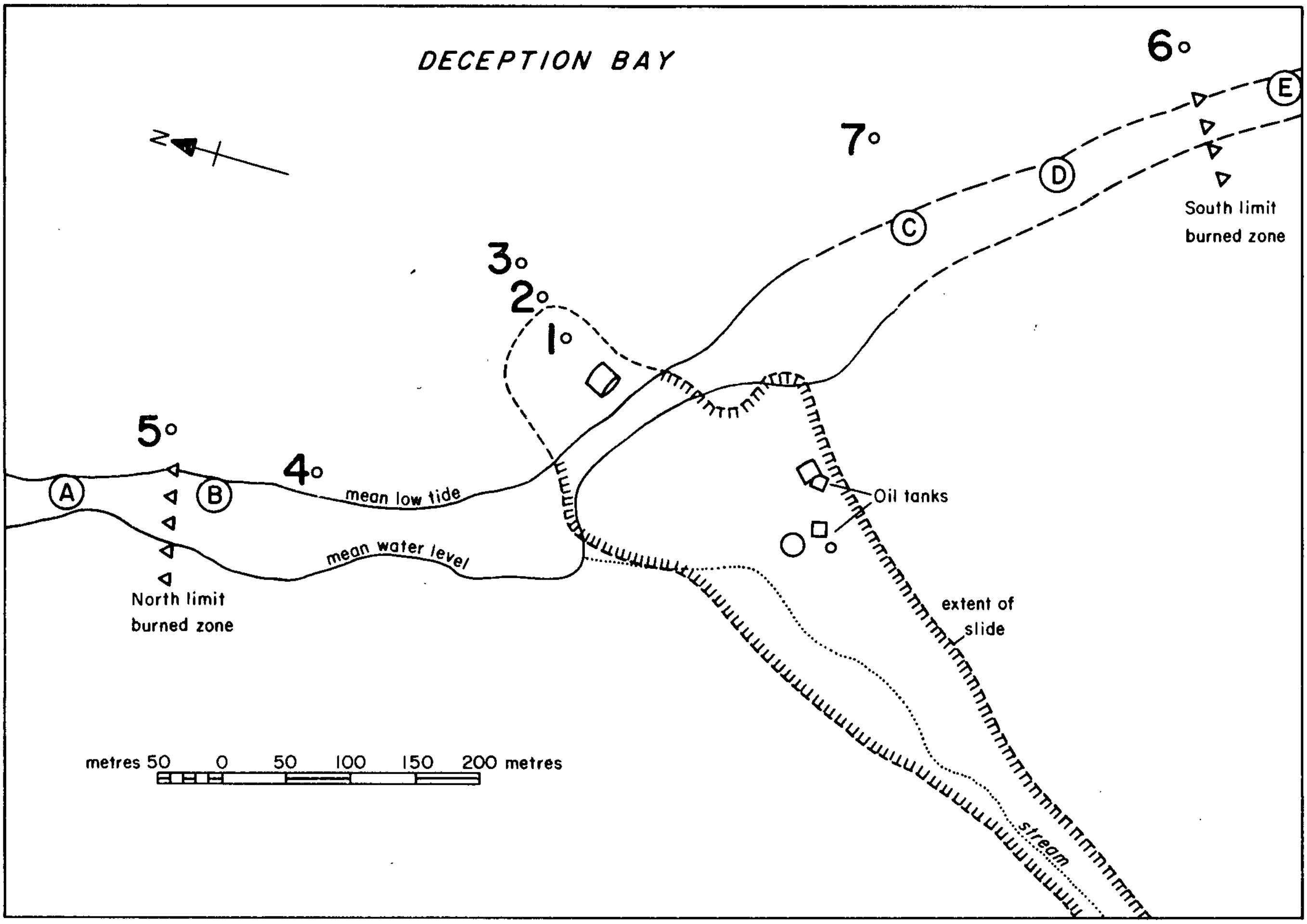


Figure 5.1 Map showing original location of fuel tanks and extent of snow slide

sea ice had disappeared completely, and the part of the slide below the mean low tide line (as shown on the map) had sunk or been transported away on the ice. The tank had sunk in approximately the same position as shown on the map, being partly exposed at low tide and entirely covered by water at high tide.

The maximum tidal amplitude in Deception Bay is about 6 metres. The intertidal area is in general fairly flat, with abundant boulders interspersed with finer materials ranging from mud to coarse sand. Temporary pools are numerous. On 25 July the central part of the region studied, immediately below the fuel tanks, was conspicuously darkened by oil and fire. The smell of oil was evident and oil was clearly present in the finer substrate material. Attached *Fucus* was present, but limp and discoloured to a yellowish green. Sedentary animals were few, including some *Mytilus*. Only very few *Littorina* were to be found. The occasional *Gammarus* was seen under rocks in pools. Many dead *Mytilus* were observed with shells open and soft parts either missing or much shrunken. These, with attachment threads gone, were found often in piles in beach depressions, probably a consequence of water movement acting on the light and largely empty shells. Evidence of burning was clearly seen, especially on the larger rocks in the lower part of the intertidal area. The blackened rocks had a characteristic burned smell, and were cracked, evidently as a consequence of intense heat. Charred *Fucus* holdfasts and burned *Mytilus* remnants were found in association with these. It would appear that many *Mytilus* had died as a result of heating.

Close observations were made along the intertidal stretch from north of the northern limit to south of the southern limit of the oil zone, as shown on the map. These limits were defined on the basis of evidence of burning and of the conditon of the flora and funa. In general, there was a trend towards reduced mortality and a healthier condition in the intertidal animals and plants from the centre towards the extremities of the oil zone. *Littorina* gradually became more abundant towards the outer limits of the zone. *Fucus*, which appeared in an unhealthy state over the entire oil zone, showed a normal appearance beyond the zone extremities. Within the oil zone the plants were nearly all pale and limp, compared with the healthy plants found elsewhere. The outer covering of the thalli was found to be softer and more easily bruised in the plants affected than in those apparently untouched by oil or heat. On handling, the plants were extremely easily torn, especially at the tips of the thalli but along their full length as well, exposing the central cell structure. Examination of a number of thallus ends of the affected plants suggested that natural damage had occurred, perhaps resulting from contact with abrasive surfaces while submerged. In a number of instances evidence was found of severe disarrangement of internal thallus cells in the affected plants, as a result of external pressures. Neither of these maladies was found in normal plants. Nearly all the affected plants were attached by holdfasts, however, and were presumably living when collected. Whether they would survive or die is not yet known.

Mytilus showed a very clear trend in its response to the spill and perhaps subsequent burning.,Collected at points A (outside the primary spill area; see map), B, C, D and E (also outside the spill area), the following ratios of living to dead animals were found.

Collection point	Living	Dead
A	7.3	1
B	1.2	1
C	1.2	1
D	2.1	1
E	11.0	1

Seven subtidal stations at depths of 6-9 m (see map) were sampled with a 0.07-m clam-type grab. Samples from stations 1 (4 grabs), 4 (1 grab), and 7 (2 grabs) were sieved through a 0.1-mm screen and preserved in formalin for subsequent study. Bottom materials from grabs at the other stations were inspected and discarded. Grabs from all 7 stations contained live animals but a noticeable odor of oil was present, and the fine sediment was saturated with oil.

Using odor and general appearance of the substrate, admittedly a crude method, the stations were ranked as to degree of saturation as follows: 1, 2, 4, 7, 3, 5, 6.

The preserved samples from stations 1, 4, and 7 were analyzed in terms of species, number of individuals, and condition of specimens. Seventeen species were found in the grabs from station 1; 16 species from station 4; and 42 species from station 7. A summation of the individual representation is presented in the table below. The values from station 1 and station 7 have been adjusted for comparison with those of station 4.

Taxa	Station 1	Station 4	Station 7
Polychaetes	6	113	175
Pelecypods	1	85	17
Gastropods	4	16	4
Nematodes	6	0	47
Others	0	0	11
Total	17	214	254

The 4 grabs from station 1 contained a quantity of terrestrial plant and slide debris. The smaller number of animals at this station may be accounted for by the inundation of the bottom by this material. Any damage to the biota by oil would be masked by the physical effects of the slide.

Station 4 was outside the slide area but near the point where the stream enters the marine environment. Some terrestrial plant debris was present in the grab from this station. The polychaete, *Pholoe minuta* and the bivalve, *Mytilus edulis* were the most abundant species.

Five shells of *Mya truncata* and 31 shells of *Crenella faba* were present in the grab. This appears to be a higher number of intact empty shells than usually found in grab samples. In these shells the ligament connecting the valves was present and the valves showed no erosive effects of weathering. The siphons were still attached to 2 of the shells of *Mya truncata,* suggesting recent mortality. Allowing for natural mortality, about 50 per cent of the populations of these two bivalves could have died as a result of oil effects in this area. This would be about 17 per cent of the biota of the station.

The most abundant species at station 7 were the polychaetes, *Scoloplos armiger, Pholoe minuta* and *Paraonis gracilis*; the bivalve, *Astarte* sp.; and nematodes. With the exceptions of a few small polychaetes all animals appeared to have been in a healthy condition. About 10 small specimens of *Scoloplos armiger, Capitella capitata* and other mud ingesters were in a state of deterioration. One does not often encounter partial remains of animals that died naturally in bottom samples. Such mud ingesters would be subject to deleterious effects of the oil-contaminated substrate. It is estimated that at most only 5 per cent of these polychaetes could have died from oil.

Judging by the condition of the animals and substrate from the other stations, deleterious oil effects decrease seaward from stations 1, 4, and 7. A crab, *Hyas coarctatus* was found in the grab from station 2, and brittle stars were common at station 3.

Water samples taken on 13 June by Mr. Wybe Hoek from the surface of ice holes were examined for plankton. One sample, described as originating about 140 metres from the spill, contained no evidence of either living or dead plankton, only unidentifiable detrital material. There was slight evidence of oil in the sample. Another sample, taken about 600 metres from the spill, showed similar content except for oil which was not detectable in the water.

A net plankton collection taken on 18 June by Mr. Raymond Bergeron contained apparently normal plankton, mainly the copepods *Pseudocalanus, Acartia* and *Oithona*. Zooplankton collected between 6 metres and the surface at station 3 (see map) on 26 July was plentiful and apparently normal. It consisted of several copepods (calanoids, cyclopoids and harpacticoids, among which were *Calanus, Pseudocalanus, Oithona, Oncaea* and others), including nauplii, young scyphozoans (*Cyanea*), larval cirripedes (*Balanus*) and decapod crustaceans (zoeae), larvaceans (*Oikopleura*) and chaetognaths (*Sagitta*). Larval copepods and cirripedes, which were not present in the June collection, probably entered the plankton during the interval. Emergence of these young stages was to be expected during that time in an undisturbed environment, that is at about the time of spring ice break-up. It would seem that they appeared on schedule. Phytoplankton, collected on 26 July at the same station, appeared to be normal.

Conclusions

(1) About 7 weeks after the spill occurred, evidence of oil was found in the intertidal region along nearly 900 metres of beach, and in the substrate below low tide as far as 150 metres off-shore.

(2) Approximately 90 per cent of the biota in the subtidal slide area (15,000 m^2) was destroyed by the physical effects of the slide. Barring long term effects of the oil, this area could recover within a short period of time.

(3) As much as 50 per cent of certain bivalves could have been killed by oil in inshore subtidal areas. This would account for 17 per cent of the total biota.

(4) At most, 5 per cent of the polychaete fauna (mostly mud ingesters) could have died from the effects of oil.

(5) *Fucus* and *Mytilus* were the intertidal species most affected by the spill and its aftermath, and both appear to have been much more severely harmed by heat (evidently from the burning of oil from the sea ice surface in June) than by oil.

(6) There were no observed effects of oil upon the plankton.

(7) No assessment can be made on the long term effects of the oil. The area should be sampled again in the summer of 1971.

(8) Overall damage was slight and localized.

Typical Ice-Oil Situations

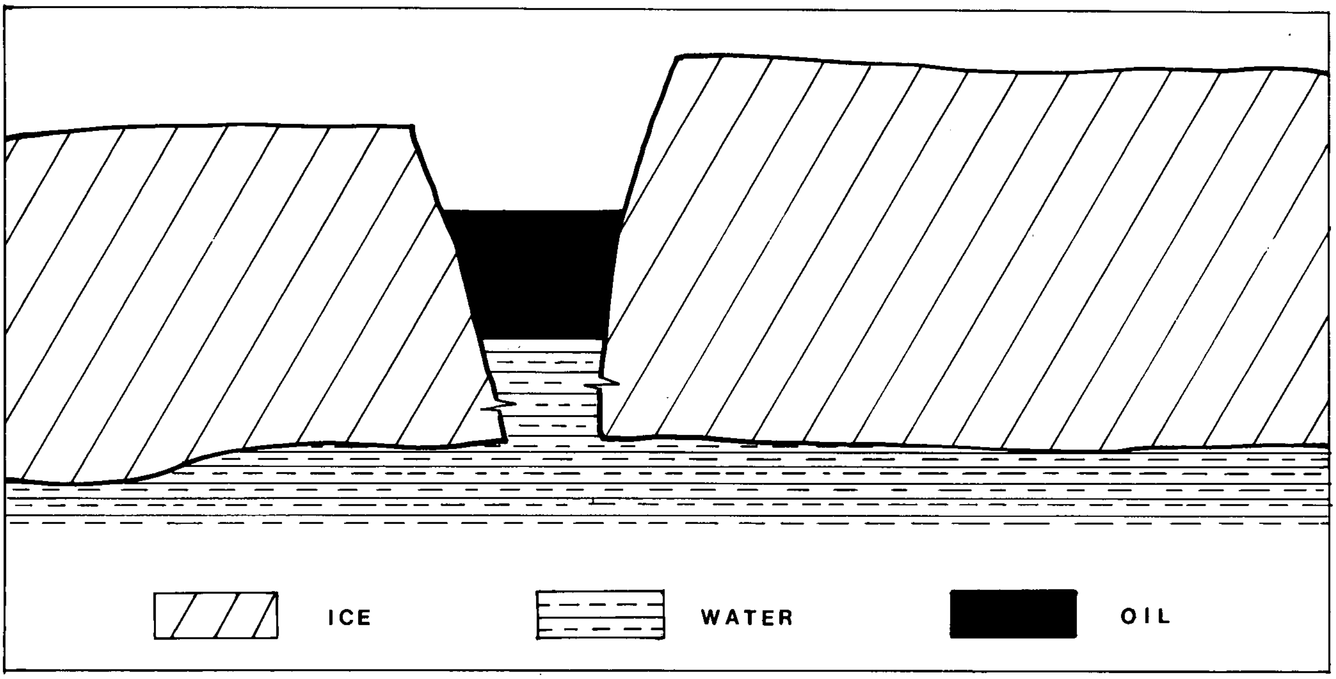


Figure 6.1 Ice surface close to pumping station.

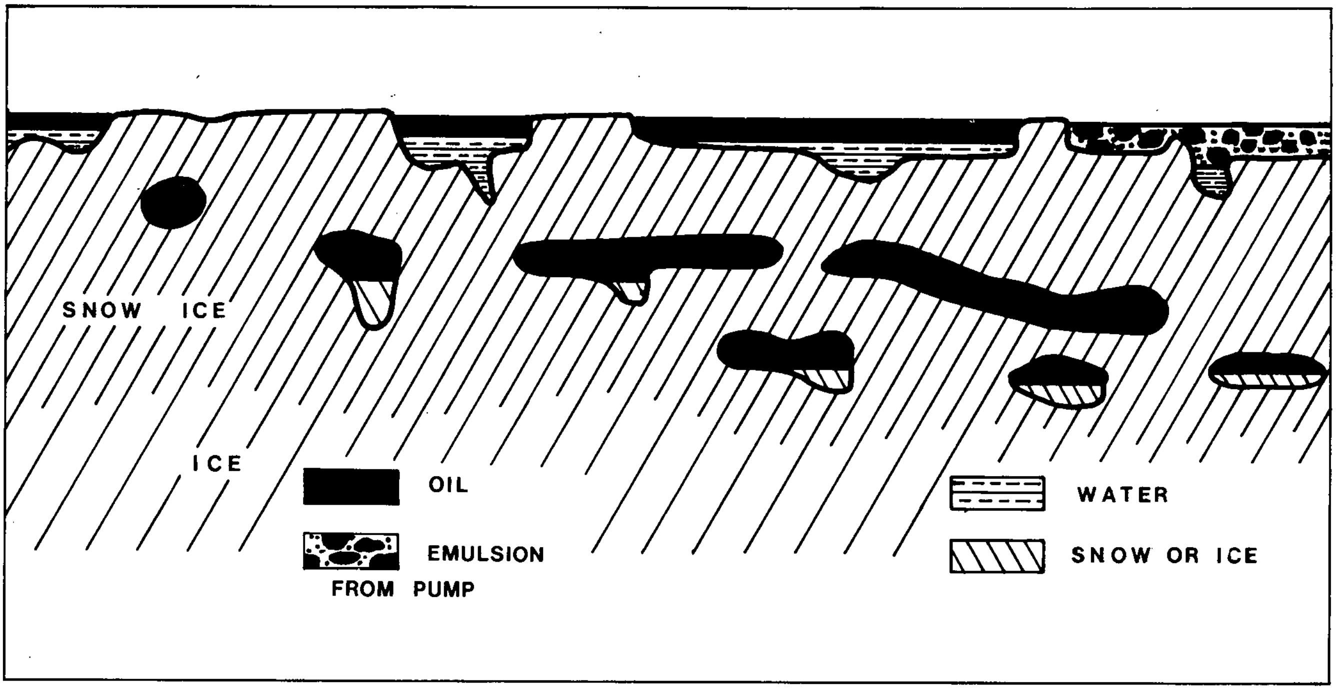


Figure 6.2 Oil around ice.

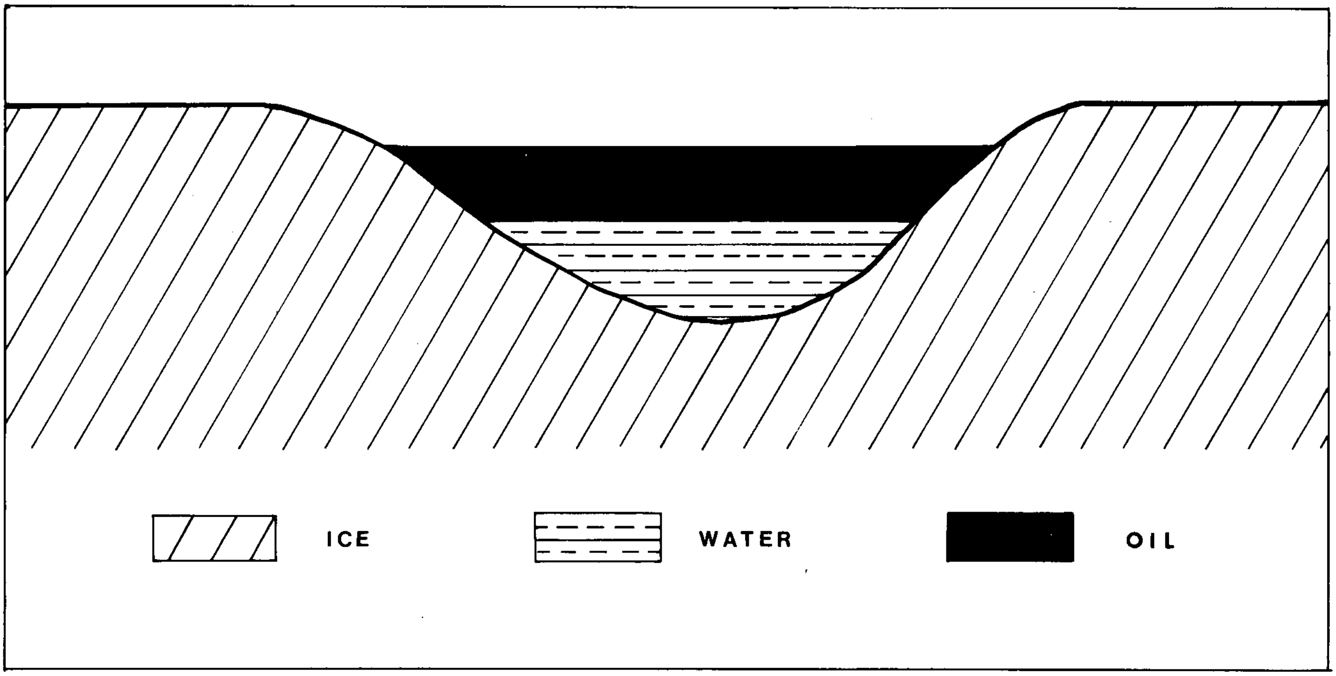


Figure 6.3 Oil-water pool on ice.

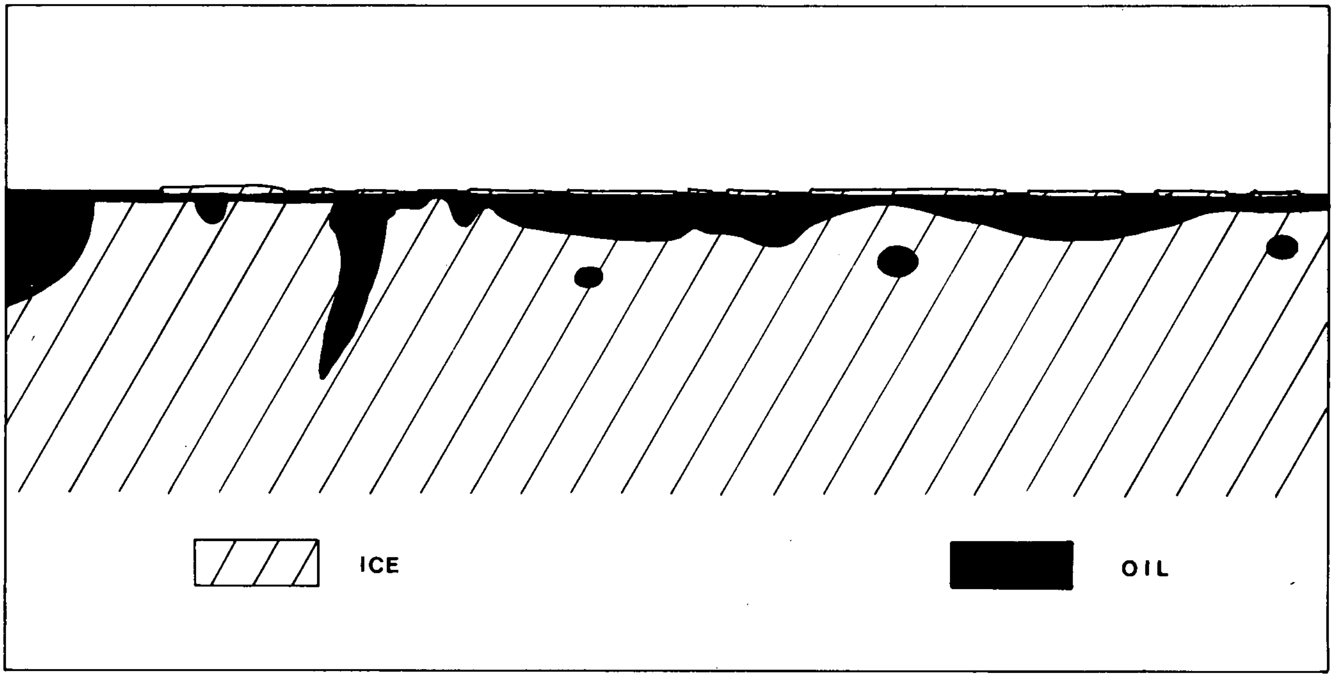


Figure 6.4 Oil on ice.

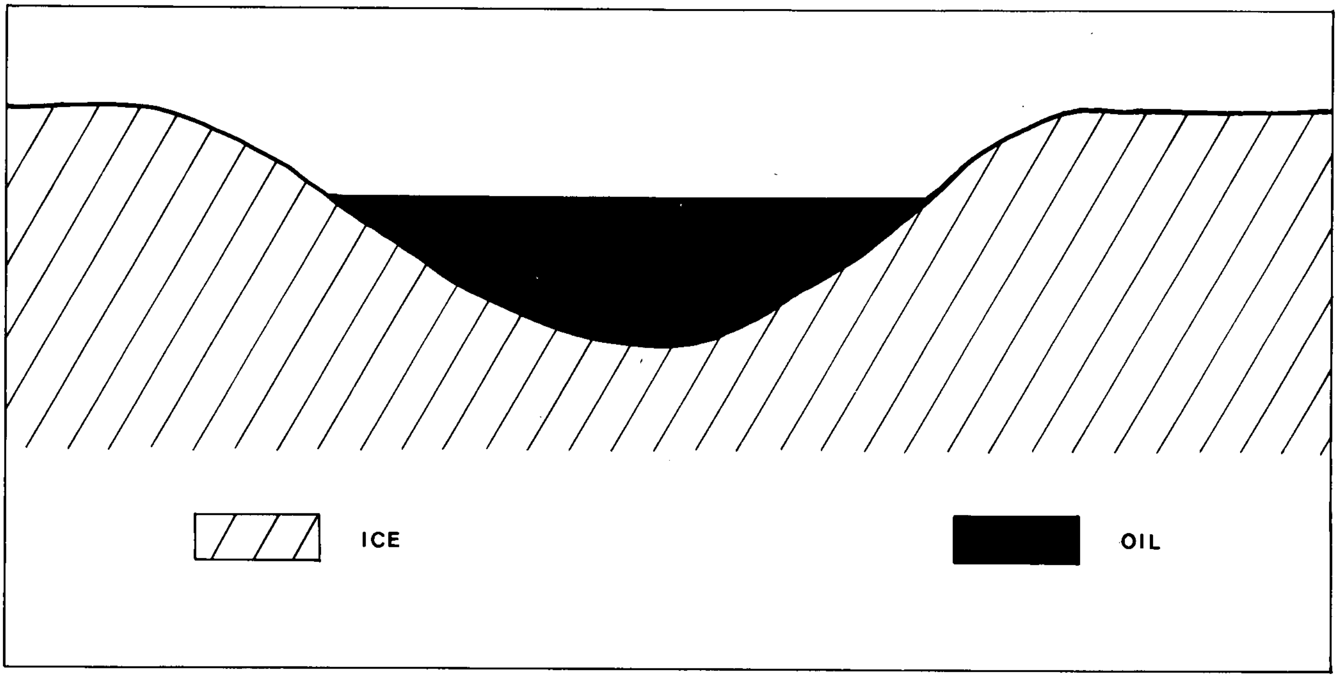
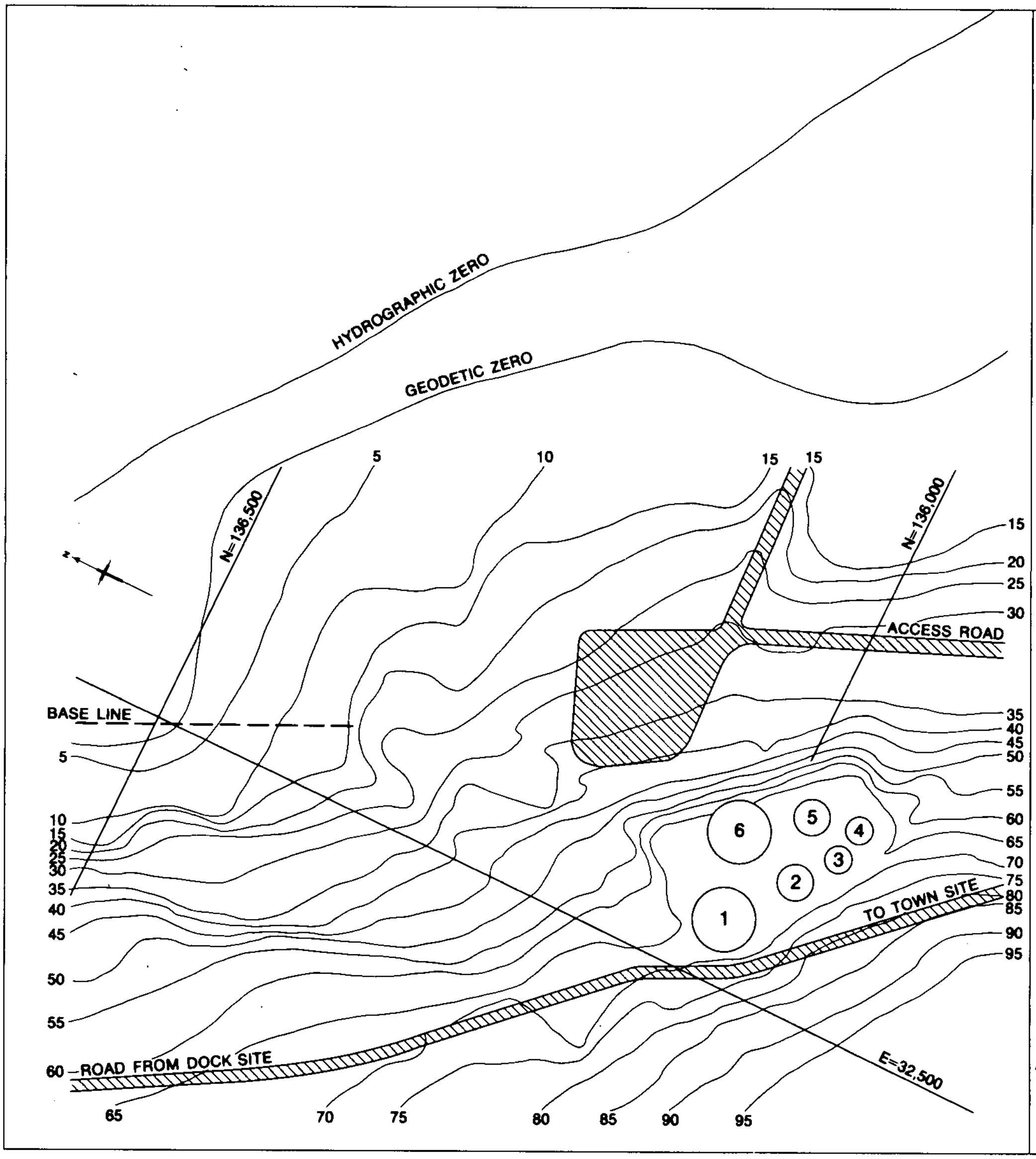


Figure 6.5 Oil pool on ice.

APPENDIX 7

Maps of Oil Distribution



TANK FARM

TANK NO	CAPACITY		INVENTORY JUNE 8, 1970
	BBL	GAL	GAL
1	13,500	486,000	48,601
2	4,000	144,000	57,927
3	1,500	44,000	36,896
4	1,500	44,000	920
5	4,000	144,000	EMPTY
6	13,500	486,000	319,068

NOTICE :- MEASURES GIVEN HERE ARE APPROXIMATE (±5%). THE MAP WAS PREPARED FROM INFORMATION (DATA & MAPS) SUPPLIED BY THE ASBESTOS CO.,LTD. AT DECEPTION BAY, QUEBEC.

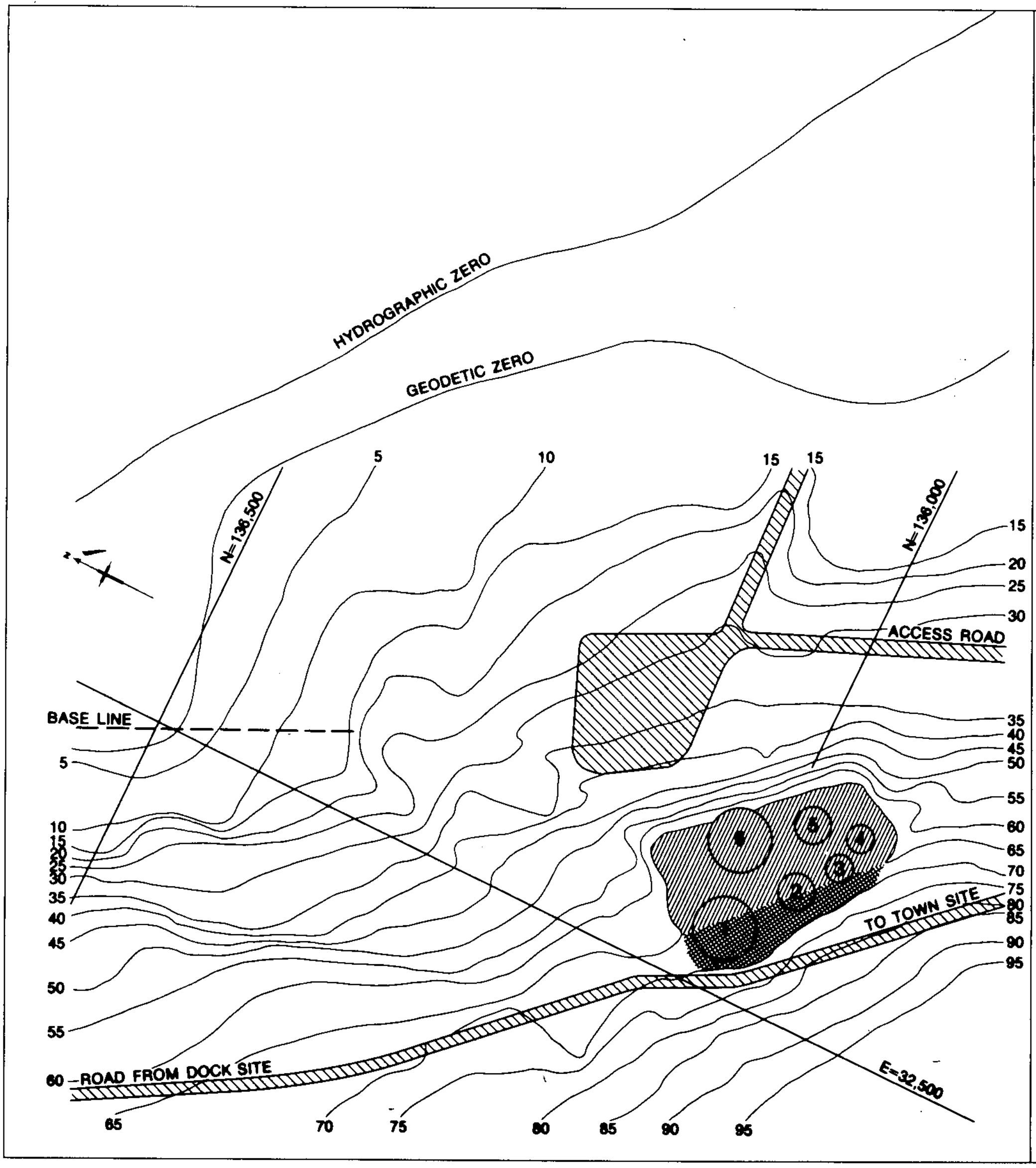
SCALE OF FEET

50 25 0 25 50

DECEPTION BAY, QUE.

TANK FARM AREA OF
THE ASBESTOS CO.,LTD.

Map No. 1. Approximate plan of tank farm area as per original maps from the Asbestos Co. Ltd.



▩ EXCAVATED AREA

▨ FILLED IN AREA

APPROXIMATE VOLUME OF FILLED IN MATERIAL
200' x 100' x 10' AVERAGE DEPTH = 200,000 FT^3

TANK FARM

TANK NO	CAPACITY		INVENTORY JUNE 8, 1970
	BBL	GAL	GAL
1	13,500	486,000	48,601
2	4,000	144,000	57,927
3	1,500	44,000	36,896
4	1,500	44,000	920
5	4,000	144,000	EMPTY
6	13,500	486,000	319,068

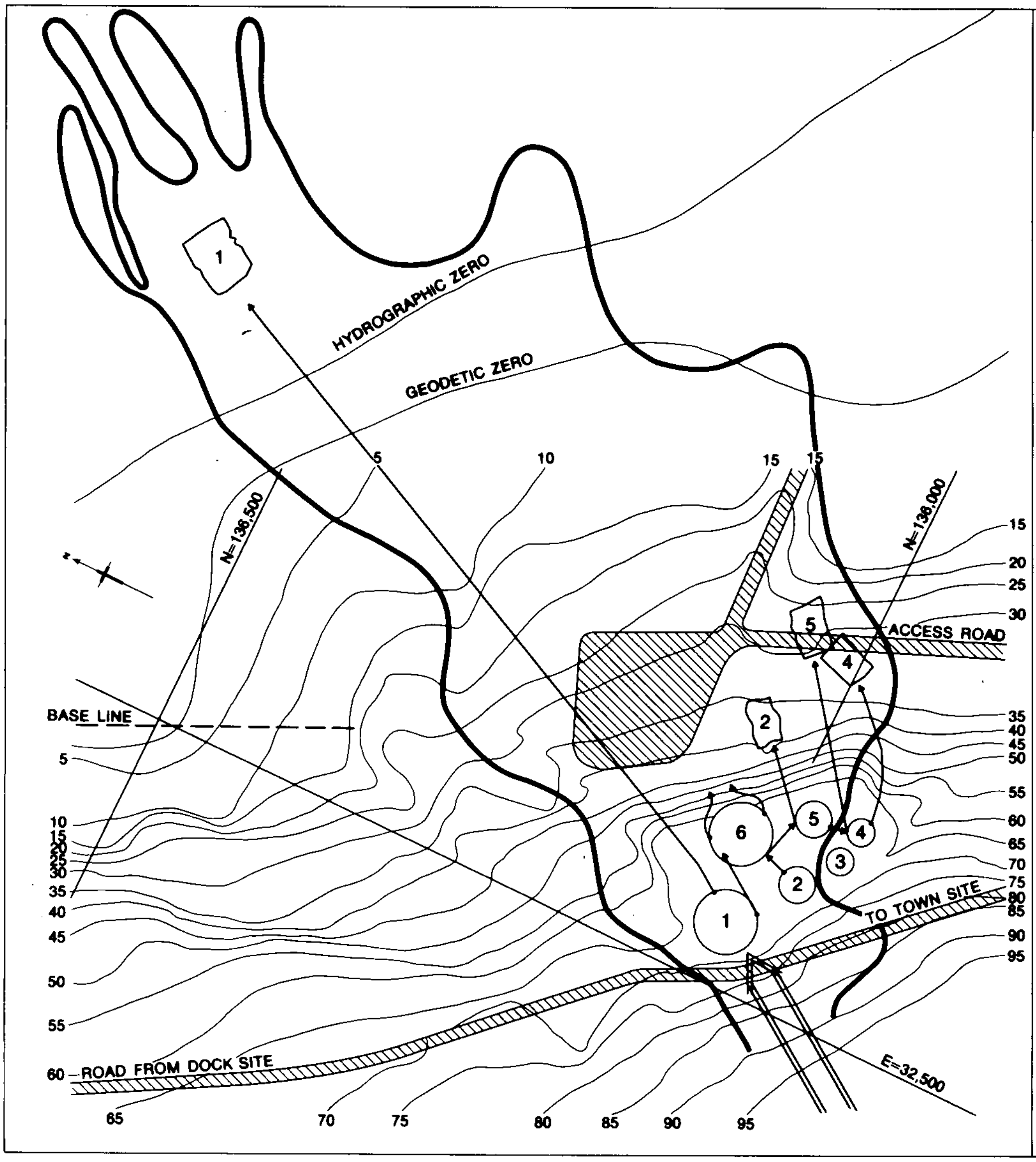
NOTICE:- MEASURES GIVEN HERE ARE APPROXIMATE (±5%). THE MAP WAS PREPARED FROM INFORMATION (DATA & MAPS) SUPPLIED BY THE ASBESTOS CO.,LTD. AT DECEPTION BAY, QUEBEC.

SCALE OF FEET
50 25 0 25 50

DECEPTION BAY, QUE.

**TANK FARM AREA OF
THE ASBESTOS CO.,LTD.**

Map No. 2. Site before avalanche and landslide.



PROBABLE PATH OF TANKS DURING LANDSLIDE

AVALANCHE (SNOW & SAND LAND FROM ROAD AND STONES FROM CREEK BED)

LIMIT OF LANDSLIDE (LAND SAND, GRAVEL, STONES, etc.)

OIL CONCENTRATION IN GROUND:

JUNE 10, 1970 ESTIMATED AMOUNT 4.0% w
JUNE 12, 1970 AVERAGE ANALYSIS 3.0% w
JUNE. 16, 1970 AVERAGE ANALYSIS 1.5% w

TANK FARM

TANK NO	CAPACITY		INVENTORY JUNE 8, 1970
	BBL	GAL	GAL
1	13,500	486,000	48,601
2	4,000	144,000	57,927
3	1,500	44,000	36,896
4	1,500	44,000	920
5	4,000	144,000	EMPTY
6	13,500	486,000	319,068

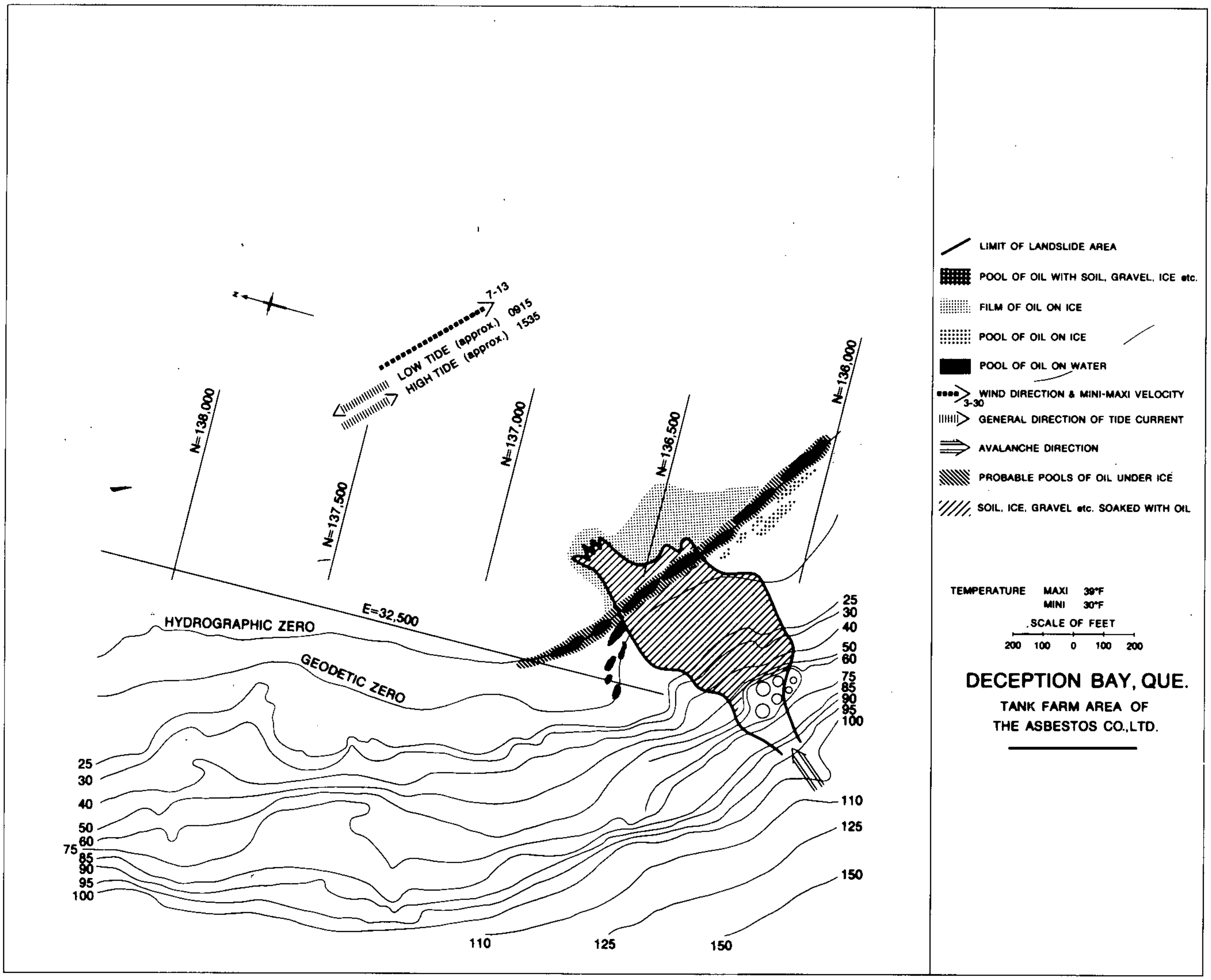
NOTICE:- MEASURES GIVEN HERE ARE APPROXIMATE (±5%). THE MAP WAS PREPARED FROM INFORMATION (DATA & MAPS) SUPPLIED BY THE ASBESTOS CO.,LTD. AT DECEPTION BAY, QUEBEC.

SCALE OF FEET
50 25 0 25 50

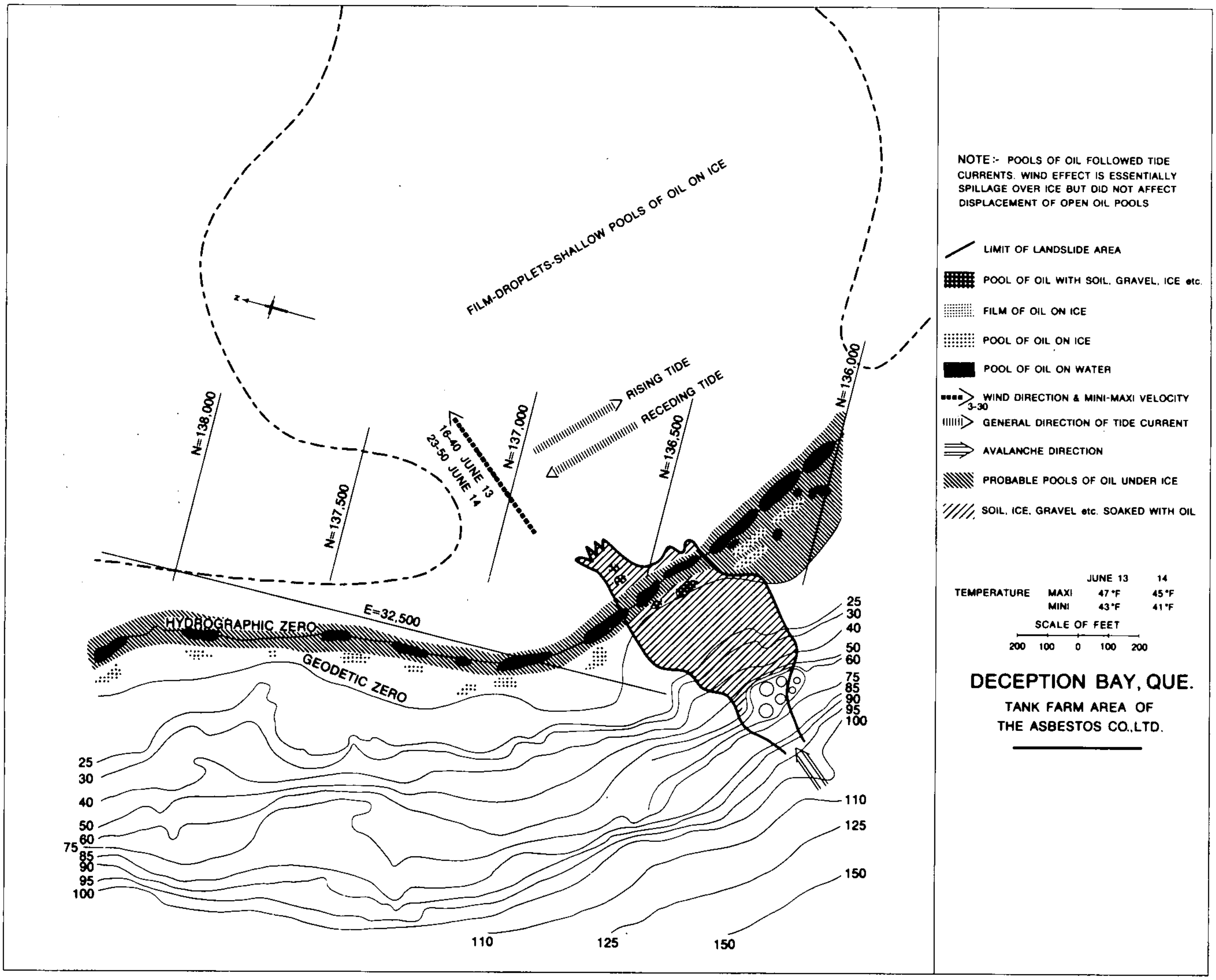
DECEPTION BAY, QUE.

TANK FARM AREA OF
THE ASBESTOS CO.,LTD.

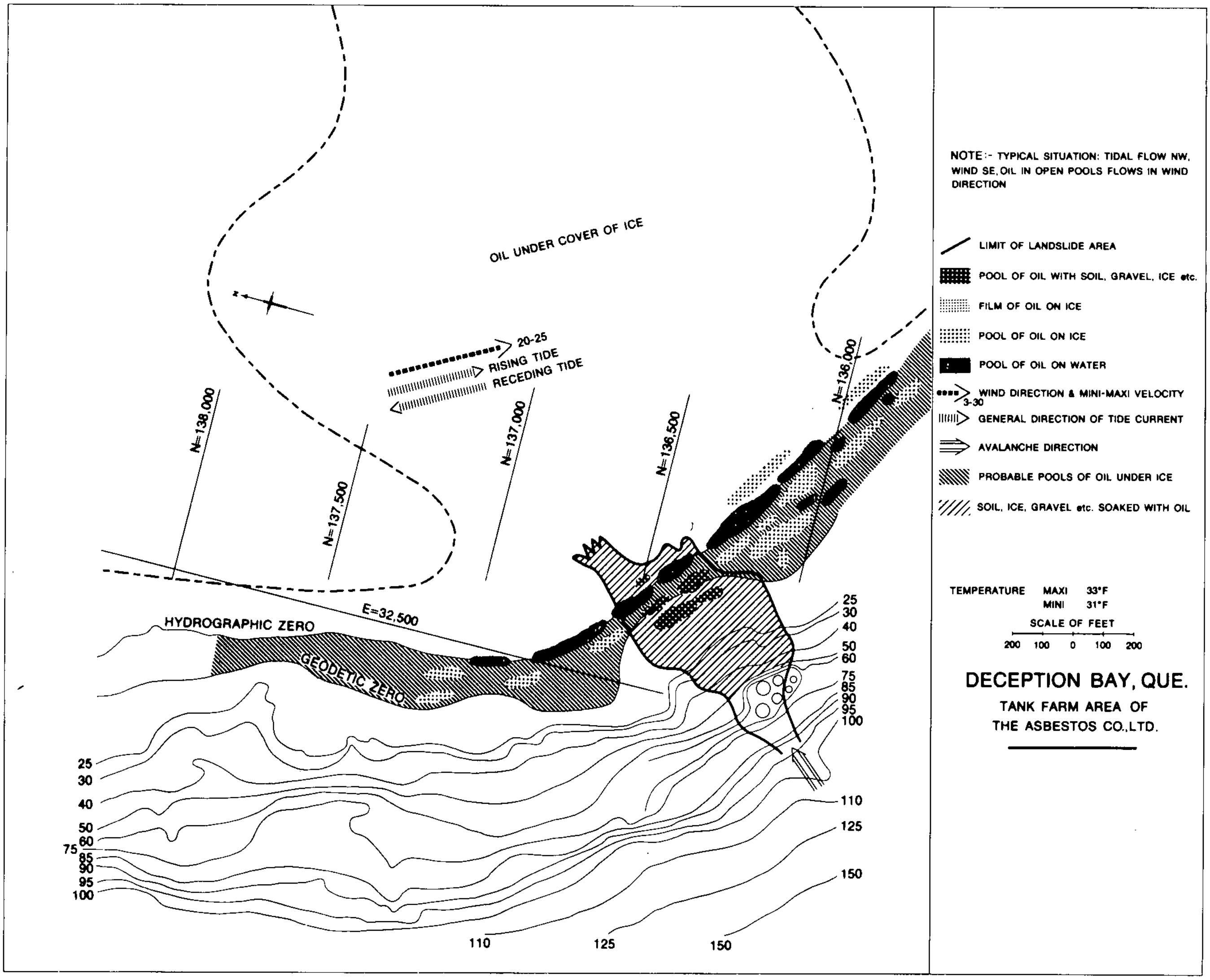
Map No. 3. Site after avalanche and landslide.



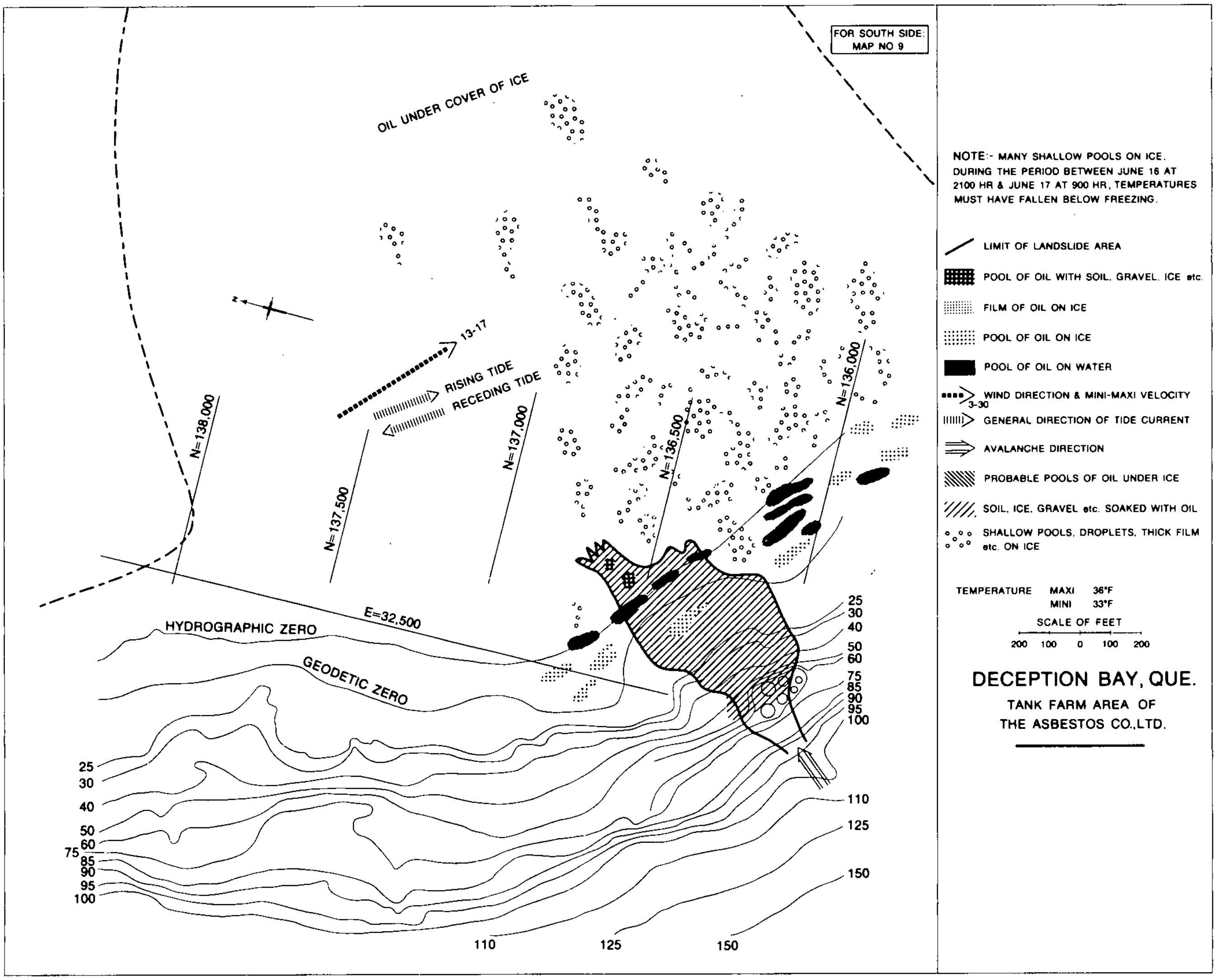
Map No. 4. Approximate situation on June 12, 1970.



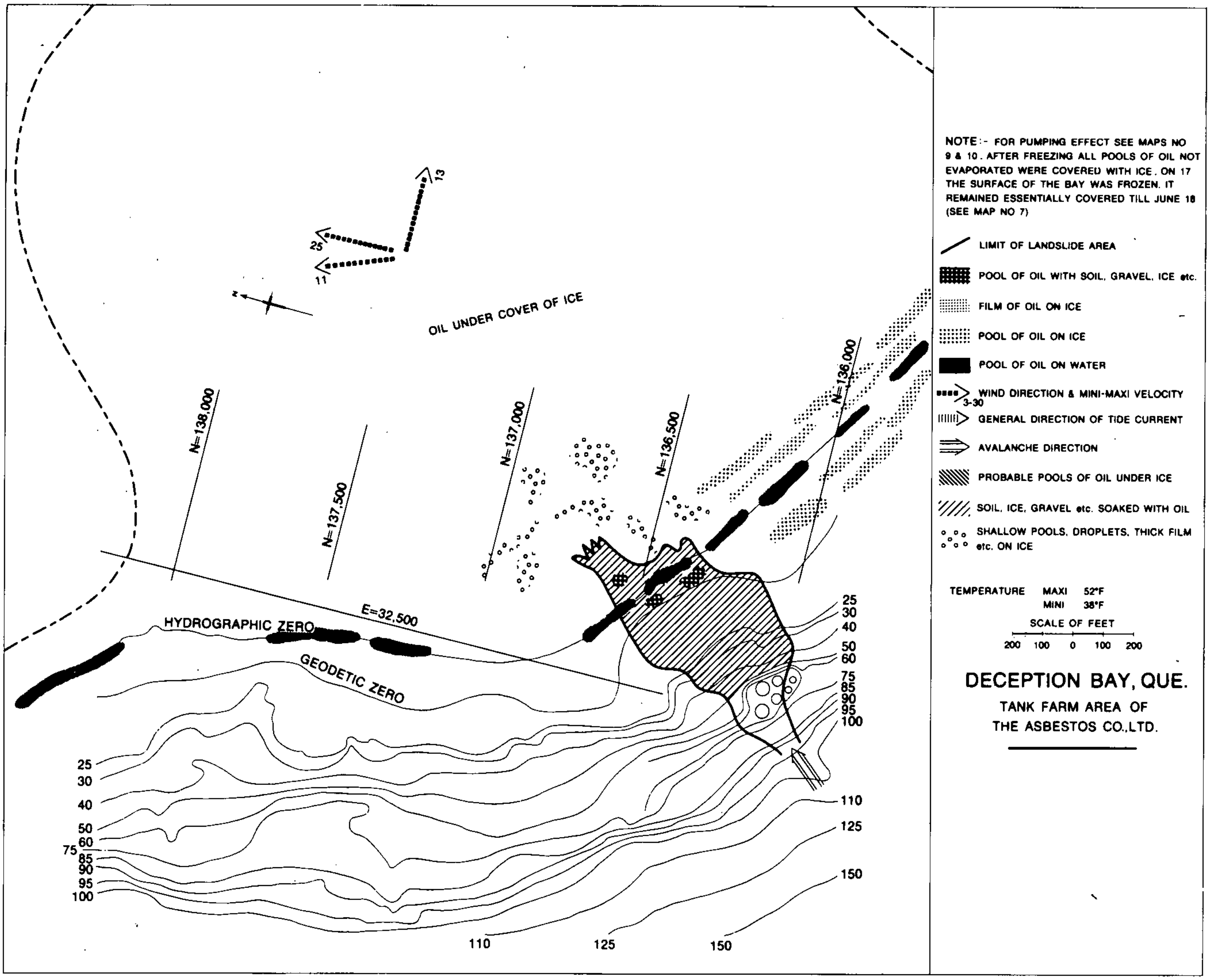
Map No. 5. Approximate situation on June 13 and 14, 1970.



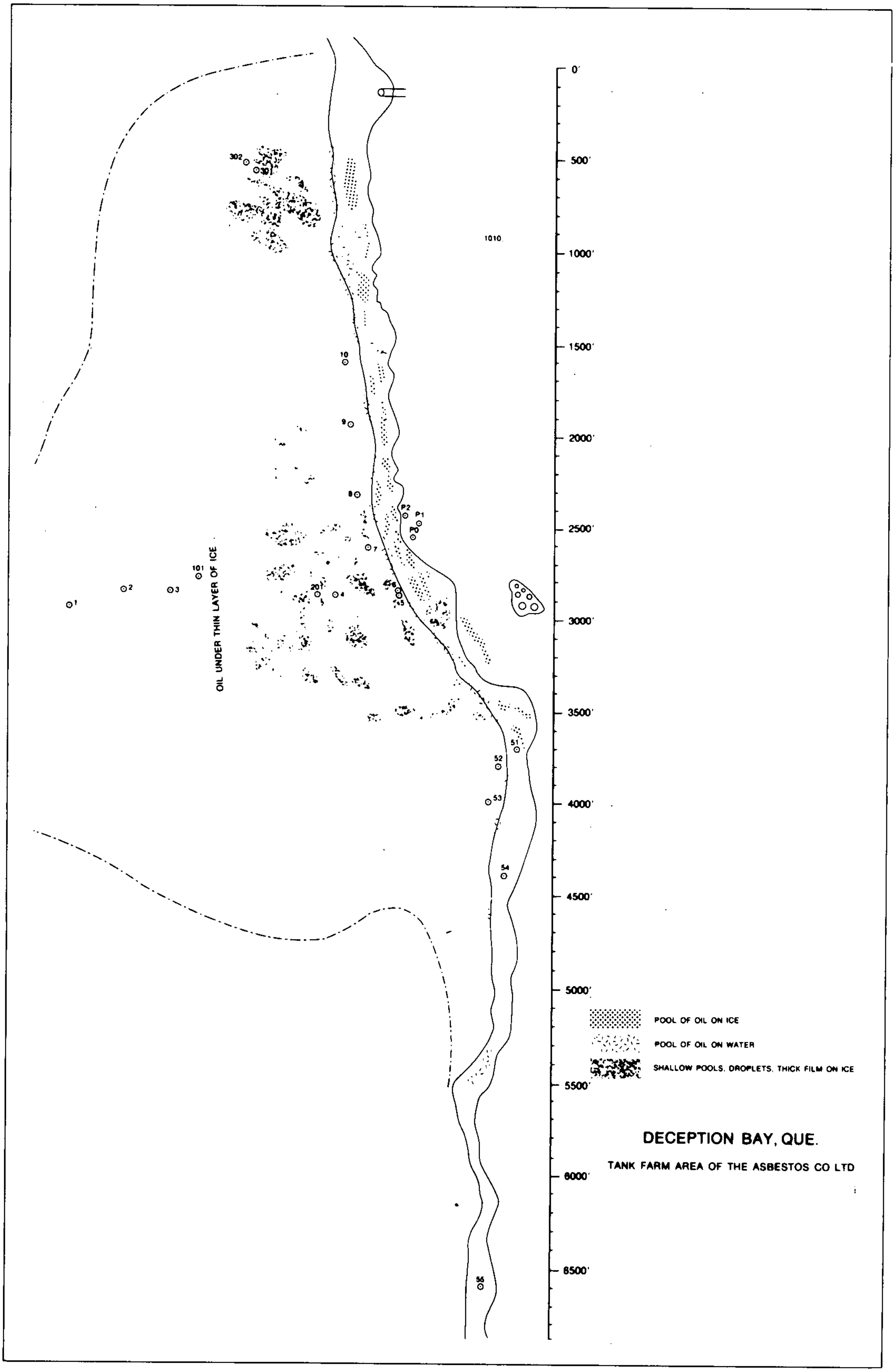
Map No. 6. Approximate situation on June 15, 1970 after 16:00 hr.



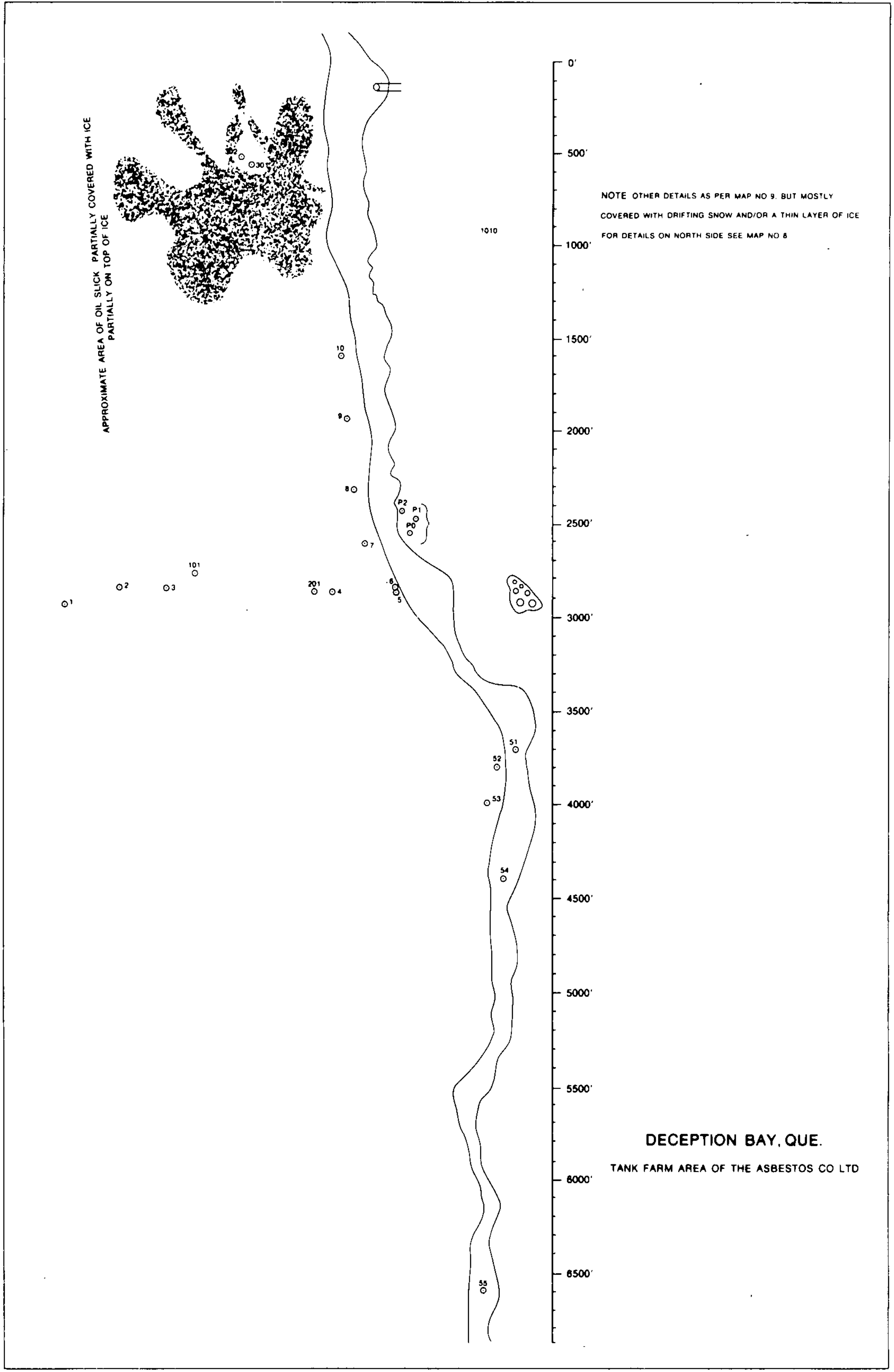
Map No. 7. Approximate situation on June 16, 1970.



Map No. 8. Approximate situation on June 17 and 18 (morning), 1970.



Map No. 9. Approximate situation on June 16, 1970.



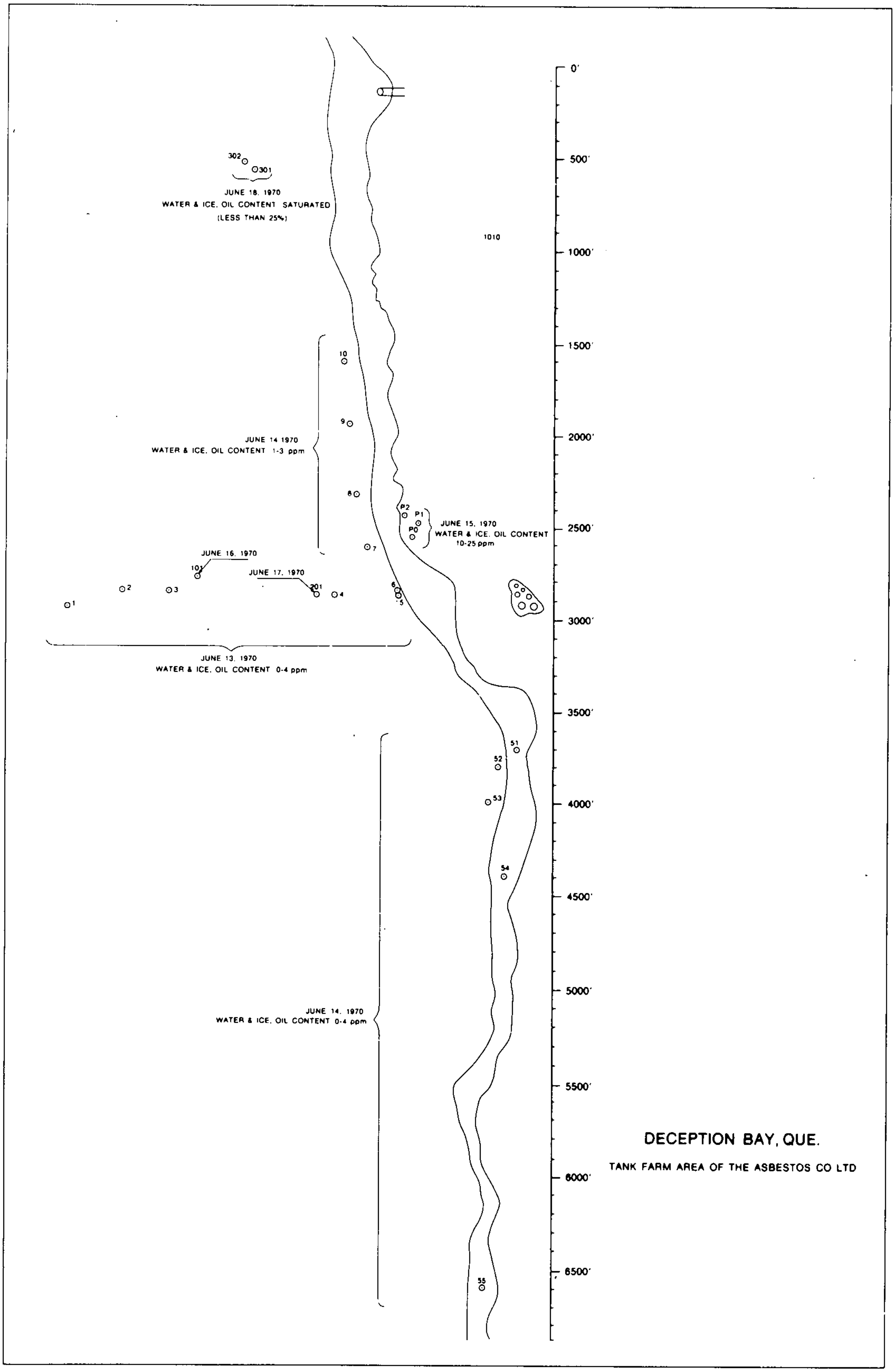
NOTE OTHER DETAILS AS PER MAP NO 9. BUT MOSTLY COVERED WITH DRIFTING SNOW AND/OR A THIN LAYER OF ICE

FOR DETAILS ON NORTH SIDE SEE MAP NO 8

DECEPTION BAY, QUE.

TANK FARM AREA OF THE ASBESTOS CO LTD

Map No. 10. Situation on June 17 after 24 hours of steady pumping.



Map No. 11. Location of sampling holes on ice, soil samples, dead animals, and quadrats.

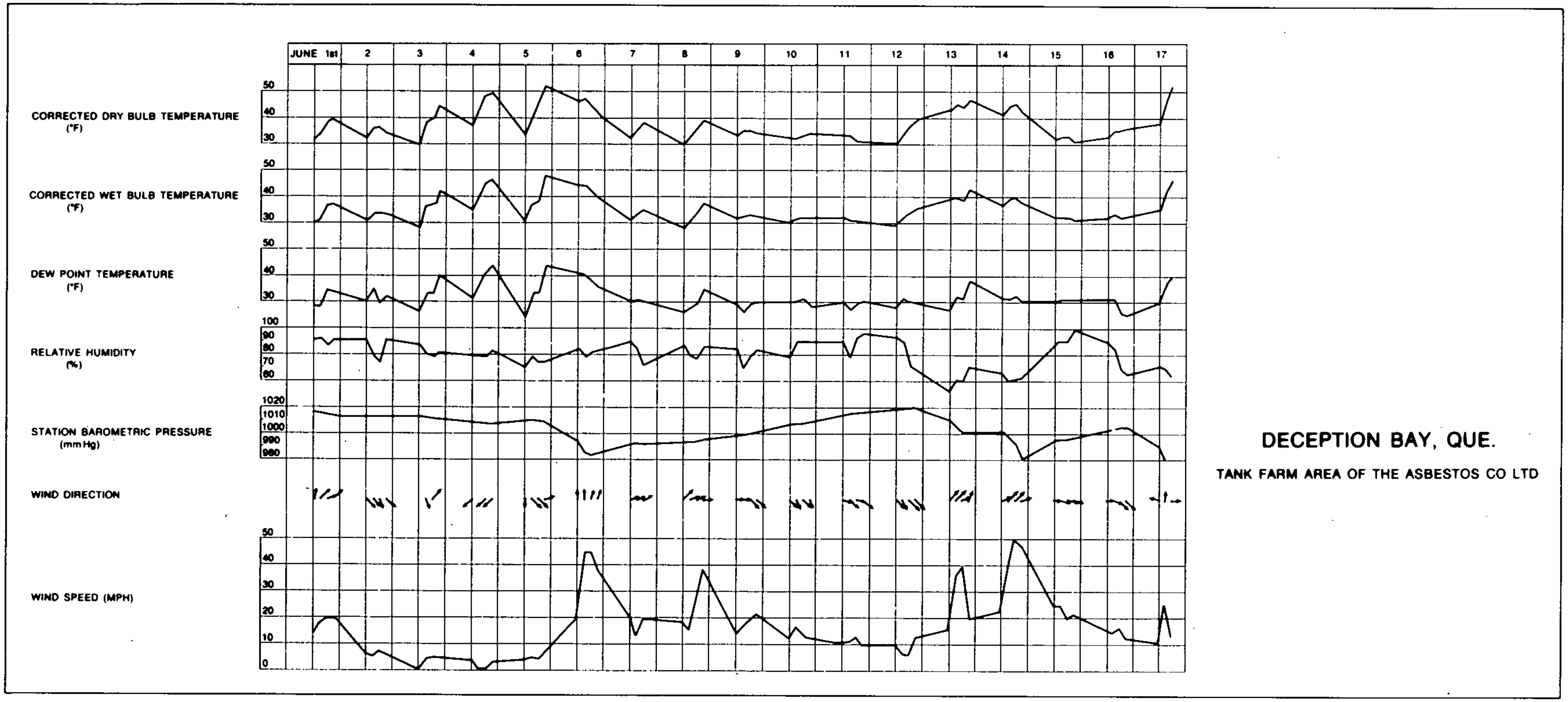


Figure 7.1 Simplified meteorological records from the meteorological station at Deception Bay.