GEOLOGICAL SETTING AND SURFICIAL SEDIMENTS OF FATTY BASIN, A SHALLOW INLET ON THE WEST COAST OF VANCOUVER ISLAND, BRITISH COLUMBIA

by

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April, 1971

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ABSTRACT

Fatty Basin and Useless Inlet result from modification by water and ice erosion of depressions caused by Early Tertiary faulting. Uplift of the land due to post-glacial rebound is in excess of 6 m (20 ft) for the last 7000 years.

Shallow entrance sills cause the inlets to act as traps for organic detritus brought in by tidal action. The rate of deposition of fine-grained suspended debris is in the range of 900 g/m^2/year, with maximum deposition during late summer, when phytodetritus is most abundant.

Five sedimentary environments exist in Fatty Basin, namely mud zones, rock slopes, beaches, deltas, and zones of strong currents. In addition to boulder accumulations and bedrock exposures, general categories of sediments are pebbles and gravels, terrestrial sands, shell debris, muds, and shell-gravel mixtures. Statistical analysis of the size distribution of 125 samples resulted in recognition of 8 groups of sediments, which were then subdivided into 13 types on the basis of composition and grain shape. Olive-green mud rich in organic matter covers almost three-quarters of the bottom surface in the Basin. Coarse terrestrial sands are derived mainly from bedrock exposures within about 300 ft of the shore, whereas most of the fine sands, silts, and clays originate from glacial sediments. The source area for glacial debris is in the Henderson Lake region, underlain dominantly by Karmutsen basalts. Shell debris, notably barnacle plates and calcareous worm tubes, is essentially confined to the rock-slope

environment, where it accumulates in a narrow zone along the base of steep slopes.

The rock-slope environment represents a preferred habitat for lobsters, because it offers better shelter and food supply than the other environments. In Fatty Basin, the total area most suitable to lobsters amounts to about 38,000 m^2 (= 7% of the bottom surface), in Useless Inlet, this area covers 135,000 m^2 (= 5% of the bottom surface).

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ACKNOWLEDGMENTS

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The writer is grateful to Mr. and Mrs. Charles Hill, who made life in the Fatty Basin camp enjoyable and the summer 1969 a most memorable one, and to Miss Elizabeth Amezcua for typing the final draft of this thesis.

INTRODUCTION

1. Nature and Objective of Study

Fatty Basin is located in the northeast corner of Barkley Sound on the west coast of Vancouver Island, near the head of Useless Inlet and just north of the entrance into Alberni Channel (Figure 1). In 1964, the Basin was chosen by the Fisheries Research Board of Canada as a suitable site for a lobster transplant experiment, to be conducted by the Nanaimo Biological Station. A permanent camp and hatchery were constructed, and in 1965 the first lobsters were introduced into Fatty Basin.
Numerous and intensive studies have been carried out since that time, mostly concerned with the ecologic and oceanographic characteristics of the Basin and neighboring inlets. The present investigation on the geological environment of Fatty Bassin and Useless Inlet is one of a series on all important aspects of the lobster habitat. Furthermore, it is an attempt to recognize characteristics of marine sedimentation within these shallow inlets, and to relate them to similar coastal features in British Columbia and strongly glaciated areas elsewhere.

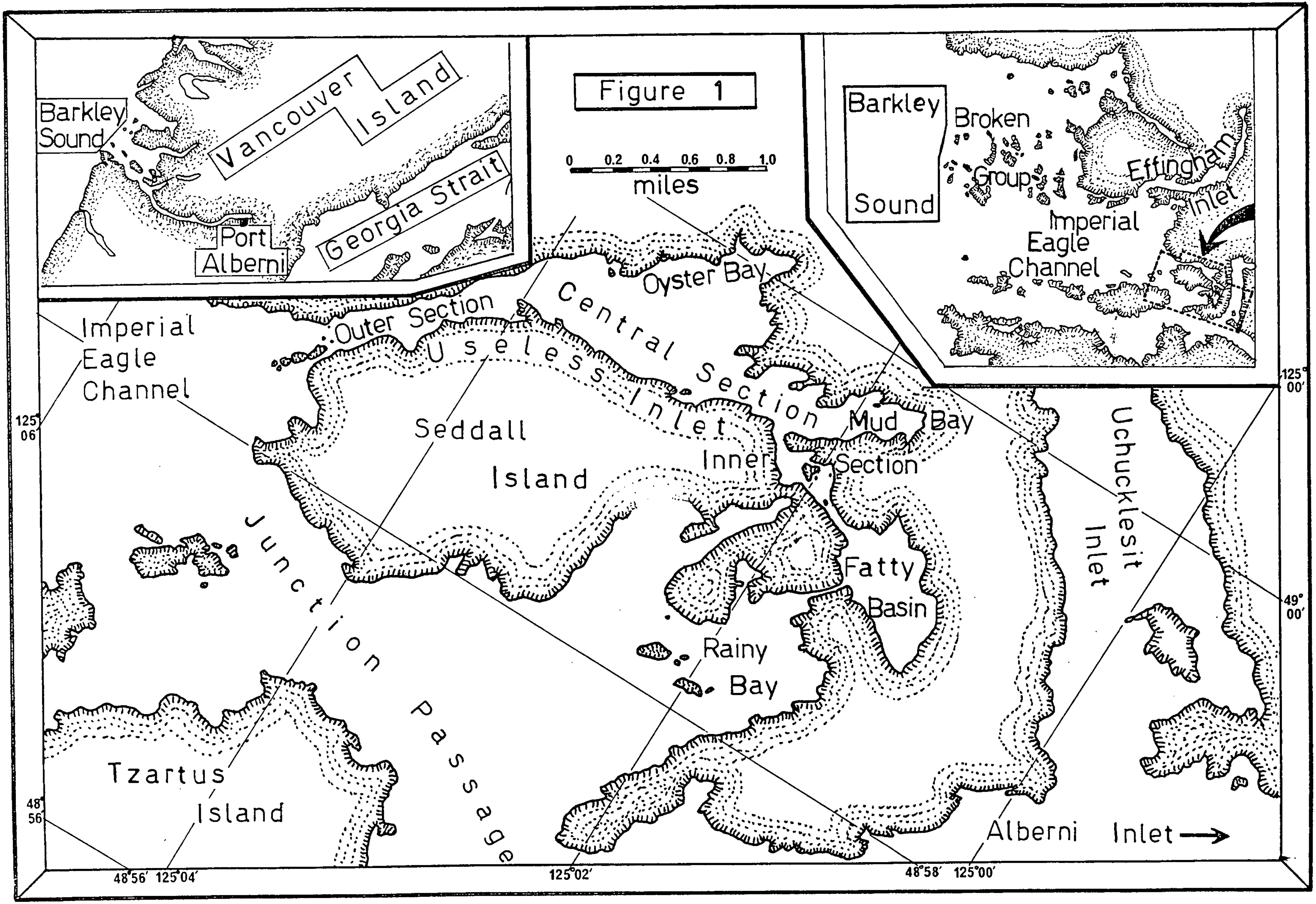


Figure 1
Barkley Sound
Vancouver Island
Georgia Strait
Port Alberni
0 0.2 0.4 0.6 0.8 1.0
miles
Barkley Sound
Broken Group
Effingham Inlet
Imperial Eagle Channel
Imperial Eagle Channel
Outer Section
Central Section
Oyster Bay
Useless Inlet
Mud Bay
Inner Section
Seddall Island
Fatty Basin
Rainy Bay
Junction Passage
Uchucklesit Inlet
Tzartus Island
Alberni Inlet
125° 06′
125° 00′
49° 00′
48° 56′
48°56′ 125°04′
125°02′
48°58′ 125°00′

2. Field and Laboratory Work

Sediment samples were collected from boats provided by the Fisheries Research Board at the Fatty Basin station, which included:

(i) A diesel-powered work boat of about 15 ft length, equipped with a small hydraulic winch;

(ii) a flat-deck boat, consisting essentially of a floating platform powered by a small outboard motor;

(iii) a small speed-boat;

(iv) a row boat.

Most of the bottom sampling was done with a miniature version of a Pettersson grab sampler. A small snapper was also used, but proved unsatisfactory on many occasions.

Coring was first attempted with a small Phleger gravity corer. Because of unsatisfactory results, especially in soft muds, coring was then done by hand during Scuba-dives, with only a plastic core liner which was pushed and rotated into soft sediments. Cores up to 2 feet in length were obtained this way.

Many surface sediment samples were collected by hand during Scuba- and skin-diving excursions. This method allowed excellent observation of the sediments 'in situ' as well as selective and representative sampling.

Positioning of sample locations in Fatty Basin was done in a similarly unconventional way. A strong (120 lbs pull) fishing line, with small plastic floats attached at 30 ft intervals, was extended from fixed shore points. At the end of the line, a larger float attached to a heavy anchor kept the line straight and in a steady position, and a subsequent compass reading gave its correct bearing. The boat was then moved along the line, and samples were taken next to each of the plastic floats. Accurate positioning of sample sites to within a few feet was assured by this method.

In the less protected and deeper waters of Rainy Bay and Useless Inlet, however, stronger winds and currents usually prevented such accurate positioning. Consequently, locations of sample sites here were determined mostly by compass readings from the boat to various fixed shore points, with the results estimated to be accurate to within a few tens of feet.

An attempt was made to determine the sedimentation rate and its variations in Fatty Basin throughout a full year. Four sediment bowls (glass jars, opening diameter 7.3 cm, height 18.5 cm) were placed 2 feet above the bottom at four locations within Fatty Basin (Map No. 1), where they were exchanged at approximately monthly intervals by FRB-personnel.

Echosounding runs were done with the "Decibar", a research vessel of the Fisheries Research Board, which is about 30 ft long and probably the largest ship able to enter Useless Inlet and Fatty Basin through the shallow and narrow passages.

Rocks and geologic structures were studied along the shorelines from a boat, and also during several foot traverses along prominent ridges in the area. The study of structures was aided by aerial photographs (1/4 mile to the inch), available for the entire area.

Laboratory work involved sieving and hydrometer methods for grain-size analysis; separation and study of heavy minerals; identification of clay minerals; determination of organic carbon contents; identification of the major shell-bearing fauna.

Detailed accounts of the methods used are presented in the appendix.

3. Previous Work

Previous investigations in the area under consideration were concerned mainly with the biological and physical oceanography of Fatty Basin. They were carried out by the Fisheries Research Board of Canada as part of the lobster transplant project since 1964.

In early 1969, the Canadian Hydrographic Service conducted a depth survey of Fatty Basin on a 30-ft grid pattern. Results of that survey were used in this study for preparation of a bathymetric map of Fatty Basin.

In 1970, Carter completed a PhD-thesis on the surficial sediments in Barkley Sound, which borders the presently studied area. Frequent comparison of results proved helpful to recognize sedimentation characteristics exclusive to the restricted environments of Fatty Basin and Useless Inlet.

1

View of Fatty Basin towards west. The camp is visible in the background centre, reefs 2 and 3 appear just below the water surface, and reefs 1 and 4 form two islands in the background. The object just off the north-delta is a small barge carrying lobster traps. The Big Gut opens in the background to the left, the Small Gut is hidden behind the bluff in the left centre. The picture was taken near the end of a flood tide, and off the two guts, the now slowly inflowing waters cause a very smooth surface as compared to the main part of the Basin.

2

View across Fatty Basin towards north. The large, U-shaped valley in the far background is now occupied by Henderson Lake

3

View across Fatty Basin towards south-west. The narrow passage of the Small Gut, connecting the Basin with Rainy Bay, is clearly visible in the left centre. Tzartus Island appears in the far background left, and the open expanse of Barkley Sound stretches in the far background to the right.

4

Aerial view of the north-western shore of Fatty Basin, with the camp in the centre, reef 1 in the foreground, reef 4 in the far left centre, and the north-delta (flooded) in the right background.

5

View into the Outer Section of Useless Inlet from Junction Passage. High mountains of the Vancouver Island Ranges are visible in the background.

6

View of Rainy Bay from a high hill south-east of Fatty Basin.

THE SETTING

1. Geomorphology

Low, rounded, heavily forested hills characterize the immediate vicinity of Fatty Basin, strongly reflecting the effects of heavy Pleistocene glaciation. Steep cliffs, in most cases nearly vertical, are common along the many faults and fracture zones criss-crossing the area. Along the NW-side of Useless Inlet and NE-shore of Uchucklesit Inlet and thus bordering the area of interest, mountains of the Vancouver Island Ranges (Holland, 1964) rise steeply to over 700 m, whereas near Fatty Basin the maximum elevation is only about 250 m. Most slopes are covered with heavy overburden, largely due to extensive deposits of glacial drift, confining rock outcrops to shorelines and fault cliffs.

Fatty Basin is a shallow, bowl-shaped, elongate depression about 4000 ft (1220 m) long, up to 2000 ft (610 m) wide, and 104 ft (32 m) deep. Connection with the ocean is through two narrow passages, the "guts". The Big Gut, between the Basin and Useless Inlet, is about 900 ft (275 m) long, of about 120 ft (37 m) average width (with a minimum width of only 20 ft at the very narrow NW-end), and with about 3 ft (1 m) average depth at low tides. The Small Gut, between the Basin and Rainy Bay, is about 800 ft (244 m) in length, averages 35 ft (11 m) in width, and 4 ft (1.2 m) in depth at low tides (the NE-end into the Basin, however, is completely exposed at very low tides!).

Two small, rocky island in the Basin rise above high-tide level, and two more are exposed at low tides. All are referred to as "reefs" here. Five other rock exposures within the Basin rise only a few feet above the muddy bottom, but are nevertheless fairly extensive. The camp is located on an outcrop extending from the shore into the Basin, and is forming an island at high tides.

The maximum depth of about 104 ft (32 m) is reached in one of two deep depressions ("holes") just off the Small Gut, which act as traps for coarse debris being swept into the Basin through the two guts.

Fresh water inflow is maintained by three permanent creeks, which debouch at the north and south ends and the north-eastern side of the Basin, and by several seasonal creeks and trickles, whose mouths lie mostly along the eastern shore.

Useless Inlet may be separated into three parts, which are named here the Outer, the Central, and the Inner Section, all differing distinctly from each other.

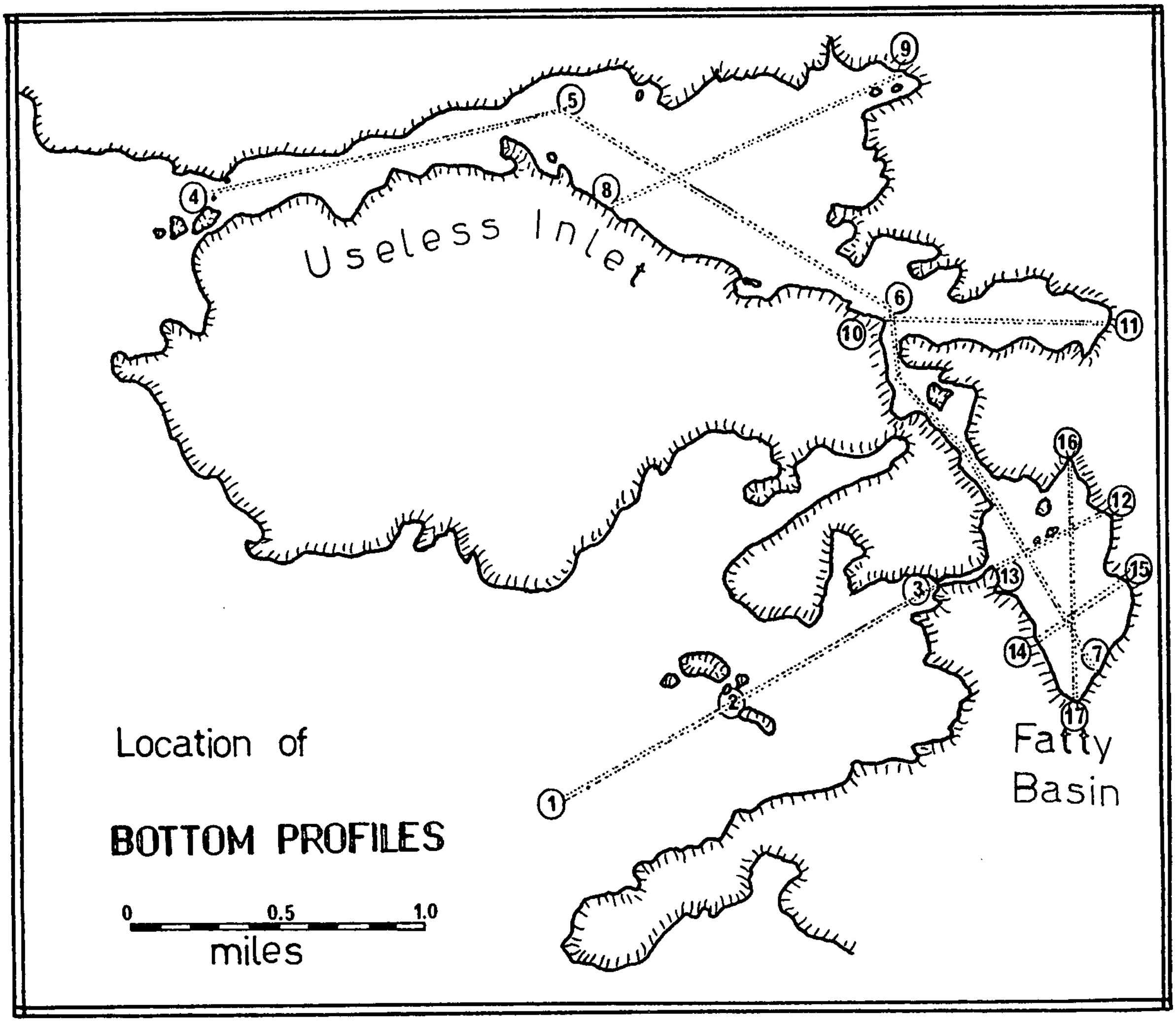
In the Outer Section (Plate III, Photograph No. 5), the inlet is of the fjord type common to the west coast of Vancouver Island (e.g. Effingham Inlet, Pipestem Inlet). A straight channel of about 5500 ft (1678 m) length extends from the inlet mouth to the Central Section. The NW-shore is very straight and steep, but the SE-shore has a gentler slope and is dissected by many small bays. Here, several almost vertical cliffs strike nearly at right angles to the general shoreline direction.
The bottom topography is irregular, with numerous small depressions and rises (see Figure 3), and differs from most other fjords in its sedimentary

cover, which is predominantly sand. A rocky sill of about 6 fathoms (11 m) depth occurs at the mouth of the inlet, but some rocks here protrude right up to above the surface, rendering the entrance narrow and treacherous for any larger ships.

The Central Section has the deepest point of Useless Inlet (34 fathoms = 62 m). Unlike typical fjords, this part is very wide relative to its length, with a strongly indented shoreline along its northern side. The bottom topography, however, is smooth, with sediment, dominantly mud, blanketing any irregularities that may have existed. Whereas only one small, permanent creek flows into the Outer Section, several relatively large creeks enter the Central Section and have brought abundant sediment to this part of the inlet, which has resulted in an extensive development of deltas.

The Inner Section, with a bedrock sill at its entrance, is but a narrow branch-off from the Central Section; the actual head of Useless Inlet is formed by Mud Bay within the Central Section. The Inner Section may be envisaged as a passage between Fatty Basin and Useless Inlet, not being an integral part of either, but for the purpose of this paper it is regarded as a section of Useless Inlet. It is characterized by a very irregular bottom topography, with numerous rocky rises separating small basins, and by shallow depth with a maximum of 8 fathoms (15 m).

Rainy Bay is a wide bay open to the more exposed waters of Junction Passage. Several rocky islands form part of a bedrock sill across its mouth, but near the SE-shore this sill is poorly developed. Some large bedrock exposures rise to within 8 fathoms (15 m) of the

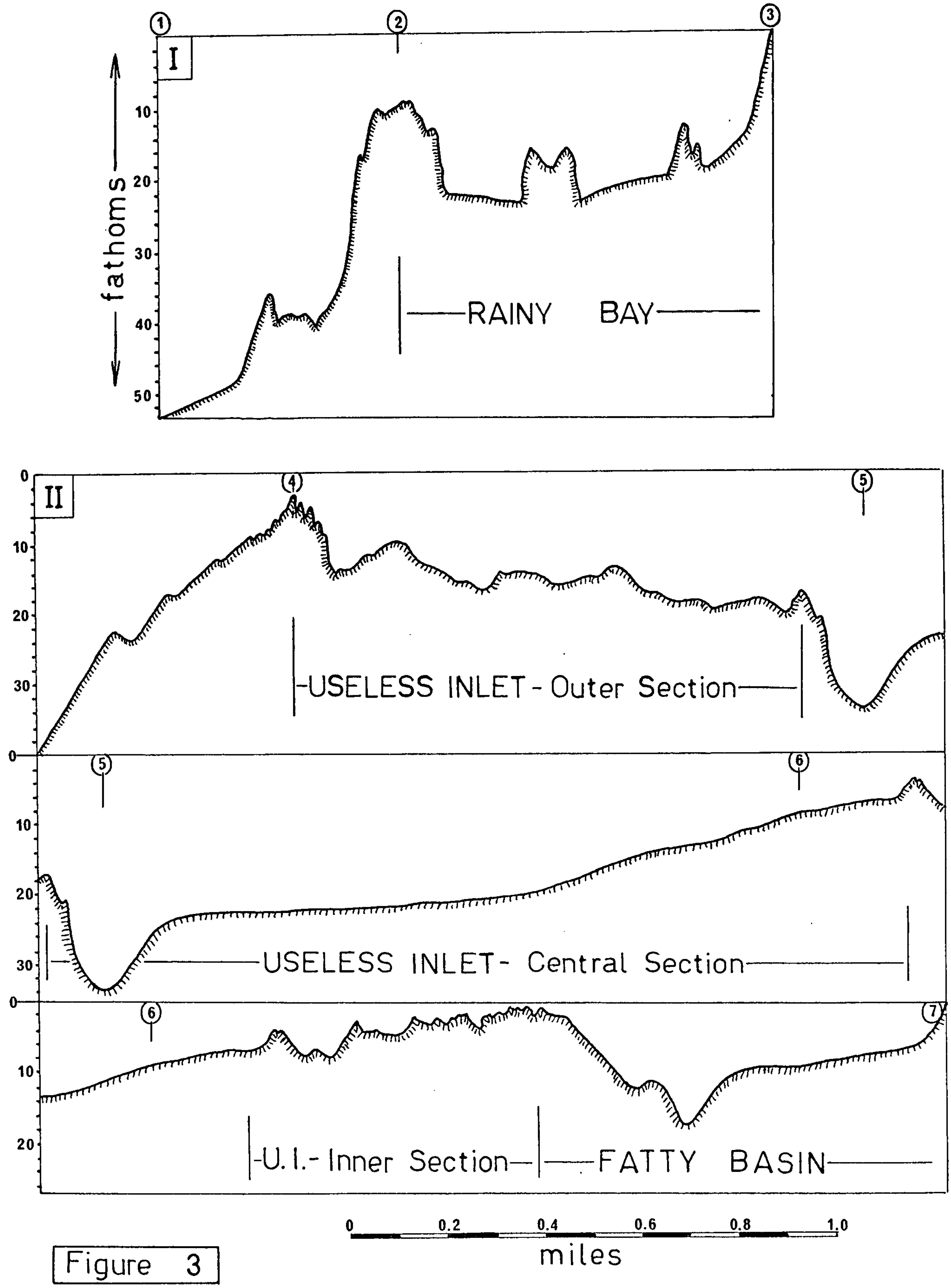


The map indicates locations of the bottom profiles presented on the following pages.

Vertical exaggeration on all profiles is approximately 1 : 13 .

Depths are given in fathoms (1 fm = 6 ft).

Figure 2



1
2
3
I
fathoms
10
20
30
40
50
RAINY BAY
II
0
4
5
10
20
30
USELESS INLET - Outer Section
0
5
6
10
20
30
USELESS INLET- Central Section
0
6
7
10
20
U.I.- Inner Section
FATTY BASIN
0
0.2
0.4
0.6
0.8
1.0
miles

Figure 3

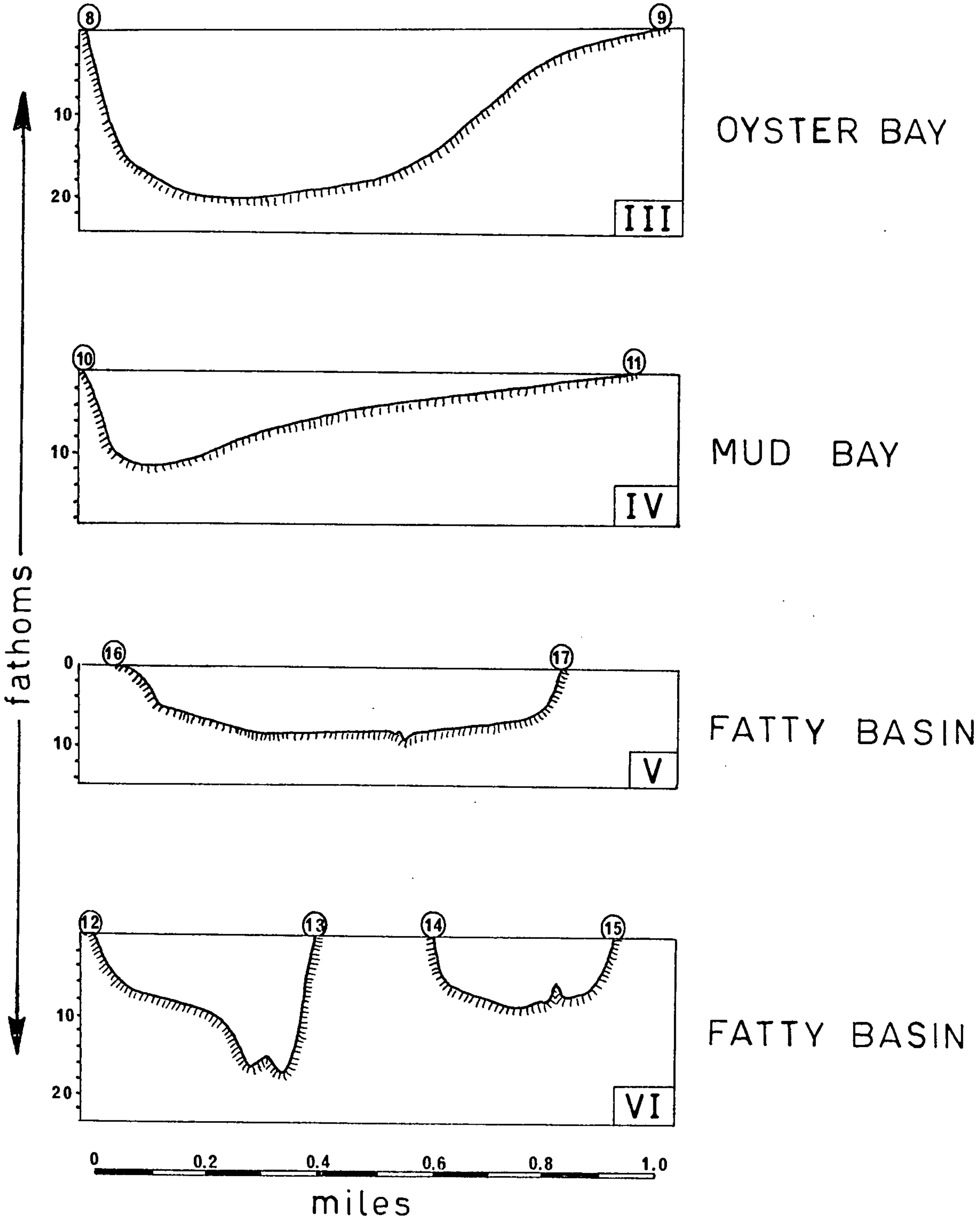

OYSTER BAY
MUD BAY
FATTY BASIN
FATTY BASIN
III
IV
V
VI
fathoms
0
10
20
0
0.2
0.4
0.6
0.8
1.0
miles
8
9
10
11
12
13
14
15
16
17

Figure 4

surface, but most of the bottom of Rainy Bay is blanketed with the common olive-green mud, giving the bay a smooth bottom topography.

2. Pre-Pleistocene Geology

Rock exposures in this region are mostly confined to shorelines and fault cliffs, because the slopes are generally covered with heavy overburden, thick underbrush, and forest. Examination of the rocks, therefore, had to be limited to the shorelines in most places. The intricate system of inlets and bays, however, offered an excellent picture of the geology of the area. Furthermore, most of the many faults are very evident both in nature and on aerial photographs.

Following are generalized descriptions of the major rock units exposed in the Fatty Basin - Useless Inlet area (Figure 5). The stratigraphic nomenclature is that of Muller and Carson (1969).

(i) Volcanic rocks of the Bonanza Subgroup (Upper Triassic to Lower Jurassic) dominate the area of interest. They are characterized by andesites, dacites, and tuffs, with andesites the by far most abundant. Occurring as distinct flows of various thicknesses, the andesites are mostly greenish-grey to reddish-brown, but great variation may be found; the individual flows usually are sharply defined by an abrupt change in colour. The mineralogy consists dominantly of phenocrysts and microlites of intermediate plagioclase, associated with small amounts of (clino-)

pyroxene and very little hornblende; secondary minerals like chlorite, calcite, and epidote are commonly present. Chlorite alteration is widespread and probably responsible for most of the greenish colour tints. Small amounts of calcite and epidote are almost ubiquitous throughout the andesite flows, and secondary quartz commonly occurs as fillings of fractures and vugs.

Dacites and ryhodacites are relatively rare and have been observed mostly along the northern shore of Fatty Basin. Lithic tuffs, graded by gravity sorting, occur sporadically and are best exposed at a few localities in the Basin.

(ii) The Quatsino Formation (Upper Triassic) is exposed mostly as massive, light to dark grey limestone, with extensive outcrops along southern Seddall Island and the NE-Shore of Uchucklesit Inlet. Predominantly fine-grained, the limestone is in many places crystallized to a fine-sugary or coarsely-crystalline texture near contacts with volcanic rocks. These contacts commonly appear in intricate shapes, with veins or minute veinlets of andesite extending far into the limestone. Frequently, andesite fragments are scattered throughout the contact zone of a carbonate rock, and in at least one case (Uchucklesit Inlet), a breccia of large volcanic fragments within a light-grey, fine-grained matrix was observed over a zone about 30 feet wide. Features like these are possibly the results of lava flows being extruded over poorly consolidated lime muds of the present Quatsino Formation.

On the SE-shore of Mud Bay in Useless Inlet, a small exposure of limestone breccia was observed. Angular limestone blocks of various sizes here are densely scattered throughout a fine-grained, light grey limestone matrix, and in these blocks the only fossils within the area of interest were found. They were recognized as crinoid stems, but poor preservation prevented further identification.

(iii) Diorites occur in two small exposures in Fatty Basin and near the mouth of Uchucklesit Inlet, respectively. The latter is a slightly altered hornblende diorite, with some of the hornblende replaced by chlorite and epidote. The rock in the Fatty Basin outcrop, however, has undergone excessive alteration, and most of its hornblende has been replaced by chlorite and epidote. Remnant grains of clinopyroxene are surrounded by a dense mass of finely-fibrous tremolite-actinolite, chlorite, and epidote, and the effects of the Quatsino limestone, which probably was penetrated by this small diorite stock, are apparent in the form of abundant calcite throughout the rock, an otherwise rather uncommon feature within diorites.

These intrusives are most likely part of the West Coast Diorite, which in turn may be part of the West Coast Crystalline Complex (Muller and Carson, 1969). They are excellently exposed on Tzartus Island across Junction Passage, and appear as fine to medium grained hornblende diorites. The unaltered rock consists mainly of plagioclase (andesine) and hornblende, associated with only minor quartz and potash feldspar; accessory minerals are epidote, magnetite, biotite, and sphene.

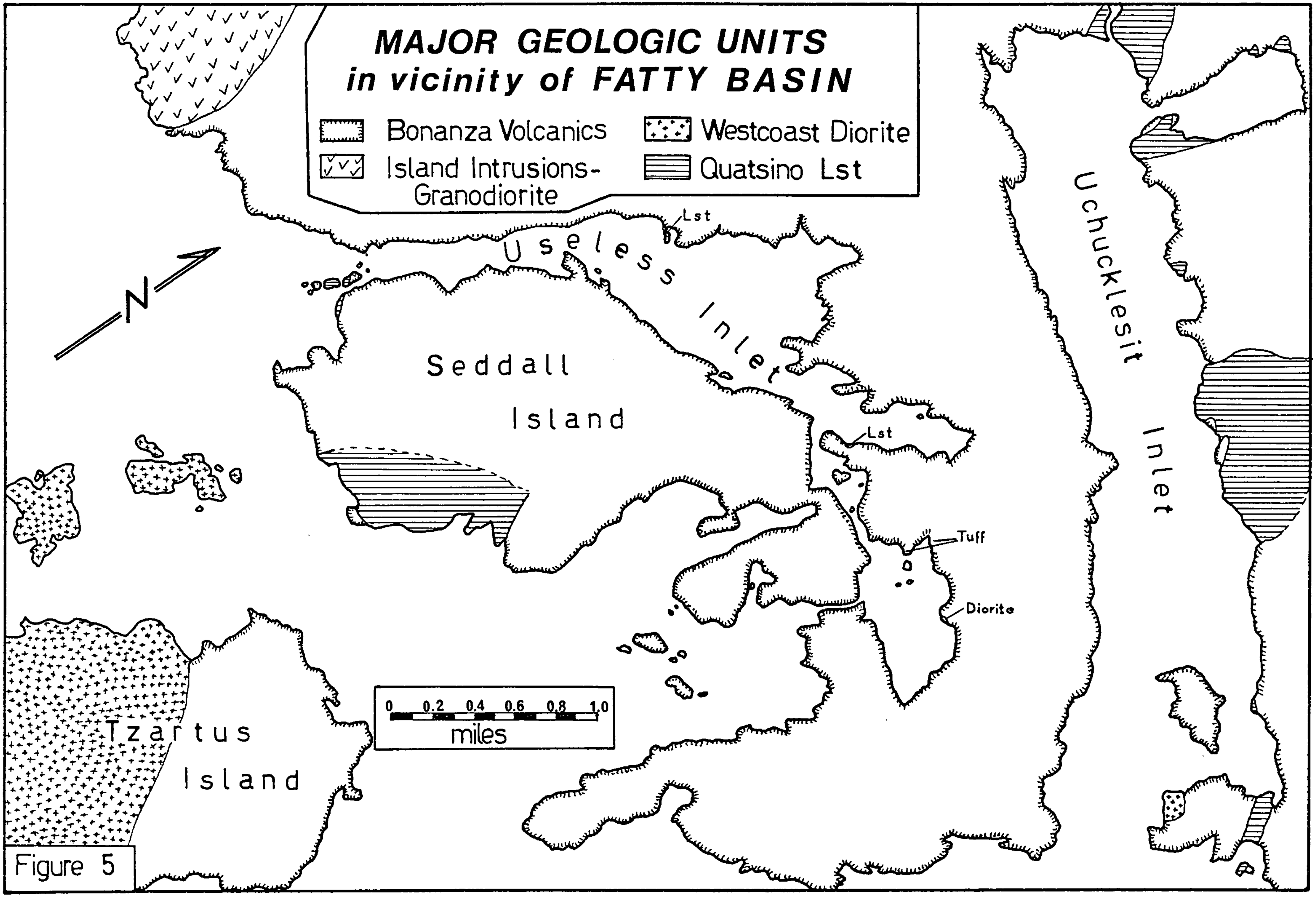
(iv) About 4000 feet west of the Useless Inlet entrance, the contact between Bonanza volcanics and granodiorites of the Island Instrusions (Middle to Late Jurassic) is exposed on the shore. This intrusive is part of the Kennedy Lake Batholith and consists mainly of plagioclase (oligoclase), with minor quartz, hornblende, potash feldspar, biotite and chlorite, and accessory magnetite, apatite, and sphene.

(v) The Karmutsen Formation (Lower to Upper Triassic), which is characterized by extensive green, massive basalts, is exposed along Henderson Lake (north of Uchucklesit Inlet) and Alberni Channel. It does not appear in the immediate vicinity of Fatty Basin and is not shown on Figure 5, but it constitutes an important source for the sediments of the area.

The basalts consist mainly of plagioclase (andesine to labradorite), associated with minor hornblende, clinopyroxene (augite), and magnetite. The matrix is very rich in chlorite, and numerous veins are filled with chlorite, epidote, or feldspar.

(vi) Mafic dykes, 5 to 15 feet wide, have been observed in a few outcrops in both Fatty Basin and Useless Inlet. They tend to follow the directional trends of major faults and fracture zones.

The mineralogy of the dykes is dominated by feldspar (andesine to labradorite) and clinopyroxene (augite). Epidote is very abundant, and minor replacement by chlorite and tremolite-actinolite was observed.


MAJOR GEOLOGIC UNITS
in vicinity of FATTY BASIN
Bonanza Volcanics
Westcoast Diorite
Island Intrusions-Granodiorite
Quatsino Lst
N
Useless Inlet
Lst
Seddall Island
Lst
Tuff
Diorite
Uchucklesit Inlet
Tzartus Island
0 0.2 0.4 0.6 0.8 1.0
miles
Figure 5

3. Origin of the Inlets

Numerous faults and fracture zones criss-cross the Fatty Basin - Useless Inlet area and are strikingly apparent on aerial photographs. Their distribution is presented in Figure 6, and their directional trends are summarized in the frequency rose of Figure 7 (a). From the latter, two dominant strike directions for the faults and fracture zones can be recognized, one of them trending S 60° W - N 60° E, the other N 60° W - S 60° E.

Interestingly, these directions appear to coincide with the general trends of inlets and bays. On Figure 7 (b), such directional trends have been superposed upon the frequency rose as determined from the surface fractures alone. The obvious coincidence in preferred directions suggests a major influence of the faults and fracture zones upon the origin of the bays and inlets.

The relationship between fault structures and coastal depressions becomes very apparent when both are actually observed in the field. Faults and wide shear zones commonly parallel the shoreline, and often the steep to vertical bedrock slopes along the inlet perimeters are actual fault faces. In other cases, faults strike at some angle to the coastline, causing offsets of the latter by as much as 30 feet and forming vertical to overhanging cliffs. Both the Big Gut and Small Gut are surface expressions of wide shear zones, which, due to the soft nature of the strongly sheared rocks, have been preferentially eroded by ice and water.

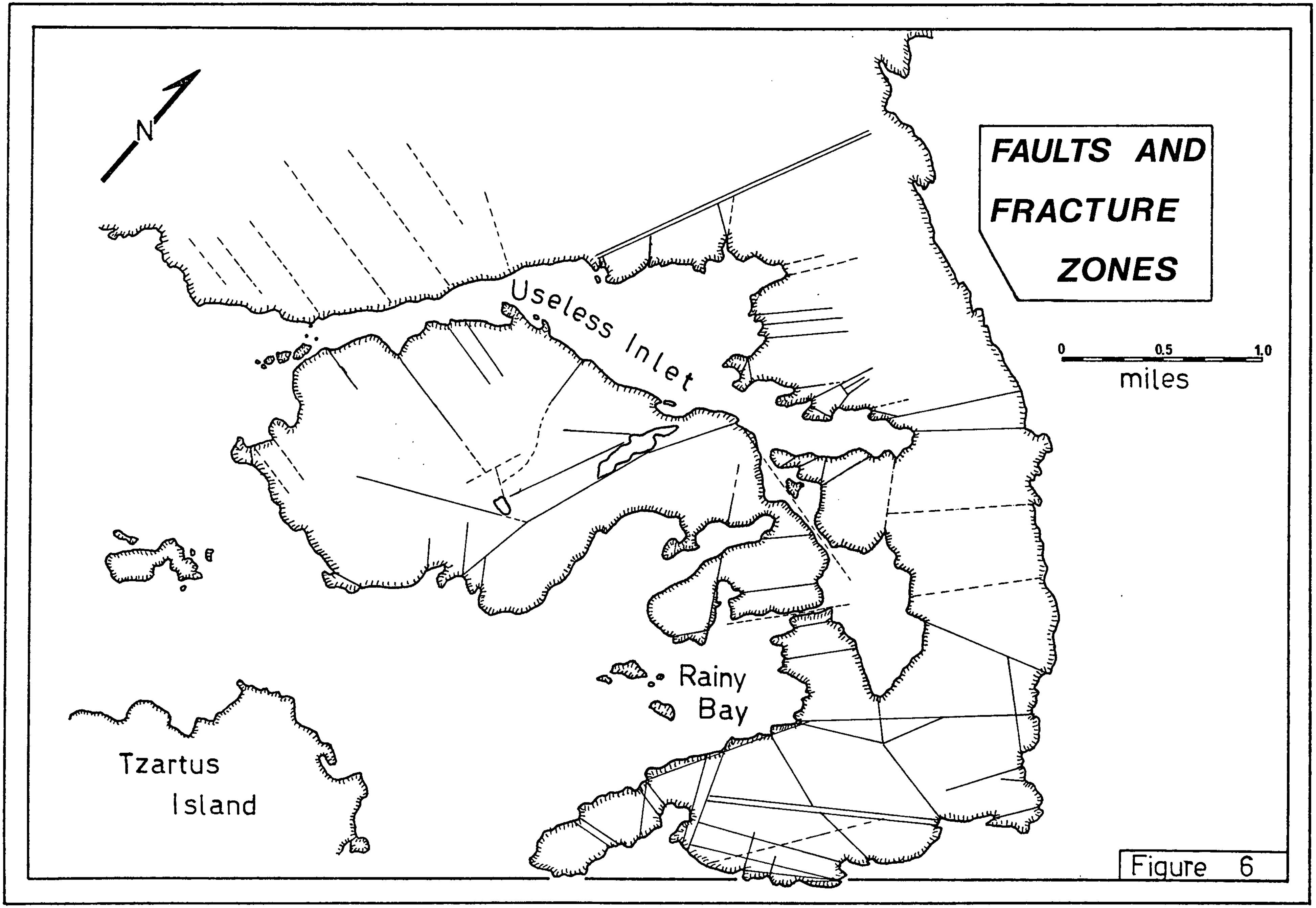
The shear-zones likely originated before completion of the extrusion of the Bonanza volcanics. Narrow dykes of strongly fractured andesite and andesite-breccia in the immediate vicinity of and parallel to some of the wide shear-zones (most notably the Big Gut), have been intruded into these zones of weakness, located probably at the contacts between previously extruded lava flows. The rocks forming the dykes are andesites similar to most of the surrounding bedrock, which suggests that they are probably also part of the Bonanza volcanics. The shear-zones may therefore have originated towards the end of the extrusion of the Bonanza subgroup in early Jurassic time. Thus, since they follow the dominant directions discussed above, the latter also seem to have originated in the Early Jurassic.

A major episode of block faulting occurred along the west coast of the present Vancouver Island during Early Tertiary (Muller, 1969). We assume the faults of the Fatty Basin area to have formed during that time, following the pre-existing directional trends of the many shear-zones.

Most of the faults dip 70° - 90°, but good evidence for the direction of movement is scarce. Only in the small canyon above Oyster Beach were structures resembling slickensides observed, which here pitch about 80° on a steeply dipping fault cliff. Numerous minor faults, however, show vertical displacements of up to several feet, and both the similarity between these and the large faults as well as the criss-crossing network of steep fault scarps suggest that the major fault structures had the same sense of motion. Most of the fault movement probably was of the dip-slip type, with only minor lateral displacements.

A few low-angle faults occur in the area, but these are unrelated to the main fault system. They cut older fractures with little displacement, they do not seem to be associated with any shear zones, and their strike directions seem to be at random relative to the directional trends followed by other faults.

In conclusion, it is suggested that the inlets of the Fatty Basin - Useless Inlet area originated primarily from large-scale block faulting during the early Tertiary. Depressions formed at that time were subjected to subsequent erosion and possibly renewed minor faulting. The final shape of the inlets was attained during the last glacial period, when ice flows concentrated in and accentuated the depressions.



N
FAULTS AND
FRACTURE
ZONES
0
0.5
1.0
miles
Useless Inlet
Rainy
Bay
Tzartus
Island

Figure 6

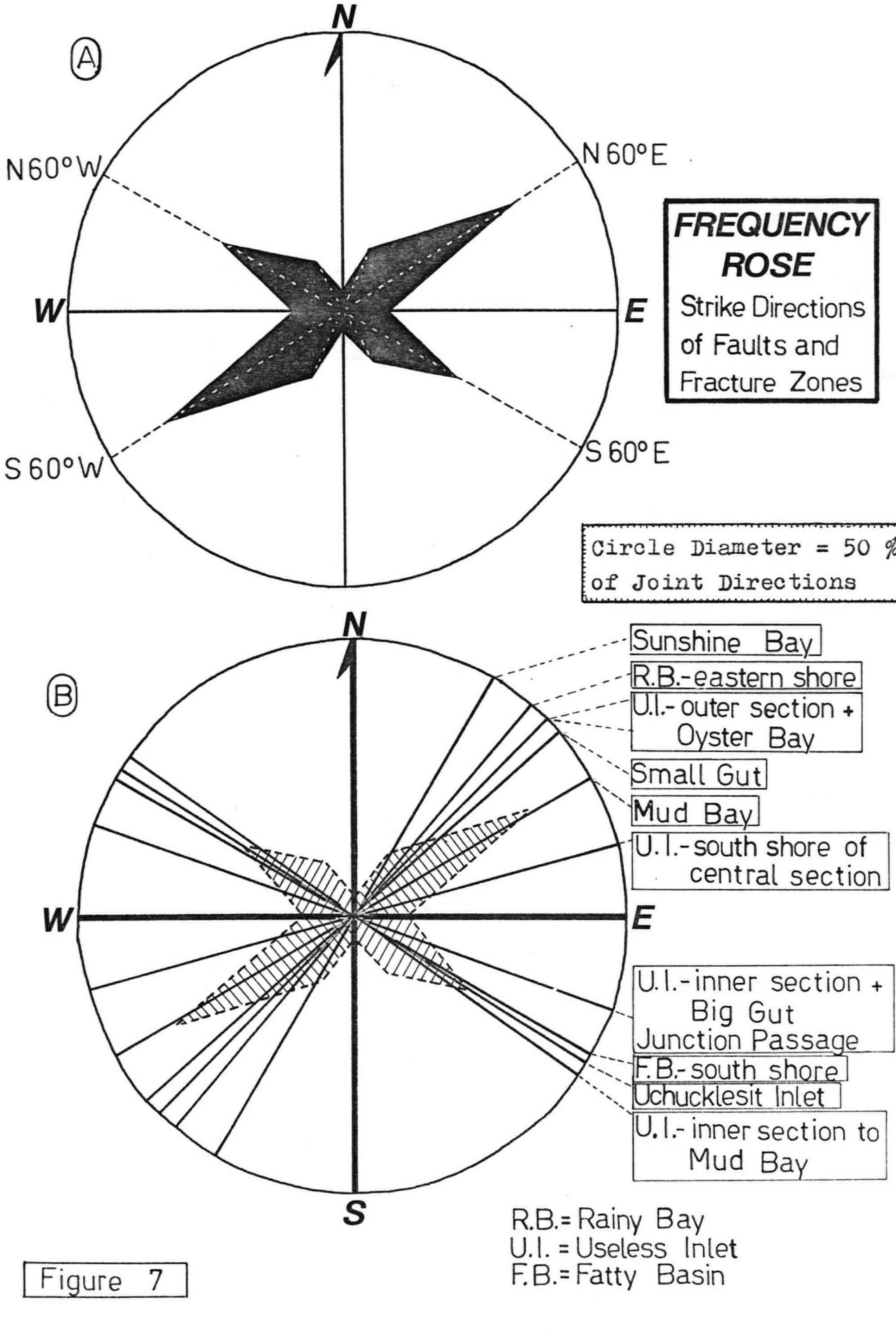

A
N
N 60° W
N 60° E
W
E
S 60° W
S 60° E
FREQUENCY ROSE
Strike Directions of Faults and Fracture Zones
Circle Diameter = 50 % of Joint Directions
B
N
W
E
S
Sunshine Bay
R.B.-eastern shore
U.I.- outer section + Oyster Bay
Small Gut
Mud Bay
U.I.- south shore of central section
U.I.-inner section + Big Gut Junction Passage
F.B.-south shore
Uchucklesit Inlet
U.I.- inner section to Mud Bay
R.B.= Rainy Bay
U.I. = Useless Inlet
F.B.= Fatty Basin

Figure 7

4. Glacial History

The region was last covered with ice during the Late Wisconsin Glaciation, which locally corresponds to the Vashon Stade of the Fraser Glaciation. Starting at about 25,000 years B.P., the ice advanced and reached a maximum approximately 15,000 to 17,000 years ago, when it extended to the continental break about 40 miles west of Barkely Sound (Carter, 1970). The ice then receded rapidly, and with diminishing thickness, it formed valley glaciers on the present west coast of Vancouver Island. Such glaciers last covered the Fatty Basin area between 11,000 and 12,000 years ago, at that time retreating towards the north-northwest (Henderson Lake). Most of the glacial drift, mainly cobble- and pebble-sands, probably originated from these retreating valley glaciers, whereas clayey silts were deposited earlier under the more extensive ice cover.

Evidence for the glacial past is abundant throughout the area of interest, in the form of U-shaped valleys and, on bedrock exposures, numerous deep grooves, striations, irregular furrows, and generally smooth, rounded surfaces. The ice flow directions were strongly influenced by the topography, since glacial striations parallel the shorelines of the inlets in most cases. Even shallow and narrow depressions like the Big Gut, which trends in a direction almost at a right angle to the over-all ice movement here, deflected the flow of the ice. As discussed in a previous chapter, the depressions are fault-derived and have existed already prior to the glacial advance.

Glacial sediments, as briefly mentioned above, are yellowish-brown tills and medium to light grey clayey silts. Most of the sands, silts, and clays in Fatty Basin and Useless Inlet are derived from these glacial deposits. Since the probable directions of former ice movements are known, the source areas for an appreciable percentage of the terrestrial sediments in this area can be roughly outlined. They are mostly within the Henderson Lake region, underlain predominantly by Karmutsen and Bonanza rocks; Photograph 4 gives a good over-all picture of the entire glacial passage from Henderson Lake to Fatty Basin.

5. Physical Oceanography

Herlinveaux (1966) published an account of the physical oceanography of Fatty Basin and Useless Inlet in volume No. 228 of the Manuscript Report Series of the Fisheries Research Board, and most of the information presented in this chapter is taken from that paper. The data are based on observations during a one-year period from 1964 to 1965.

The factor most responsible for the oceanographic characteristics of Fatty Basin is the constricted nature of the entrance passages, the two guts, which commonly causes a head difference between the sea levels in the Basin, Rainy Bay, and Useless Inlet. This head difference may reach maxima up to 1 foot during spring tides of large tidal ranges, with the sea level outside being higher during the flood and lower during ebb tides.

The head difference results in a very rapid and turbulent water flow through the two guts, the so-called "jets", which cause extensive mixing of the transported waters. Fatty Basin receives little runoff, and consequently the incoming and outgoing tidal volumes are nearly equal, but may change significantly in magnitude. During large spring tides, the volume transported can be as high as 8.5×10^6 ft^3 or 26.6% of the Basin volume, whereas on neap tides, the volume may be as little as 1.3×10^6 ft^3 or only 4.1% of the Basin volume.

Since creeks contribute only relatively small amounts of fresh water to Fatty Basin, most of the low-salinity water appears to come in from Alberni Inlet through Rainy Bay and the Small Gut. Salinities in Rainy Bay are usually lower than those in Useless Inlet, and consequently the waters entering Fatty Basin through the Small Gut tend to override the water from Useless Inlet. This phenomenon can be commonly observed during upcoming tides.

The temperature in Fatty Basin is marked by an annual cycle, with a maximum of 19.8° C in summer and a minimum of 5.9° C in winter. The cycles at all depths usually appear to be in phase; only during a short period in May, 1965, did the temperature at 24 m stop rising parallel to the temperatures at shallower depths. Both the positive gradients in winter (surface waters colder than deep waters) and the negative gradients in summer (surface waters warmer than deep waters) were intensified during neap tides and weakened during spring tides. This tidal effect is likely due to the increase or decrease of the "jet action" and its mixing effects in the Basin with spring or neap tides, respectively.

In January, the vertical positive gradient reaches its greatest development, and it is generally more significant in Useless Inlet and Rainy Bay than in Fatty Basin. Similarly, the negative gradient during summer also seems to be less pronounced in Fatty Basin, where the temperatures at depth are higher than in the surrounding inlets.

The isotherms, which reach from Junction Passage into Useless Inlet without disruption, are broken at both the Small and the Big Gut, where water stratifications are destroyed in vigorous mixing processes. Furthermore, the two guts are shallow to the extent that normally only surface waters can enter the Basin at all times.

In early June, 1965, a marked thermocline was noted in Fatty Basin between 20 and 24 meters depth, indicating a lack of exchange down to the bottom waters.

A positive salinity gradient exists in the area throughout the year and at all depths, but it seems to be best developed near the surface in winter and spring due to winter precipitation and the resultant increase in runoff. Like the temperature gradient, the vertical salinity gradient is always less in Fatty Basin than in Useless Inlet, since salinity is strongly affected by the jet-action as well. Periodically, the water column in Fatty Basin is agitated from the surface to the bottom.

Coinciding with the sharp thermocline, a marked halocline was noted between 20 and 24 meters in Fatty Basin during early June, 1965.

The dissolved oxygen concentration seems to move through a seasonal cycle, with a maximum in January and a minimum during November in the whole water column. In early June, 1965, however, when a lack of exchange near the bottom in Fatty Basin was indicated by marked haloclines and thermoclines, the concentration of dissolved oxygen dropped to zero at 24 meters.

High concentrations occur during September and are probably the results of an autumnal phytoplankton bloom and good water exchange at all depths. Throughout most of the year, the dissolved oxygen concentrations are higher at corresponding depths in Fatty Basin than in Useless Inlet or Rainy Bay.

In conclusion, the oceanographic characteristics of Fatty Basin are strongly influenced by the shallow entrance passages, the two guts. Water exchange is entirely dependent upon tidal flushing through these narrow channels, which causes two jets of water that tend to keep the whole Basin mixed to homogeneity, especially during spring tides. Furthermore, only surface waters can enter the Basin over the shallow sills.

During late May and early June, just after the "spring bloom" of phytoplankton with its associated oxygen maximum, when the surface salinities are low, stagnant bottom waters occur in the deep "holes" of Fatty Basin. As soon as the surface salinities increase, however, the usual good exchange of the bottom waters takes place again, and an oxygenated regime resumes.

7

<u>View of the Big Gut</u> from the Inner Section of Useless Inlet, with Fatty Basin in the background. The entrance to the gut here is also its narrowest section; at this point, a head difference between the waters on either side up to 1 foot may develop during maximum tidal exchange, causing the "jet-action" as discussed in the text.

8

<u>View of the Small Gut</u> from the Fatty Basin side during a very low tide. Bedrock exposures block the entrance to the gut in the foreground, and most of the waterflow concentrates in a narrow channel of about 8 to 10 feet width to the right. Both guts represent surface expressions of faults and shear zones, indicating the major influence of these structural features upon the shaping of the inlets.

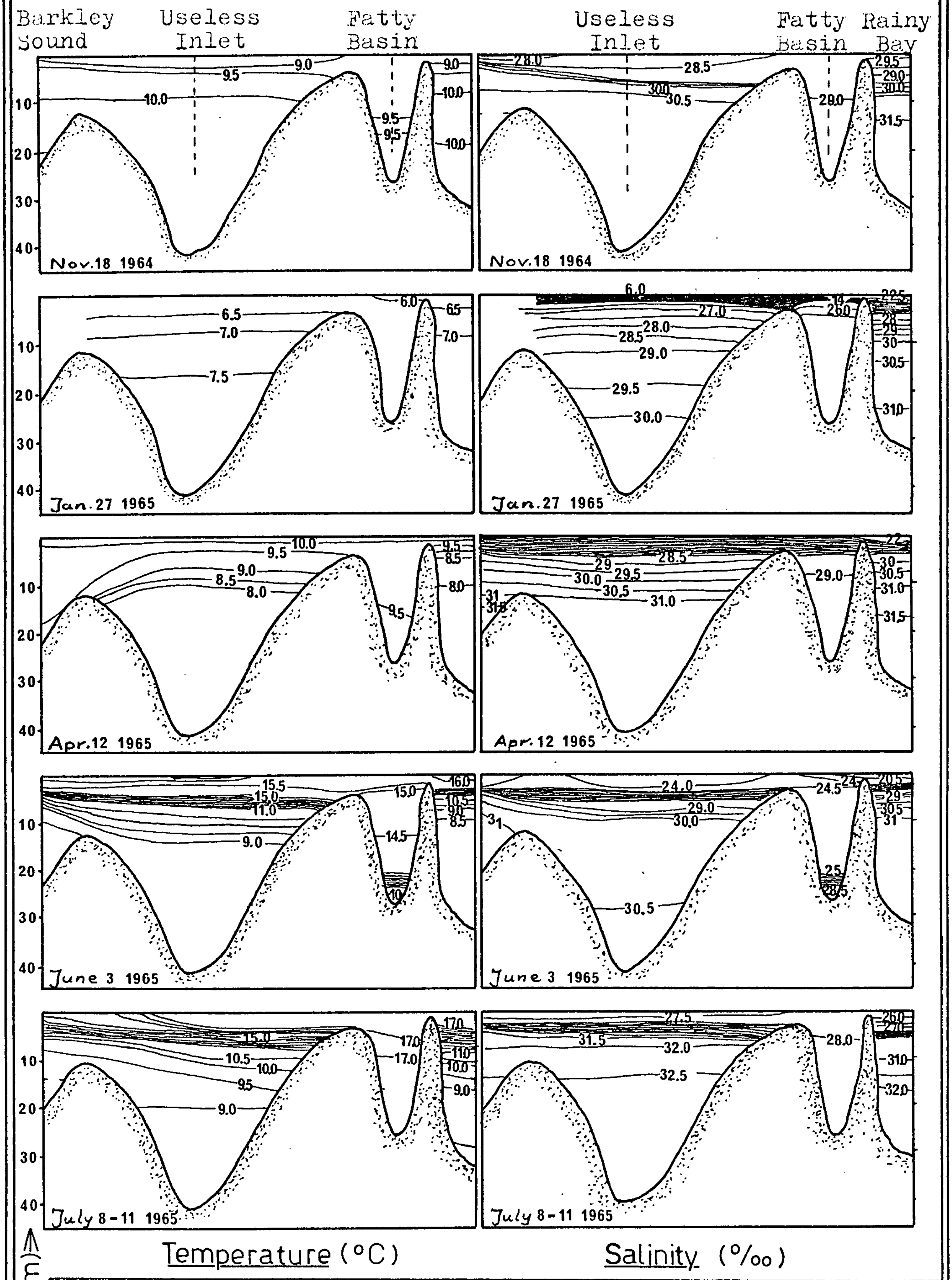
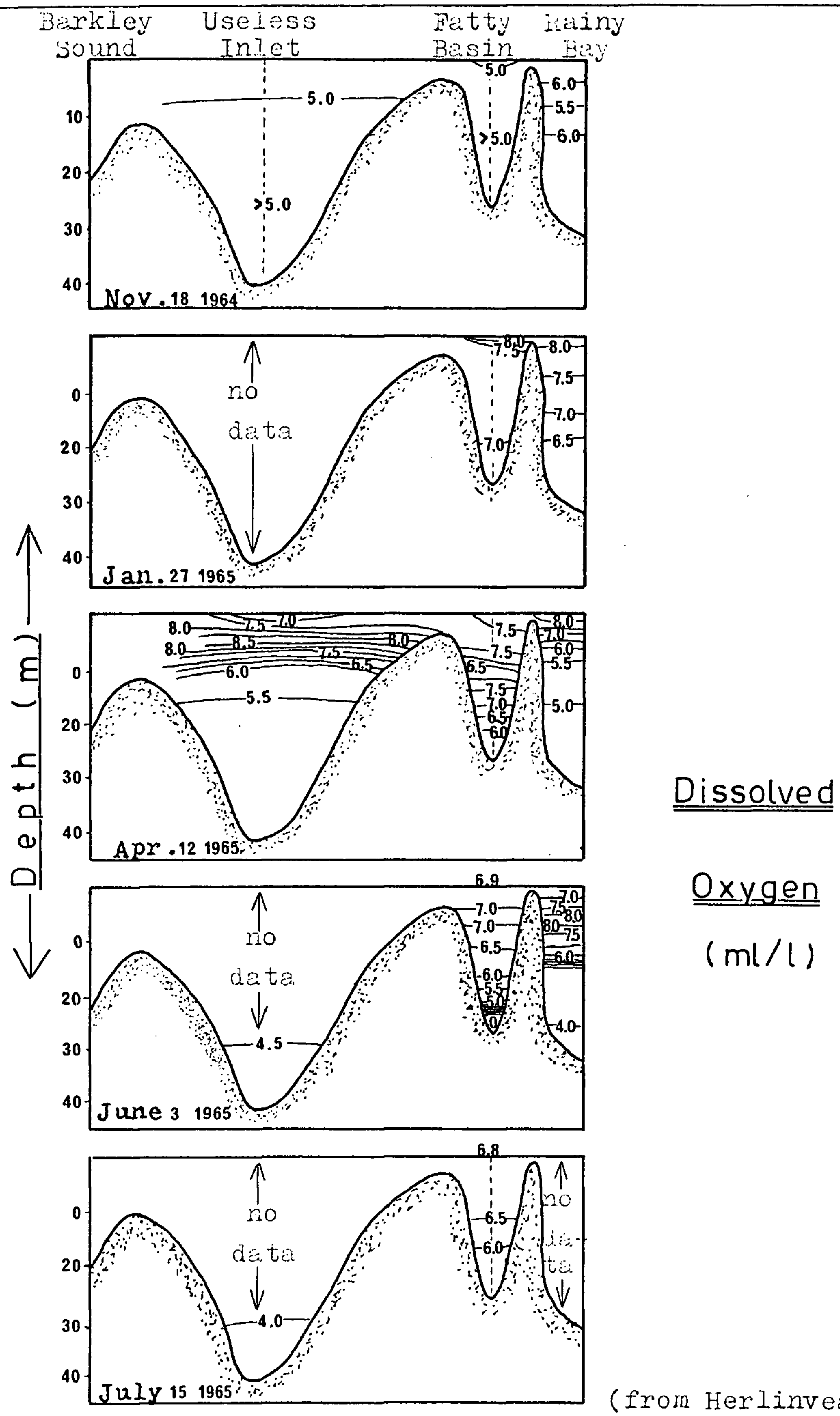


Figure 8

Longitudinal sections of temperature and salinity distributions from Junction Passage through Useless Inlet, Fatty Basin, and Rainy Bay.

(from Herlinveaux, 1966)



(from Herlinveaux, 1966)

Figure 9 Longitudinal sections of dissolved oxygen distributions from Junction Passage through Useless Inlet, Fatty Basin, and Rainy Bay

THE SEDIMENTS

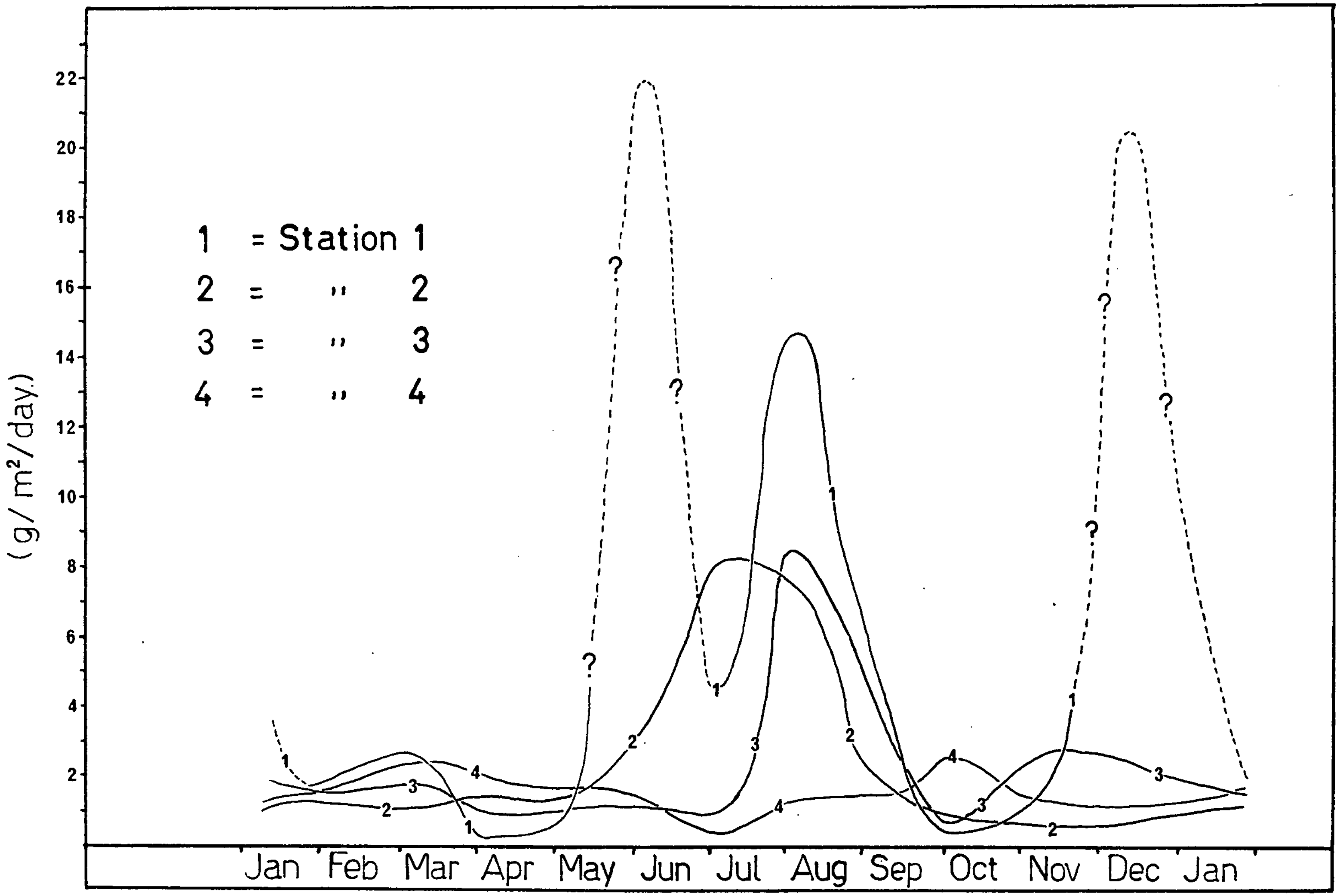
1. Rate of Sedimentation

Due to contamination or actual loss of several samples during retrieval of the sampling bowls, the data for monthly sedimentation rates at the four stations in Fatty Basin are incomplete. The exchange of bowls, furthermore, could not be maintained at exactly one-month intervals, and was entirely omitted during December, 1969. Consequently, extrapolation of data was necessary in some cases, and the sedimentation rate referred to in Figure 10 is the average daily rate of sedimentation, as determined from the weight of each sample, divided by the number of days since collection of the previous sample. The total amount of sediment deposited from suspension during a one-year period averages about 900 grams per square meter in Fatty Basin, and the variation in sedimentation rate throughout the year is shown in Figure 10.

A maximum rate of sedimentation occurs during the period July to September, immediately preceded by a minimum in May and June. A relatively minor increase in the sedimentation rate can also be observed in February and March, probably reflecting the increased precipitation and resultant runoff at that time of the year.

The summer maximum may be caused largely by phytodetritus derived from the euphotic zones. During July, the stratification of the water column is well developed outside Fatty Basin (Figure 8) and may result in particularly significant concentrations of phytoplankton near the surface. Consequently, since only surface waters enter Fatty Basin from Rainy Bay and Useless Inlet, the amount of debris carried into the Basin during each upcoming tide appears to be considerable. This influx has been visually confirmed many times by skin diving in the strong-current zones off the two guts, when during a flood tide the visibility under water drops to very few feet, due to the great amounts of organic detritus suspended in the inflowing waters. The considerable mixing of incoming waters with the entire water column of Fatty Basin results in less organic suspended material being swept out again during the ebb tide. The Basin, therefore, seems to act as a large natural trap for phytoplanktonic debris.

The influence of phytoplankton upon sedimentation rates in a shallow coastal environment was studied by Stephens, Sheldon, and Parsons (1967) during investigations in Departure Bay on the east coast of Vancouver Island near Nanaimo. They noted an increase in the size of suspended particles from January through June, caused either by aggregation of detrital particles or by larger phytoplankton species. This increase could cause a higher sedimentation rate during summer, since, if one assumes constant density and general morphology of the plankton, a doubling in particle size will result in a fourfold increase in settling velocity. In addition, these workers also suggested a decreased buoyancy during senescence of several species of diatoms, which then, too, would increase the sedimentation rate in summer.



Rates of Sedimentation in FATTY BASIN

Figure 10

2. Clay Mineralogy

The clay mineralogy was determined with X-ray diffraction methods, outlined in the appendix. Representative mud samples from Rainy Bay, Useless Inlet, and Fatty Basin were analysed and compared to glacial clayey silts and the clay fractions of glacial drift. Only clay mineral groups as outlined in Grim (1968) were identified; further distinction of individual mineral species was not attempted.

Chlorite group minerals were identified by their basal reflections at 14.1 - 14.5, 7.1, 4.7, and 3.55 A^{o} . Most of these peaks were distinct in all samples analysed, regardless of the sample location and whether they were from muddy sediments, silty clays, or glacial drift. The peaks were unaffected by K^{+} - saturation, but heating to 540^{o} C resulted in an increased 14 A^{o} peak, a decreased 7.1 A^{o} reflection, and a disappearance of the lower-order peaks.

Kaolinite minerals usually break down upon heating to above 500^{o} C. However, since the main peaks of kaolinite coincide with second and lower order chlorite peaks, and since poorly crystallized chlorites are similarly unstable above 500^{o} C, criteria other than heating to high temperatures had to be used to identify kaolinites.

Several samples were treated with warm hydrochloric acid, which tends to dissolve chlorites, but normally does not affect kaolinite. Subsequently, most of the chlorite peaks had disappeared; very small remnants of both the 14 A^{o} and 7.1 A^{o} peaks remained, however, probably indicating an incomplete decomposition of the better crystallized chlorites. If kaolinite was present in any of the analysed samples, then only in exceedingly small amounts. Furthermore, an otherwise common kaolinite peak at 2.38 A° was never observed here, which also suggests the absence of kaolinite in these samples.

Illite was recognized in all analysed samples by the 10.1 A° and rarely by the lower-order 4.98 - 5.00 and 3.34 A° peaks. Glycolation of the samples had no effect on these peaks.

Smectite minerals, which characteristically expand their basal first-order reflections from 14 A° to 17 A° upon treatment with ethylene glycol, were not detected in any of the samples. If present at all, the smectite group minerals occur only in minor traces.

Since no change of the peaks was observed after glycolation, it is assumed that no vermiculite was present, which also expands its 14 A° basal reflection, although less so than the smectite minerals.

No attempts were made to determine relative abundances of the clay mineral groups present, although several methods exist. As Pierce and Siegel (1969) point out, these methods are exceedingly unreliable. Furthermore, the clay mineral assemblage in the area of interest is monotonous and hardly warrants a quantitative evaluation.

The assemblage is dominated by chlorite minerals and minor illite. Other clay minerals, like kaolinite, smectite, and vermiculite, are either absent or present only in traces. Little doubt as to the origin of these clays remains, since glacial clayey silts and overlying glacial drift, both very common in the area, have a clay mineral assemblage identical to that of the muddy sediments throughout the area. Although present weathering of the Bonanza volcanics, which contain abundant chlorite as an alteration product, will add to the chlorite content of the sediments, this mechanism is of minor importance as compared to erosion of the vast amounts of glacial drift and clayey silts, all well exposed along much of the shoreline and in most creek beds. It should be noted, however, that most of the glacial deposits have originated from Bonanza and Karmutsen volcanics, and these two rock formations probably constitute the ultimate source for most clay minerals found in Fatty Basin, Useless Inlet, and Rainy Bay.

Other localized sections of Barkely Sound are dominated by clay groups like smectite and illite (Carter, 1970), further indicating the clay mineralogy of local areas on the west coast to be primarily dependent upon the available sources, which usually are glacial deposits derived from the major rock units nearby. Additional factors, like currents and different settling velocities of the clay minerals, seem to be of minor importance in this region.

3. Heavy Minerals

Heavy minerals were separated from 30 samples, using only the size fractions between 2.5 and 4 phi, which correspond to the very fine sands. These fractions are used for heavy mineral analysis by most workers because

(i) the content of heavy mineral grains is usually greatest in the fine sand fractions;

(ii) the fractions finer than about 4 phi are generally too small to accurately identify individual mineral grains through common optical methods;

(iii) the coarser fractions contain too many rock fragments, some of which may have a specific gravity similar to or slightly greater than that of bromoform;

(iv) consistent use of these fractions is helpful when comparing the heavy mineral content of different samples, which in most cases do not have the same size distribution or content of terrestrial grains versus shell fragments.

No distinction was made between magnetic and non-magnetic opaque minerals, since finely-granular opaque material, presumably magnetite, was frequently found scattered through non-opaque grains. Because these grains usually did not react to a magnet, any percentage figures for magnetic and non-magnetic opaque minerals are inherently erroneous, if the data are based upon separation with a simple hand magnet.

The mineralogy of the opaque minerals was determined through the use of reflected light on thin sections. Magnetite appears to be the predominant mineral, ilmenite was suspected in a few cases. Limonite was rarely observed, mostly in glacial drift samples subjected to subaerial exposure. No pyrite was found, despite the relative abundance of pyrite in the rocks along the inlet perimeters.

The content of heavy minerals in the analysed sand fractions was entirely dependent upon the nature of the sediment. Heavy minerals were most abundant in terrestrial sands and least common in glacial clayey silts and especially in carbonate sands, where shell fragments dominate the light mineral fraction (see Figure 11).

Clinopyroxenes (augite) and epidote are predominant and average 32 and 34 percent of the heavy mineral suite, respectively. Orthopyroxenes were found only in very small amounts in a few samples. Hornblende, with some exceptions, occurs in much lower percentages, averaging only 13 percent, but no distributional pattern is apparent. Opaque minerals average 19 percent, with highs of 30 and lows of 5 percent. Chlorite is very common and was observed in most of the samples, but never in significant quantities. It is probably more abundant in the finer size fractions (clays). Sphenes in small, irregular grains commonly occur as accessories, but other minerals such as garnet, spinel, zircon, and topaz are very rare.

This assemblage dominates the heavy mineral fractions in the Fatty Basin area. In other parts of Barkley Sound, amphiboles (hornblende) are the dominant heavy minerals, followed by epidote and, occasionally, chlorite (Carter, 1970). Pyroxene percentages are very low, but accessories like garnets are relatively abundant in that region. The characteristically high pyroxene and low amphibole contents of the heavy mineral suites in the

Fatty Basin area, therefore, appear to be a localized feature.

The Bonanza volcanics and especially the mafic dykes commonly contain pyroxene (augite) phenocrysts. These weather out easily when exposed, leaving behind a distinctly pitted rock surface. Much of the hornblende seems to have been altered to chlorite, epidote, or magnetite, all exceedingly abundant in the andesites. The small diorite intrusions, originally hornblende diorites (Westcoast Diorite), all have undergone extensive alterations, and the hornblende often is entirely destroyed.

Most of the heavy minerals in the sediments are probably derived from glacial drift deposits. Since the general direction of ice flows here has been towards the south-west, the origin of the drift is to the north and north-east of the area of interest. Extensive exposures of Bonanza volcanics and Karmutsen basaltic lavas occur in that region, both probably containing more pyroxenes than amphiboles among their mafic constituents. Hornblende-rich intrusives are rare in that part of Vancouver Island.

On the other hand, most remaining sections of Barkley Sound are bordered by intrusive rocks, all of which have hornblende as main mafic mineral.

These rock exposures are highly irregular and appear in numerous islands throughout the Sound region. Present-day mass-wasting and erosion is considerable, as indicated by abundant accumulations of fresh, angular diorite and granodiorite fragments below steep bedrock slopes (Carter, 1970). During glaciation, when ice acted as an abrasive tool (glacial grooves and striations), erosion must have been very strong. Consequently, most of the glacial gravel and the majority of lithic fragments of the sands are derived from the intrusive rocks of the region (Carter), whereas in Fatty Basin and Useless Inlet equivalent sediments contain mainly andesites and basalts. It may be concluded, therefore, that the difference between heavy mineral suites from the localized Fatty Basin area and the remaining Barkley Sound region is largely due to different source rocks. Furthermore, sediment mixing caused by bottom and longshore currents is considerable in Barkley Sound, exposed to the influence of the open ocean, whereas in Fatty Basin, Useless Inlet, and Rainy Bay such mixing is prohibited by shallow entrance sills.

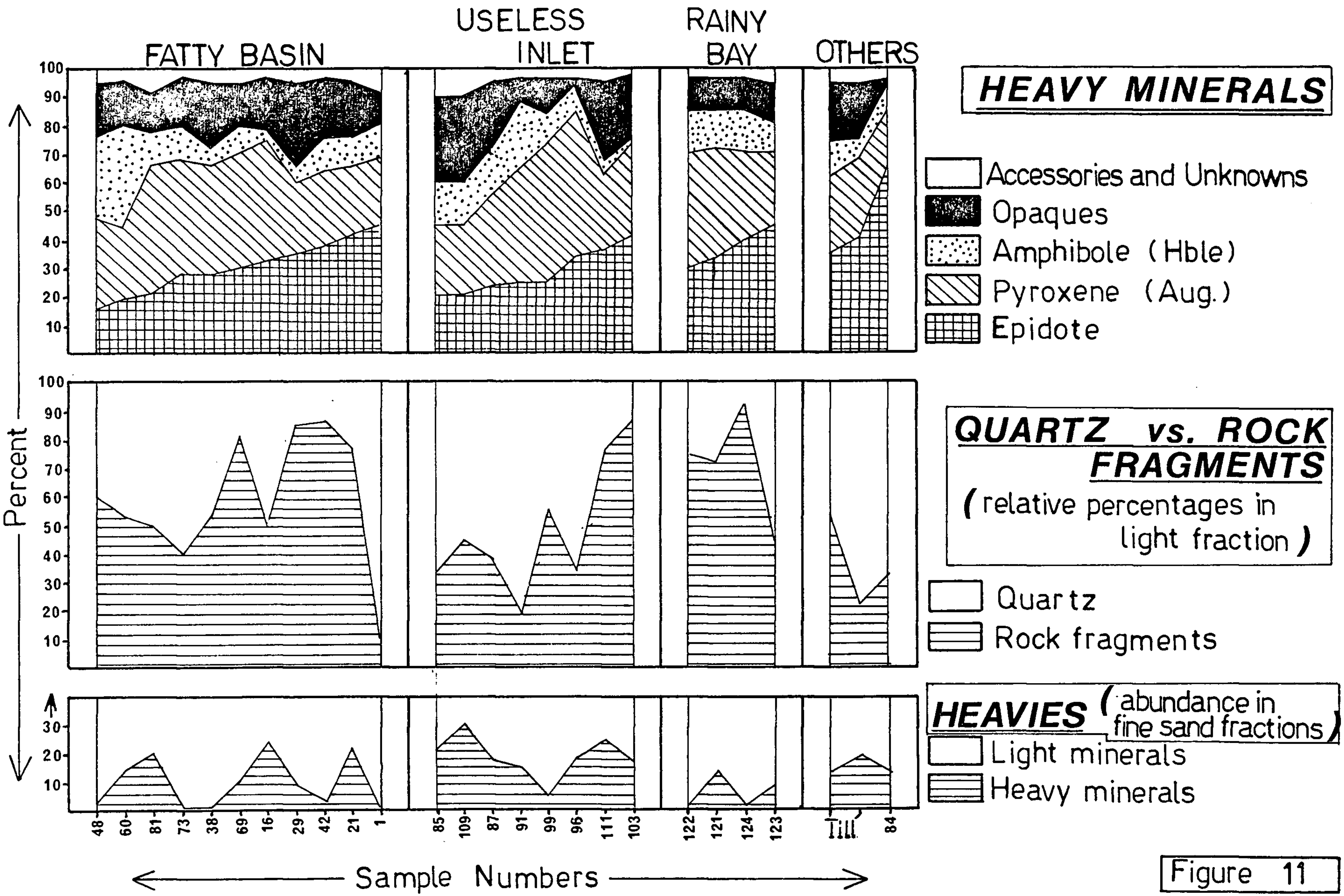

FATTY BASIN
USELESS INLET
RAINY BAY
OTHERS
HEAVY MINERALS
Accessories and Unknowns
Opaques
Amphibole (Hble)
Pyroxene (Aug.)
Epidote
QUARTZ vs. ROCK FRAGMENTS
(relative percentages in light fraction)
Quartz
Rock fragments
HEAVIES (abundance in fine sand fractions)
Light minerals
Heavy minerals
Percent
48 60 81 73 38 69 16 29 42 21 1
85 109 87 91 99 96 111 103
122 121 124 123
Till 84
Sample Numbers

Figure 11

Table 1 : Weight percentages of total heavy minerals in fine sand fractions, and percentages from grain-count analysis of the dominant minerals within the heavy fractions.

Sample No.	Total heavies	Epidote	Pyroxene (Aug.)	Hornblende	Opaques	Others
1	.6	45	24	11	12	8
16	24.0	32	42	4	20	2
21	21.2	41	25	9	21	4
29	9.0	34	26	6	28	6
38	1.6	28	39	5	23	5
42	2.6	38	26	11	23	2
48	1.8	16	32	29	21	2
60	12.8	20	25	35	20	tr
69	9.0	30	40	10	15	5
73	.4	28	40	12	20	tr
81	20.6	22	44	13	13	8
84	12.4	65	20	10	4	1
85	21.0	20	25	15	30	10
87	17.8	23	34	15	24	4
91	15.2	25	40	13	20	2
96	18.0	35	48	10	6	1
99	4.8	25	48	10	15	2
103	17.1	41	32	1	25	1
109	29.6	20	25	15	30	10
111	24.0	37	27	3	30	3
121	13.4	34	37	14	15	tr
122	.1	30	40	15	15	tr
123	9.2	45	25	10	15	5
124	.1	40	30	15	15	tr

Note: "Others" usually include chlorite, sphene, and unkowns. Spinel, garnet, zircon, topaz, and trem.-actinolite are very rare.

Table 2 : Percentages of dominant minerals in light fractions of fine sands.

Sample No.	Quartz	Fspar	Chert	Rock Frags.	Shell Frags.	Mica	Unknowns
1	80	10	tr	8	tr		tr
16	40	4	5	40	4	tr	
21	20	5		70	5		
29	10	tr		60	30		
32	30			60	5	tr	tr
38	35			40	25		
42	10	tr	10	65	15		
48	10	tr	5	15	70	tr	
60	35	5	5	35	15		5
69	15	6	5	70	tr	3	tr
73	15			10	70	3	
81	40	10	10	40	tr		
84	60	10		30			
85	50	15		25	5		5
87	40	5		25	30		
91	75	5	10	15	tr		
96	60	5		30	5		
98	40	10		50	tr		
99	40	5		50	5	tr	
103	10	5	5	70	10		
109	50	5		40	5		
110	30	15	10	45			
111	20	5		65	10		
116	40	8		50	2		
121	25	tr		65	10		
122	5			15	80		
123	25	10		20	30	tr	tr
124	5			60	35		

Note: "tr" = trace (less than 1%)

4. Delta Developments

Most of the terrestrial sediments of Fatty Basin and Useless Inlet are transported by streams, which are short due to a relatively low terrain and the dissection of the country by inlets and bays. Numerous small, seasonal creeks and trickles occur and are responsible for a significant sediment transport, but only the large, permanent creeks build deltas of various sizes at their mouths, depending upon the availability of unconsolidated glacial material. These deltas perform a significant role in the sedimentation processes of the area, because much of the terrestrial debris in the inlets is derived from here. Study of the deltaic sediments, therefore, provides a conclusive picture of the terrestrial material encountered elsewhere in the inlets.

In Fatty Basin, the two most significant delta developments occur at the northern and southern ends, respectively. They differ distinctly in shape and sediments and represent two types of deltas, repeated throughout this region.

Type A is exemplified by the north delta, built by a relatively sluggish creek and sloping gently and uniformly towards the Basin. No clear distinction between top- and foreset-beds can be made here. Although the delta is completely submerged at high tides, it is exposed for about 100 feet during low tides.

Boulders are abundant in the upper part, but the lower section above low-tide level is covered largely with grey mud, intermixed with coarse pebbles and shells and partly over-grown with eel-grass. The grey mud extends for about 250 to 300 feet into the Basin, where it dips underneath the ubiquitous olive-green mud. A rough stratification of the grey mud was observed, and at two feet depth, a five-inch layer of very tough, light-grey, massive glacial clayey silt was encountered. This silt has essentially the same composition as other glacial clayey silt deposits along the shore, constituting the dominant source for the grey muds.

The creek above the delta appears graded and very mature in most parts. Its downdrop is mainly in the last 100 feet of its course, otherwise it sluggishly meanders through a relatively wide, swampy, heavily forested valley. It appears unlikely that the water discharge increases significantly even during the spring runoff. Consequently, deposition on the delta is slow and characterized by silts and clays with low contents of organic matter

Delta type B is represented by the south-delta of Fatty Basin, built by a highly immature creek with rapid water flow and many small falls along its course. About 600 feet from the Basin, three different flows combine to form the main creek of 3 to 5 feet width and 1/2 foot average depth. Erosion is very active in the drainage and has caused steep banks of soft, unconsolidated till and soil.

The delta here is rapidly advancing, with distinct top and foreset slopes that seem to override the green mud. Deposition is concentrated on the steep foreset-slope and the outer sections of the topset-slopes, where sediments are characterized by dark-brown mud and an abundance of small twigs and other coarse organic debris. Near low-tide level, a dark layer composed almost entirely of woodchips was encountered

9

View of the ridge south and south-east of Fatty Basin, showing logged area in the watershed of the creek above the south-delta. The creek and the "notch" in the ridge mark the position of one of the large faults.

10

View of the south-delta in Fatty Basin. The delta is of type B, as defined in the text, shows distinct top- and foreset beds, and is rapidly advancing.

Towards the right, a steep boulder slope can be seen, a feature common along the inlet perimeters.

11

The north-delta of Fatty Basin, a good example of delta type A. Some angular boulders appear in the foreground, derived from steep-sided bedrock exposures to the left of the picture.

12

Outcrop of organic material on the upper section of Oyster Beach, consisting mainly of wood-fragments, twigs, roots, and similar debris, which was dated at almost 7000 years B.P. It is considered to be part of a former delta, since it parallels deltaic strata below and above.

at 2 feet depth. These chips originated about a dozen years ago as the waste product of a logging operation in the drainage above the delta (see Photograph 9), and are still abundant in thick layers along several sections of the creek. Hence almost two feet of sediments have been added to the outer parts of the topset-slope in only a dozen years, indeed a rapid rate of deposition.

Most of the intertidal delta top is covered by very coarse debris, with a gradation outward from the head of the delta from boulders to cobbles, pebbles, and coarse gravel. Little deposition takes place here at present, and the finer debris has been winnowed out by wave- and current-action or has settled below the cobble and pebble layer. In this section of the delta, the creek has cut a distinct channel through the coarse surface sediments.

At the head of the delta, older deltaic deposits are exposed on the banks of the creek. They consist of well-rounded boulders, pebbles, and sands in strata laid down at a steeper angle than the modern topset-beds. The erosive and depositional capacities of the creek, therefore, have changed since the older delta was first built. The change may be due in part to the increased runoff after the logging of the watershed, but it may also indicate re-juvenation of the creek due to uplift of the land.

Evidence for uplift is apparent at the so-called Oyster Beach in Useless Inlet, a delta similar to the south delta of Fatty Basin (delta type B). Here, the creek runs along a course of very steep gradient and is choked with huge, angular boulders. Near the head of the delta, the creek has cut down several feet into earlier-deposited deltaic sediments, which slope at a slightly greater angle than the present topset beds and form an actively eroding, small cliff above the modern delta. These older strata contribute abundant coarse debris to the sediments, and cobbles and pebbles accumulate as steeply sloping deposits below the unconsolidated cliff. Here, an exposure of a 3- to 5-inch layer of dark brown to black organic material appears, consisting of partly decomposed wood-fragments, twigs, and pieces of tree-bark (Photograph 12). A carbon-14 age of 6820 $\pm$ 320 years was determined for this material, which in composition seems to be similar to the layer of wood fragments found below the surface of the south-delta in Fatty Basin. That layer originated from waste debris of a logging operation, was transported by the strongly increased creek flow and subsequently deposited near the low-tide level on the surface of a rapidly advancing delta. If a similar origin is postulated for the dark organic layer at Oyster Beach, where an event like a forest fire in the watershed of the creek could have provided the wood debris, this material now indicates an uplift of at least 8 - 10 feet relative to the present level of the sea. At about 7000 years B.P., the post-glacial sea level rise was largely completed to within about 10 feet of the present level, and consequently the total uplift of the land here during the last 7000 years may have been in the order of 20 feet.

The dark organic layer is part of the former delta, since it parallels the deltaic beds below and above. The latter, which overlie the peat bed to a thickness of several feet, are likely to have formed during the last stages of sea level rise towards the present level.

Uplift of the land took place subsequent to the rise of sea level, which resulted in the downcutting of the creek into earlier deposited deltaic beds and the formation of a new delta, the present Oyster Beach.

The two different delta-types common to this region are illustrated on the accompanying diagram (Figure 12).

Type A occurs at the north end of Fatty Basin, at the head of Useless Inlet (Mud Bay), in several of the many small bays along the northern perimeter of Useless Inlet, and at the head of Oyster Bay. These deltas all have in common

- a sluggishly flowing creek as building agent;
- deposits of glacial clayey silt along the creek banks and adjacent shores;
- grey clayey silt derived from these glacial silt deposits as the main sediment;
- a very gentle gradient towards the inlet and a lack of distinct foreset slopes.

Type B can be observed at the south end of Fatty Basin, on the NW-shore of the Central Section of Useless Inlet (Oyster Beach), and on the NW-side of the Outer Section. All these deltas have in common

- a rapidly flowing, turbulent creek as building agent;
- deposits of coarse glacial drift along the creek beds and adjacent shores;
- coarse debris like sand, gravel, cobbles and pebbles, or wood-fragments and twigs as dominant sediment;
- distinct topset- and foreset-slopes.

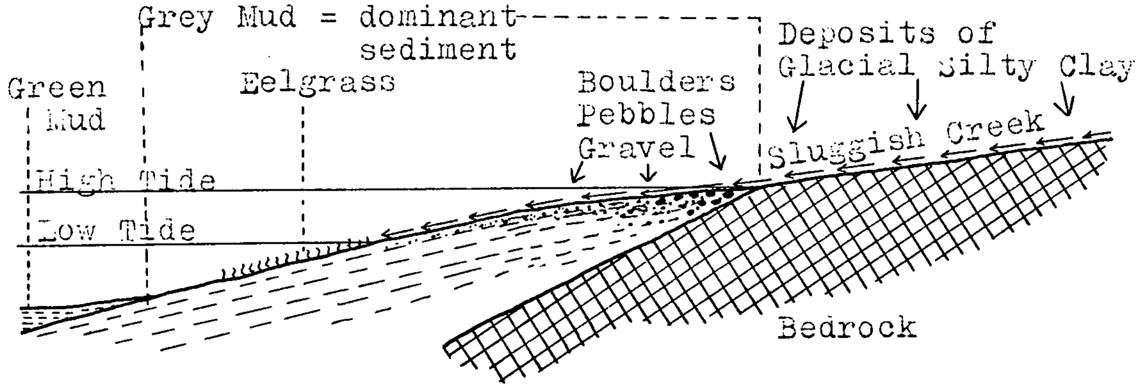


Figure 12 A

Diagrammatic cross-section of delta - Type A (e.g. North-delta in Fatty Basin)

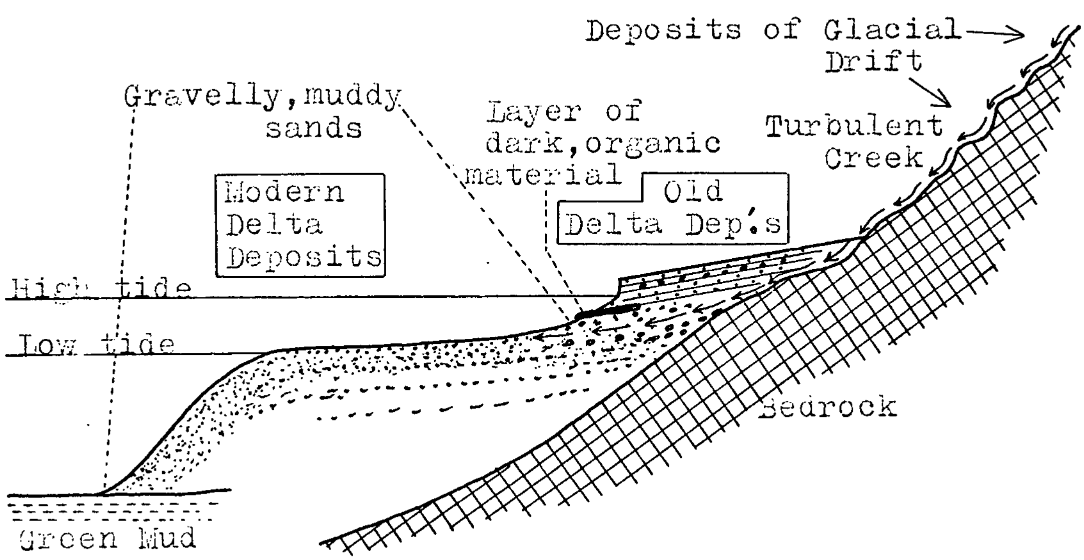


Figure 12 B

Diagrammatic cross-section of delta - Type B (e.g. Oyster-Beach in Useless Inlet)

5. Sediments in Fatty Basin, Useless Inlet, and Rainy Bay

Cumulative curves for samples analysed in detail were plotted by computer and assembled on a single diagram. Several clusters or groups of curves were noted (Figure 13) and subsequently used for the definition of various sediment types. This procedure was adopted, since cumulative curves give a good graphic representation of the main statistical parameters like mean size, deviation, skewness, and kurtosis, all of which strongly influence the positions or shapes of the curves. Cumulative curves of samples with similar parameters appear in groups as presented in Figure 13, which therefore provide an excellent basis for the definition of different types of sediments.

The hydraulic behaviour, a factor strongly influencing the statistical parameters of a sediment, may be similar for shell-fragments and terrestrial grains, especially in the fine size fractions (Koldijk, 1968). Consequently, the basic sediment types as defined by the groups of cumulative curves alone had to be further subdivided according to the abundance of terrestrial material versus carbonate fragments. Another subdivision was necessary within the terrestrial pebble and gravel groups, in order to distinguish between rounded material of glacial origin and angular fragments derived from local sources.

Altogether, thirteen sediment types have been defined this way (see Figure 14), and all the samples not analysed in detail (see Map No. 1 for sample localities) were then carefully compared with

Groups of Cumulative Curves Defining Sediment Types

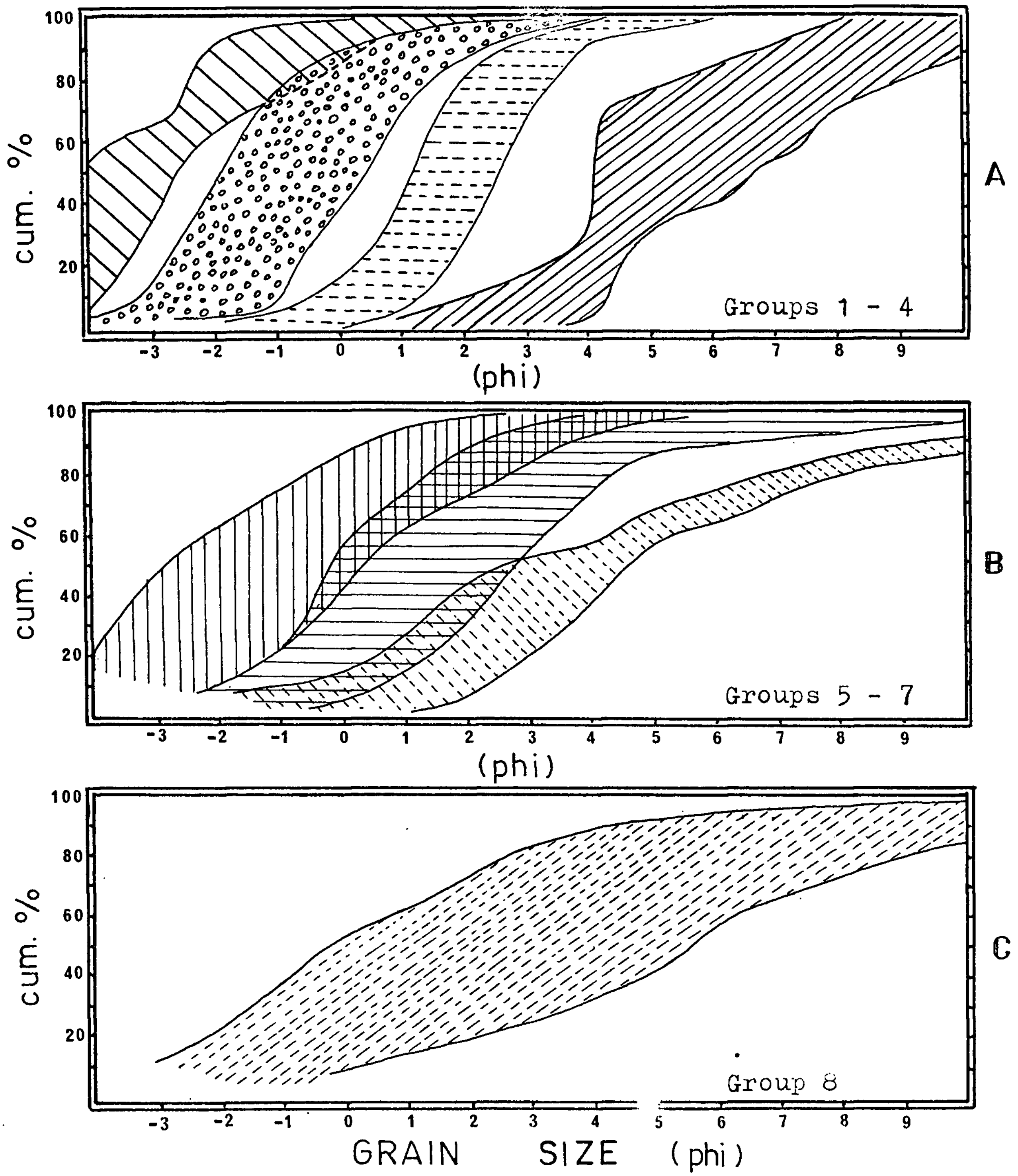


Figure 13

Sediment groups as defined from cumulat.curves	Numbers and colour representations of sediment types as shown on sediment distribution maps	Nature of sediment types
① →	3	Angular, coarse gravel
② →	5	Coarse sand, few pebbles
→	6	Coarse sand, abundant pebbles
→	8	Sand - shell mixture, coarse, muddy
→	12	Shell-debris, coarse to very coarse
③ →	4	Sand, medium to fine, little gravel
④ →	13	Grey mud
→	15	Olive-green mud rich in organic materials
⑤ →	7	Gravel and pebbles, rounded with very abundant shells
⑥ →	11	Shell debris, fine to very fine, muddy
⑦ →	10	Shell debris, medium, muddy with abundant gravel
⑧ →	9	Angular gravel - shell mixture, very coarse, muddy
→	14	Green mud with abundant small shell fragments

Figure 14 13 sediment types, defined as subdivisions of the eight sediment groups that are based on groups of cumulative curves, with the numbers and colour representations as they appear on the sediment distribution maps.

representative samples of each of the thirteen sediment types and classified accordingly. Sediment distribution maps could then be prepared with considerable accuracy for Fatty Basin, less for Useless Inlet, and least for parts of Rainy Bay, with the accuracy rating dependent upon sample spacings in each of these areas. In relatively shallow Fatty Basin, furthermore, personal observation of the sediments 'in situ' was possible through extensive skin-diving and occasional Scuba-diving.

The main statistical parameters are plotted in Figures 17 and 18, in order to visualize characteristics and relationships that may not be readily apparent from cumulative curves alone. Parameters used here are those defined by Folk (1965), and include the Graphic Mean, Inclusive Graphic Standard Deviation, Inclusive Graphic Skewness, and Graphic Kurtosis (Table 13).

An attempt was also made to find an areal distribution pattern of the statistical parameters by plotting their values at respective sample positions on a map. No distinctive pattern was apparent, however, largely because individual sediment types commonly occur in tiny, isolated patches or are intermixed to various degrees. Statistical parameter values are entirely dependent upon bottom topography, water currents, and supply of sedimentary material, factors all exceedingly variable over short distances in the restricted environment of these inlets. Only very close sample spacings over the entire area, followed by accurate analyses of all samples taken, could possibly produce a distributional pattern as sought. Such efforts are, however, far too time-consuming to be considered here.

On the other hand, the plots of Figures 17 and 18 permit some inferences and conclusions regarding the sediments and their depositional environments, referring here only to the eight basic sediment groups as defined on Figure 13. These groups are also plotted on Figure 16, which presents a nomenclature according to relative percentages of gravel, sand, and mud, but which disregards the contents of terrestrial versus carbonate material. The diagram, slightly modified, was taken from Folk (1965) and provides the following classification of the eight basic sediment groups:

Group 1 = Gravel to slightly sandy gravel;

Group 2 = Predominantly sandy gravel;

Group 3 = Sand;

Group 4 = Mud and sandy mud;

Group 5 = Mostly sandy gravel, some gravelly sand;

Group 6 = Gravelly sand, muddy sand, gravelly-muddy sand;

Group 7 = Sandy to gravelly mud;

Group 8 = Variations from muddy-sandy and muddy gravel to gravelly mud and gravelly-muddy sand.

From Figure 17 (A), it is apparent that the least sorted sediment groups are those with large ranges in mean size (notably Group 8), but that the actual value of mean sizes has no influence upon the degree of sorting. The poorly sorted sediments are mixtures of coarse shells, gravel, sand, and mud, where a slight change in abundance of any of these materials may cause distinct shifts of the mean size, which then results in a large range of mean sizes for the sediment group as a whole.

Terrestrial sands of Group 3 and some gravels of Group 1 constitute the best sorted sediments. Mixing is of minor importance, and both groups are fairly homogeneous with only small ranges in mean size. The sands are restricted to the zone of relatively strong currents in the Outer Section of Useless Inlet, and to the lower reaches of numerous small bays, where it is concentrated through winnowing of the near-shore gravel. These well-washed gravels are common as a thin sedimentary blanket on near-shore sections of small bays as well as on many delta tops (delta type B), but at a depth of about 2 inches below the surface, the gravel invariably becomes very poorly sorted due to concentrations of fine-grained material.

Muds of Group 4 have a relatively great range in deviation, caused by the common presence of some large shell fragments and by variations in clay content.

Figures 17 (B and C) represent only Groups 1 to 4, because plots of the remaining groups, all predominantly mixtures of gravel, sand, and mud, have more random distribution and tend to obscure the clarity of the diagram. It is apparent that most sediments are fine- to strongly fine-skewed, whereas only terrestrial sands of Group 3 are symmetrical or coarse- to strongly coarse-skewed. These sands constitute a well-washed, slightly gravelly sediment with very little mud, whereas most of the other groups contain enough mud to cause a positive skewness. Even the gravels of Group 1, which are often moderately sorted, appear as a strongly fine-skewed sediment. Hence, even small amounts of mud seem to have a considerable influence upon the skewness of a coarse sediment.

The silty muds of Group 4 are also strongly fine-skewed, since they contain abundant fine clay material in the size range of less than .002 millimeter. Sediments with mean sizes intermediate between coarse gravel and fine silt tend to be less fine-skewed, since the grain-sizes commonly are gradational from coarse to fine, which subdues the effects of the clay-fraction upon the skewness of a sample.

Figures 18 (A, B, C) represent plots of skewness versus kurtosis. In (A), about half the analysed samples are shown to be mesokurtic, 34 percent to be leptokurtic, and 16 percent platykurtic. A very rough trend seems to link platykurtic and mesokurtic samples to negative and symmetrical skewness, and leptokurtic to very-leptokurtic samples to positive and strongly-positive skewness.

Platykurtic samples, which have a better sorting in the tails than in the central portions of their respective cumulative curves, are mostly sediment mixtures with an appreciable content of shell debris. The carbonate fragments introduce a very poor sorting into all but the very fine size fractions of a sample, since in the silt range few carbonate fragments persist. In the cumulative curve of such a sample, therefore, the tail representing the silt and clay fractions is better sorted than the central portion.

Leptokurtic samples are difficult to relate to any particular pattern, but both carbonate and terrestrial sands with a considerable mud fraction appear to be dominantly of leptokurtic nature. The silts and clays in these sediments are probably less sorted than the relatively homogeneous coarser fractions.

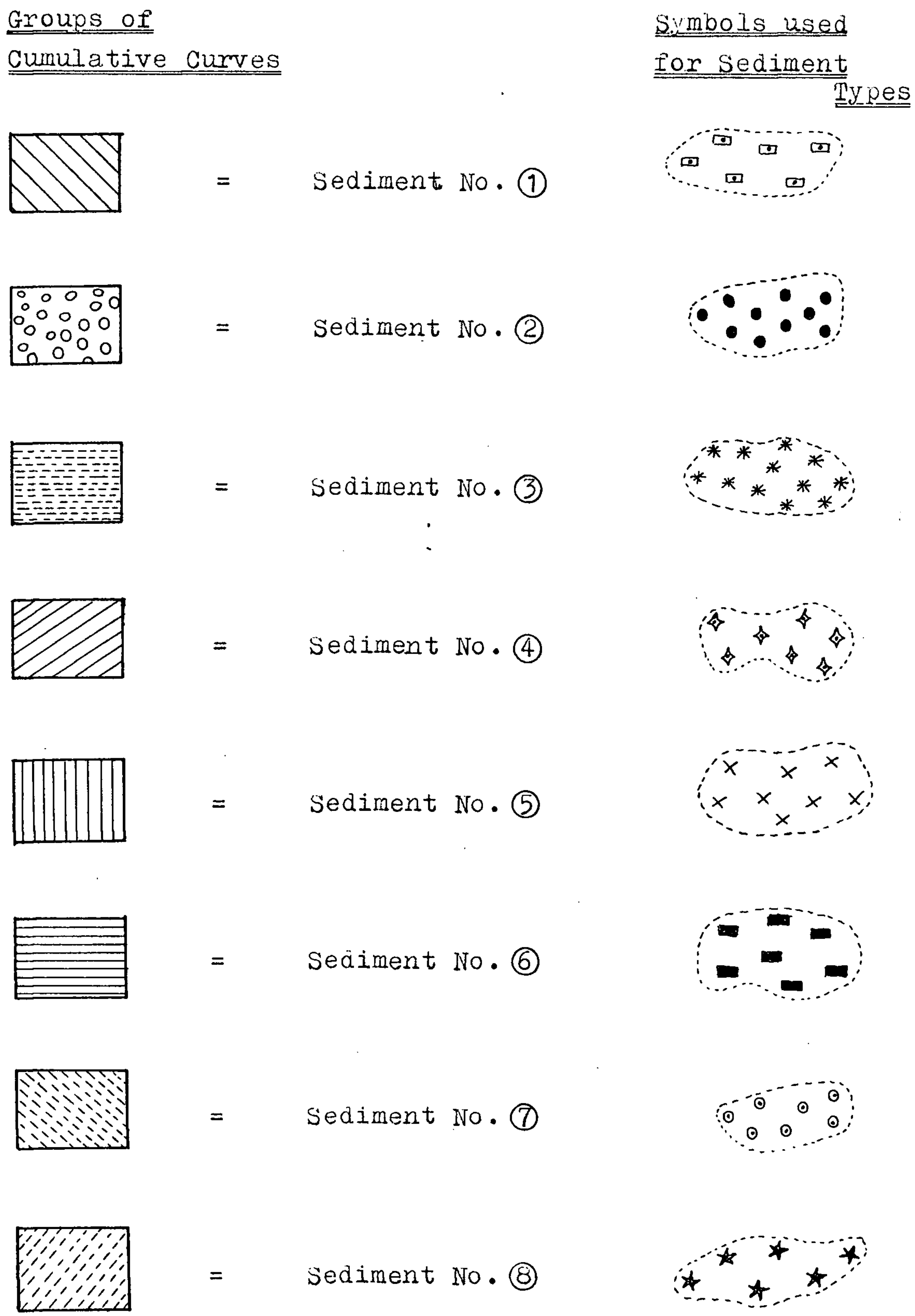
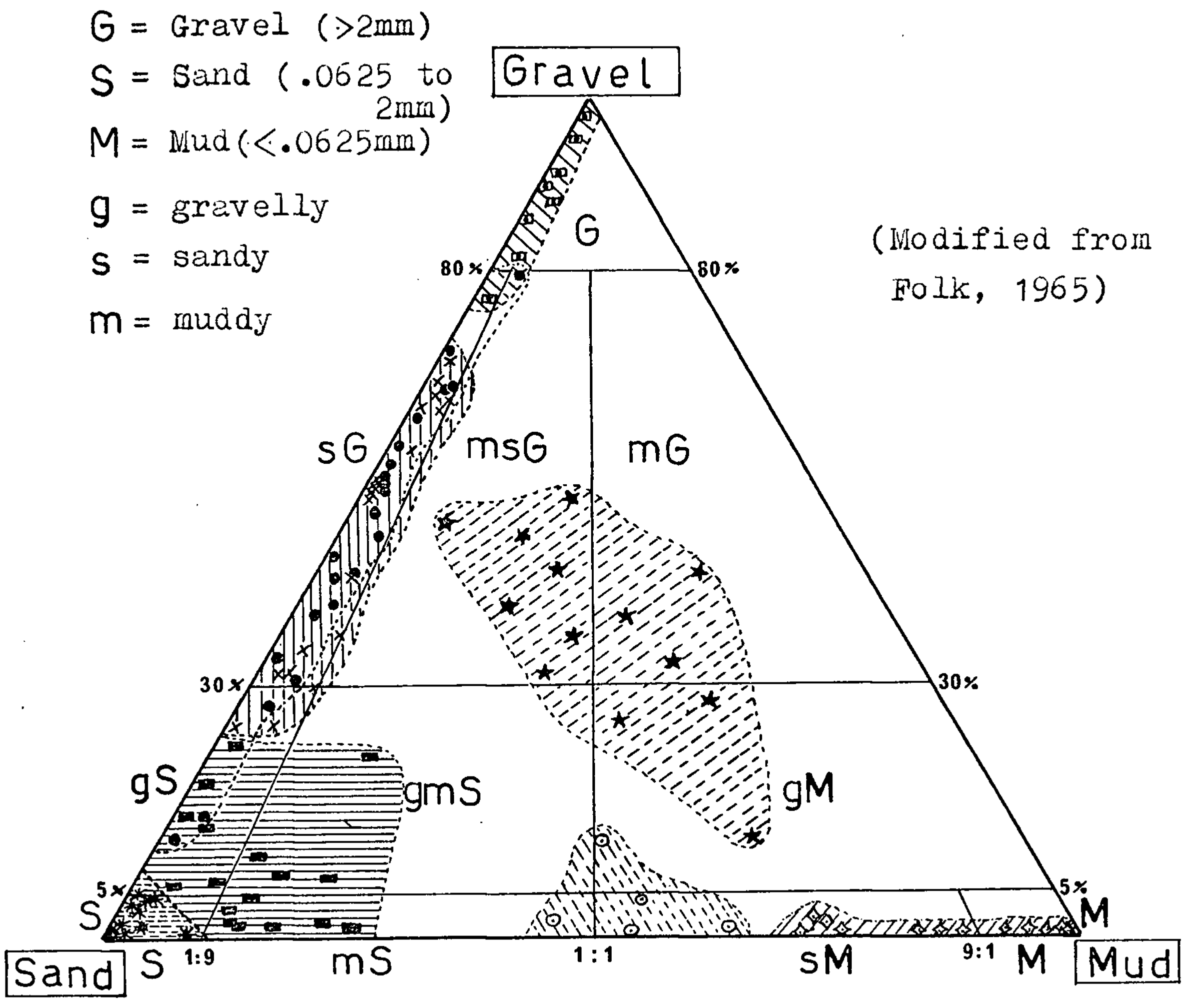

Groups of Cumulative Curves
Symbols used for Sediment Types
= Sediment No. ①
= Sediment No. ②
= Sediment No. ③
= Sediment No. ④
= Sediment No. ⑤
= Sediment No. ⑥
= Sediment No. ⑦
= Sediment No. ⑧

Figure 15



GRAIN SIZE NOMENCLATURE FOR THE 8 SEDIMENT TYPES DEFINED FROM GROUPS OF CUMULATIVE CURVES.

Figure 16

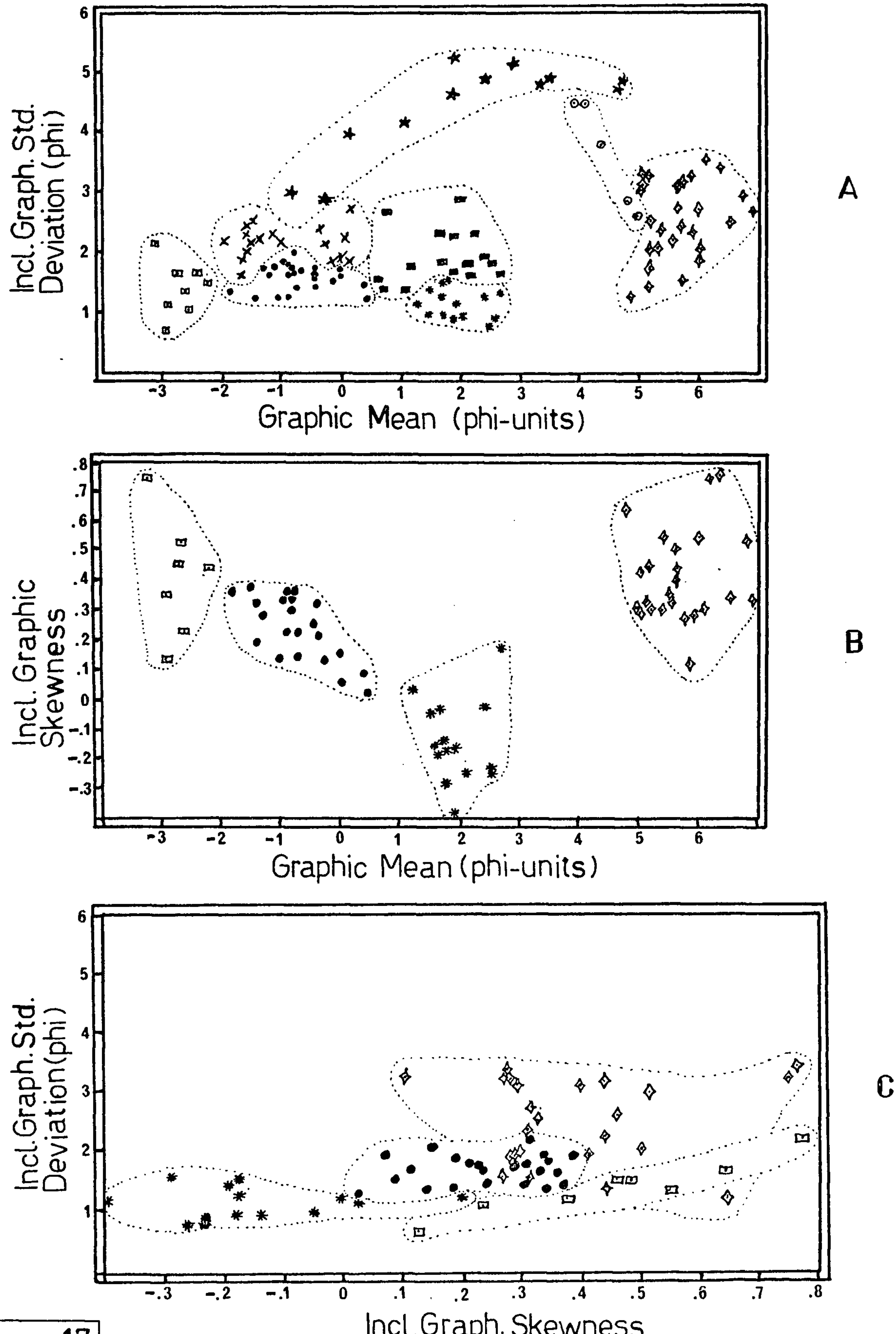

Incl. Graph. Std. Deviation (phi)
Graphic Mean (phi-units)
A
Incl. Graphic Skewness
Graphic Mean (phi-units)
B
Incl. Graph. Std. Deviation (phi)
Incl. Graph. Skewness
C

Figure 17

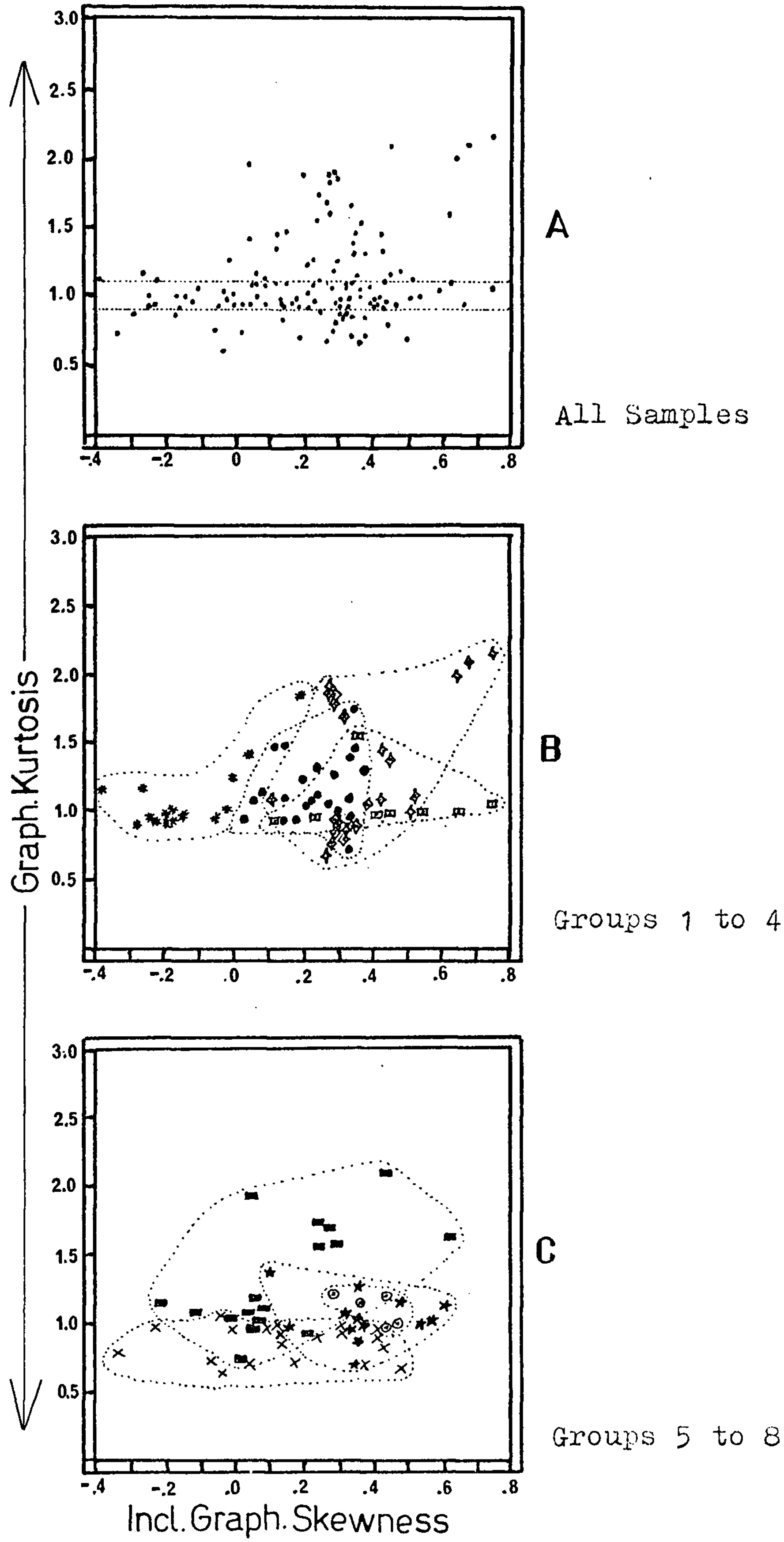

3.0
2.5
2.0
1.5
1.0
0.5
-.4
-.2
0
.2
.4
.6
.8
A
All Samples
B
Groups 1 to 4
C
Groups 5 to 8
Graph. Kurtosis
Incl. Graph. Skewness

Figure 18

Table 3

Limits of Some of the Main Statistical Parameters (from Folk, 1965)

1. Inclusive Graphic Standard Deviation (in phi-values)

Less than		.35	=	very well sorted
.35	-	.50	=	well sorted
.50	-	.71	=	moderately well sorted
.71	-	1.00	=	moderately sorted
1.00	-	2.00	=	poorly sorted
2.00	-	4.00	=	very poorly sorted
	Over	4.00	=	extremely poorly sorted

2. Inclusive Graphic Skewness

+ 1.00	to	+ .30	=	strongly fine skewed
+ .30	to	+ .10	=	fine skewed
+ .10	to	- .10	=	near symmetrical
- .10	to	- .30	=	coarse skewed
- .30	to	- 1.00	=	strongly coarse skewed

3. Graphic Kurtosis

Less than		.67	=	very platykurtic
.67	-	.90	=	platykurtic
.90	-	1.11	=	mesokurtic
1.11	-	1.50	=	leptokurtic
1.50	-	3.00	=	very leptokurtic
	Over	3.00	=	extremely leptokurtic

Table 4 : Ranges and average values of statistical parameters within each of the eight groups of cumulative curves, as shown in Figure 13.

		Mean (phi)	In.Gr.St. Dev.(phi)	Inc. Gr. Skewness	Graphic Kurtosis
Group 1					
	low	- 3.19	.71	+ .130	.871
	high	- 2.21	2.16	+ .770	1.504
	avge	- 2.77	1.32	+ .415	1.041
Group 2					
	low	- 1.81	1.24	+ .026	.710
	high	+ .47	2.02	+ .387	1.755
	avge	- .67	1.64	+ .228	1.164
Group 3					
	low	+ 1.27	.59	- .409	.849
	high	+ 2.67	1.53	+ .198	1.844
	avge	+ 1.89	1.10	- .136	1.029
Group 4					
	low	+ 4.81	1.24	+ .103	.708
	high	+ 6.95	3.42	+ .759	2.139
	avge	+ 5.88	2.53	+ .410	1.313
Group 5					
	low	- 1.99	1.63	- .338	.633
	high	+ .21	2.66	+ .497	1.023
	avge	- .91	2.13	+ .153	.836
Group 6					
	low	+ .22	1.43	- .214	.721
	high	+ 2.68	2.88	+ .625	2.155
	avge	+ 1.58	1.91	+ .132	1.314
Group 7					
	low	+ 3.94	2.62	+ .291	.904
	high	+ 5.05	4.56	+ .469	1.197
	avge	+ 4.48	3.65	+ .409	1.068
Group 8					
	low	- .85	3.06	+ .107	.699
	high	+ 4.71	5.27	+ .622	1.359
	avge	+ 1.79	4.49	+ .324	.974

Sediment Type	True surface area(in m^2) - USELESS INLET	Percent of total true surface area - USELESS INLET	True surface area (in m^2) - FATTY BASIN	Percent of total true surface area - FATTY BASIN
Bedrock	210,000	8.0	38,000	6.8
Boulders	35,000	1.3	19,000	3.4
Sed. No. 3	115,000	4.3	3,200	.6
" " 4	340,000	12.9	9,800	1.7
" " 5	30,000	1.1	2,600	.5
" " 6	45,000	1.7	15,700	2.8
" " 7	85,000	3.2	6,800	1.2
" " 8	-	-	3,800	.7
" " 9	30,000	1.1	1,100	.2
" " 10	100,000	3.8	25,000	4.4
" " 11	-	-	800	.1
" " 12	95,000	3.6	15,600	2.8
" " 13	200,000	7.6	11,600	2.0
" " 14	50,000	1.9	12,400	2.2
" " 15	1,280,000	49.5	396,600	70.6

Table 5 : True surface areas of bedrock exposures and sediments in Useless Inlet and Fatty Basin. The figures refer to areas below Low-Tide Level only. They were calculated utilizing data on width and length of exposures as well as angles of slopes.

6. Sediment Distribution

Thirteen sediment types have been defined for the Fatty Basin - Useless Inlet - Rainy Bay area and are shown on two accompanying maps, where they are represented by colour symbols and numbers from 3 to 15. Their relationship to the eight basic sediment groups defined from statistical parameters is presented in Figure 14.

Accumulations of large, angular boulders are regarded as an additional type of sediment and are listed as No. 2 on the distribution maps; they are represented by a dark grey colour. Extensive exposures of bedrock occur in the inlets and appear as light pink areas on the distribution maps; the bedrock is listed as No. 1 in the legend.

Sediment dispersal is mainly effected by currents. Waves are significant only along some gravel beaches facing an open stretch of water, especially if a good supply of terrestrial debris from glacial deposits is available. Oyster Beach in the Central Section of Useless Inlet offers the best example of this type.

The sediments, as discussed in detail below, may be roughly grouped as follows:

(A) Boulders; (B) Pebbles and gravels; (C) Terrestrial sands; (D) Shell debris; (E) Muds; (F) Coarse shell-gravel mixtures.

(A) Boulders: (Sediment No. 2):

Large, angular boulders are common along the inlet perimeters, where they usually form steep slopes. The vast majority is derived as primary products of mass wasting along steep sections of strongly fractured bedrock slopes. The petrology, consequently, is always that of near-by bedrock exposures, mainly andesites of the Bonanza subgroup. Shell debris, notably barnacle plates, as well as muds are commonly trapped in protected areas between the boulders and may form considerable accumulations. The total extent of these angular boulders amounts to about 3.4% and 1.3% of the total bottom surface in Fatty Basin and Useless Inlet, respectively.

(B) Pebbles and gravels

(i) Mostly angular, coarse gravel with few shell fragments (Sediment No. 3):

These gravels cover extensive areas in Useless Inlet, but are not very common in Fatty Basin. Like the large boulders, they are the result of mass wasting of strongly fractured bedrock and consist predominantly of Bonanza andesites. Occasionally, other gravels, derived from glacial deposits and characterized by well- to subrounded shapes and variable petrology, are intermixed with the angular material.

The sediment occurs most extensively on deltas of the type B, and also along the base of steep, strongly fractured bedrock faces or boulder slopes. Invariably, the well-washed gravel extends to only about 2 to 3 inches depth, where it becomes strongly intermixed with finer-grained material. The area covered by the gravels amounts to only 0.6%

of the total bottom surface in Fatty Basin, but 4.3 % in Useless Inlet.

(ii) Rounded pebbles and gravel (Sediment No. 7):

This coarse material is essentially confined to areas influenced by strong currents, notably the two guts, the mouth of Useless Inlet, and some creek beds near the heads of deltas (Photograph 13). Although abrasion of angular, locally derived fragments may be a factor here, most of the pebbles probably originated from glacial drift. The petrology is variable and ranges from granodiorites and monzonites to basalts (see rock units discussed in chapter "Geology"), although intermediate volcanics of the Bonanza subgroup are most abundant. The assemblage is essentially that of the coarse fractions of glacial drift deposits common throughout the region.

The currents generated by the tide as well as by the head difference in sea level (see chapter "Physical Oceanography") in the two guts reach a speed of at least 5 to 10 knots, a figure based upon own estimations along the narrowest sections of these passages. Fine-grained material is easily transported by these strong currents, and only the pebble and gravel fractions of the original glacial drift deposits remain, constituting the predominant surface sediment. Accumulations of angular fragments occur only below some steep bedrock faces, where other sediments are in short supply, and none of these pebbles showed any loss of angularity due to currents or abrasion by other sediments.

Patches of medium to coarse shell fragments are common between the rounded pebbles, wherever the current strength is less severe than in the narrowest sections of the entrance passages. Due to their platy shape, larger shells are not easily moved by a current, especially when the convex sides are up. Sediment No. 7 accounts for only about 1.2% of the total bottom surface area in Fatty Basin, but 3.2% in Useless Inlet.

(C) Terrestrial sands:

(i) Medium to fine sand (Sediment No. 4):

This sand contains very little gravel or mud and few shell fragments, and it constitutes the best sorted sediments in the area under consideration here, apart from some of the gravels of sediment No. 3. Dark grey to greenish grey in colour, this uniform sand consists mostly of andesitic rock fragments, with the Bonanza volcanics the likely source. Its greatest extent is in the Outer Section of Useless Inlet, where it forms the predominant sediment. Tidal currents here reach flow-speed maxima of over 4 knots (Herlinveaux, 1966) and keep the sediments relatively free of fine-grained material, causing the better sorting as compared to most other sediments in the area. The second common occurrence of these medium to fine sands is in the lower reaches of some bays, where they are concentrated by winnowing of the near-shore terrestrial sediments through surface currents and wave action. Towards depth, the sands gradually become muddier and eventually dip beneath the ubiquitous olive-green mud.

Due to its extensive occurence in the Outer Section, this sand covers about 12.9% of the bottom surface area in Useless Inlet, but only 1.4% in Fatty Basin.

(ii) Coarse sand with abundant gravel and pebbles (Sediment No. 6):

This sediment is confined usually to the near-shore zone of bays with abundant supply of terrestrial debris. It appears to be the product of winnowing action by surface currents and waves, which remove much of the medium to fine-grained sand (sediment No. 4), as discussed in the previous paragraph. Considerable amounts of gravel and pebbles are always present, and a gradation between the coarser and finer fractions is common. The mud content is usually negligible, but shell fragments may be abundant. The latter originate 'in situ' from bivalves like Little Neck Clams, Cockles, and Butter Clams, which accounts for the many unbroken shells.

In petrology similar to the finer sands, this sediment consists almost exclusively of andesitic rock fragments derived from Bonanza volcanics.

It covers about 2.8% of the bottom surface area in Fatty Basin, and 1.7% in Useless Inlet.

(iii) Coarse sand with some gravel, pebbles, and shells (Sediment No. 5):

This coarse sand occurs only in relatively few localized patches, usually near deposits of sediment No. 6 or of gravels of sediment No. 3. Gravel and pebbles are not abundant, and no gradations between them and sand-sized grains are apparent. The sediment represents only a localized, inhomogeneous mixture between sands and gravels. Shell fragments here, as in sediment No. 6, originate mostly 'in situ' from sand-burrowing bivalves.

This sand covers only 0.5% of the bottom surface area in Fatty Basin, and 1.1% in Useless Inlet.

(D) Shell debris:

(i) Coarse shell debris with few terrestrial fragments (Sediment No. 12):

This coarse shell debris is common throughout the area of interest, occurring mostly along a narrow zone at the base of steep bedrock and boulder slopes. It also accumulates in numerous small patches between large boulders and in hollows on bedrock exposures. Barnacle plates form the most common single constituent, but calcareous worm tubes are also very abundant along many sections of the inlet perimeters. Together, the shell remains of these two organisms may account for more than 90 percent of the calcareous fraction in samples dominated by shell debris. Towards depth, the coarse shell material grades into medium-sized, muddy debris or green muds rich in shell fragments.

The sediment covers about 2.8% of the bottom surface area in Fatty Basin, and 3.6% in Useless Inlet.

(ii) Medium-sized shell debris, very muddy and with abundant terrestrial gravel (Sediment No. 10):

This sediment commonly occurs below accumulations of coarse shell debris of sediment No. 12. The latter often forms wedge-shaped deposits with relatively steep surfaces along the base of bedrock and boulder slopes, and finer shell material probably is removed by bottom currents and deposited at a lower level. Here, muds become abundant, and the mud content of sediment No. 10 is always very high. Terrestrial gravel also concentrates in this zone, since the rock fragments tend to slide off the inclined surface of No. 12 - deposits.

Sediment No. 10 dips beneath the olive-green muds at a very low angle, and it usually can be encountered just below the mud for a distance of several feet from the actual surface contact between the two sediment types.

Whenever steep bedrock and boulder slopes reach right down to the mud zone (around islands, for example), no accumulations of coarse, well washed shells occur. Here, the muddy and gravelly shell debris fringes the slopes directly, especially if the supply of carbonate material is limited.

Sediment No. 10 covers about 4.4% of the bottom surface in Fatty Basin, and 3.8% in Useless Inlet.

(iii) Fine to very fine shell hash (Sediment No. 11):

This sediment is uncommon and was found only in a few small patches in Fatty Basin and Rainy Bay. The fine-grained shell fragments probably were winnowed out of other carbonate deposits accumulated in a few favorable locations near the mud zone. Consequently, the sediment always has a high mud content and grades into the muds of Sediment No. 14.

The extent of the fine-grained shell hash is approximately 0.1% of the bottom surface in Fatty Basin, and is negligible in Useless Inlet.

(E) Muds:

(i) Olive-green mud rich in organic matter (Sediment No. 15):

This mud is the most common sediment throughout the inlets under consideration here. It consists mainly of silt-sized particles, but clay (particle size below 2 microns) is usually very abundant. Hydrogen Sulphide (H_2S), detected by its strong odour, seems to be always present, but mud dwellers like Brittle Stars and Mud Clams occur and may even be abundant in places.

The olive-green colour is due mainly to the high content in organic matter. Treatment with hydrogen peroxide ($H_2 O_2$), which destroys the organic carbon, caused a pronounced colour change towards a medium grey, whereas hydrochloric acid and Na-dithionite (removing the carbonate and iron) had little or no effect on the colour.

The influx and deposition of organic material in Fatty Basin and Useless Inlet is considerable (see chapter "Rate of Sedimentation"). Narrow and shallow entrances cause the inlets to act as large traps for particulate organic matter, which is suspended in the surface waters that enter during each upcoming tide. Furthermore, Seki (1968) showed that in a shallow coastal area total production of organic matter in the water column exceeds its destruction by bacteria during most times of the year. In the case of Fatty Basin and Useless Inlet, little of this excess organic matter is likely to be flushed out during an ebb-tide, and consequently most of it settles on the mud.

Within the mud, anaerobic bacteria produce a reducing environment with abundant H_2S, regardless of depth and despite the fact that dissolved oxygen is present in the entire water column throughout most of the year (see Figure 9). Related literature commonly, and perhaps indiscriminately, associates H_2S-rich mud with stagnant, de-oxigenated bottom waters, whereas this in fact may not be true at all in some of the cases.

Contribution of material to the mud is considerable and varies slightly through the seasons (see chapter "Sedimentation Rate"), but no stratification was noted in any of the cores. This lack is attributed to the presence of various bottom dwellers like Brittle Stars and Polychaete Worms, as well as to bacterial activity destroying the particulate organic matter that settles on the mud surface. Upon diving, fluffy layers of feather-like organic debris were observed on the mud, easily stirred up by the slightest water movement. Below the surface, however, the mud is of monotonous homogeneity, with no large debris other than occasional shell-fragments or twigs and leaves. The upper six inches are usually uncompacted and of low density, and the mud here has coagulated into tiny (0.1 - 0.5 millimeter) balls. Below this surface zone, the mud is much more viscous and sharply increases in density with depth.

In some localities (e.g. the "holes"), concentrations of fine-grained shell-debris may occur near the surface, but none were found below the upper few inches. The strongly reducing conditions within the mud, especially in the deeper sections of the inlets, probably have a dissolving effect upon carbonate particles, thus eliminating small shell debris in time. Only a few larger shell fragments were found at some depth below the surface, and these always appeared soft and fragile, due to their partial disintegration.

Terrestrial silts and clays are brought into the inlets mainly through creeks and trickles, and they originate most likely from glacial drift and clayey silts, both common in extensive deposits throughout the area.

The olive-green muds are ubiquitous throughout the inlets and also in the more open Barkley Sound (Carter, 1970); they are deposited wherever bottom currents are weak to non-existent, and they usually cover existing irregularities to give the smooth, rounded bottom topography common in fjords and inlets. Along the perimeters, the mud overlaps upon other sediment (sands, shell debris), except for the fronts of some rapidly advancing deltas (type B), which in turn tend to override the mud with their foreset beds.

In Fatty Basin, the mud covers an overwhelming 70.6% of the total bottom surface; in Useless Inlet, where the Outer Section is dominated by sandy sediments, its extent still amounts to a large 49.5% of the bottom surface.

(ii) Olive-green mud with abundant small shell fragments (Sediment No. 14):

This sediment may be regarded as part of sediment No. 15, and occurs in narrow zones below shell deposits at the base of bedrock and boulder slopes along the inlet perimeters. It is simply a mixture of the olive-green mud with numerous small shell fragments winnowed out of the coarse shell debris.

The sediment covers 2.2% of the bottom surface in Fatty Basin, 1.9% in Useless Inlet.

(iii) Grey Mud (Sediment No. 13):

Deposits of grey mud are usually restricted to bays, where glacial clayey silts are exposed along the shore or on the banks of an inflowing creek (See also chapter "Delta-Developments"). The grey mud has similar statistical parameters and the same mineralogy as the glacial clayey silt, from which it is likely derived. The action of anaerobic bacteria is less here than in the olive-green muds, although small amounts of H_2S are commonly present. The content in organic carbon is characteristically low in these grey muds, and a faint stratification may commonly be observed in cores.

This sediment covers only 2.0% of the bottom surface in Fatty Basin, but 7.6% in Useless Inlet, where it occurs extensively in Mud Bay.

(F) Coarse shell-gravel mixtures:

(i) Coarse, muddy mixture of shells with gravel and sand (Sediment No. 8):

This sediment occurs in a few isolated patches, usually near the deposits of gravelly sand. The many unbroken shells are derived from organisms inhabiting the sandy sediments, like Cockles, Little-Neck Clams, and Butter Clams (see also Figure 21), and tend to concentrate near the contact between sand and mud (Photograph No. 22). The mixture is extremely poorly sorted.

It covers only 0.7% of the bottom surface in Fatty Basin and is uncommon in Useless Inlet.

(ii) Muddy, very coarse gravel (angular)-shell mixture (Sediment No. 9):

Similar to sediment No. 8, this mixture occurs in isolated patches near the angular gravel deposits of sediment No. 3, which are common in small bays and on delta tops. The shells are largely unbroken, too, with Butter Clams, Native Oysters, and Little Neck Clams the most abundant species.

The extent of this mixture amounts to only 0.2% of the bottom surface in Fatty Basin, but 1.1% in Useless Inlet, where gravel deposits are more extensive.

13

Rounded pebbles on the upper part of Oyster Beach, washed out of old delta strata, but ultimately derived from glacial drift deposits along the creek bed above the delta. Such deposits of rounded pebbles are also typical for strong-current zones, such as the two guts and the entrance into Useless Inlet, as discussed in the text.

14

Coarse, angular gravel and gravelly sand, exposed at a low tide on Oyster Beach. Shells are common and usually unbroken here, derived from burrowing bivalves living below the surface of the sediment. The angular gravel is fairly typical for sediment type 3.

7. Lithology of the Sediments

In this chapter, sediment colours, grain shape and roundness, as well as surface textures of grains are briefly discussed, in order to further relate the various sediments to their sources, to the methods of transport, and to their depositional environments.

(i) Sediment Colours:

Deposits of coarse terrestrial sediments, like pebbles, gravel, and sand, are mostly of dark-grey to greenish-grey colours, reflecting the predominance of andesitic rock fragments. Locally, sands may appear lighter-grey to yellow-brownish-grey, caused by a greater abundance of quartz, feldspars, cherts, and similar light-coloured minerals. Brownish colours are mainly due to iron oxides and are most common in sediments of the intertidal zone.

The colours of the muds are dependent upon the amount of organic matter present. Upon treatment with hydrogen peroxide, the green muds always changed their colour from olive-green to a medium grey, whereas the grey muds, which contain far less organic carbon, only attained a lighter hue of the same colour. Treatment with Na-dithionite and hydrochloric acid for iron- and carbonate-removal resulted only in very insignificant colour changes.

Deposits of shell-debris appear in various shades of very light greys, and mixtures between shells and terrestrial sediments may bring about numerous variations of grey colours. In the strong-current zones of the two guts and the entrance to Useless Inlet, pebbles and gravel are often overgrown with pink algae, and the entire sediment may superficially appear in this colour. Similarly, overgrowths of various other shell-secreting organisms may give light colours to an originally dark sediment.

In a few areas, creeks contribute great amounts of organic detritus to the inlets, and tiny wood fragments may be abundant enough to actually cause colour changes in the muds towards a dark brown. The south-delta of Fatty Basin and Oyster Beach in Useless Inlet are good examples.

(ii) <u>Grain Shape and Roundness</u>:

Both sphericity and roundness of gravels and pebbles are entirely dependent upon the origin, whether they are derived from glacial drift or from local bedrock through mass wasting.

The glacially derived coarse material is relatively well-rounded and of high sphericity, regardless of the rock type involved, but angular gravel and pebbles may be of very irregular shapes, and they consist almost exclusively of Bonanza volcanics. They have fresh surfaces, sharp edges, and even large, easily weathered phenocrysts may still be preserved. In many cases, these materials can be traced to their source, usually strongly fractured bedrock exposures along the shorelines or within creek beds. Some of the debris may have been transported short distances by glacial ice, but angular fragments are generally not found in glacial drift deposits. The angular material commonly mixes with rounded, glacially derived pebbles and gravels, but due to its greater abundance, dominates most of the coarse terrestrial sediments.

Sand-sized terrestrial fragments usually have good sphericity, but variable roundness. Both coarse and fine sands consist mainly of volcanic rock fragments, although the finer fractions may have a higher percentage of monomineralic grains, which are generally highly angular. Rounded grains are scarce and consist exclusively of very fine-grained volcanic rock. Near outcrops of glacial clayey silts, the fine sand fractions have relatively abundant fresh, angular quartz, whereas elsewhere the content of lithic fragments is very high (see also Figure 11).

The andesitic rocks are often extremely fine-grained and may persist even in very small fragments. Coarser-grained diorites and granodiorites, on the other hand, disintegrate readily into their constituent grains of quartz, feldspar, and mafic minerals. Since these intrusive rocks appear only in a few small outcrops in the immediate area of interest, they are a negligible source for sediments,and volcanic rock fragments consequently dominate most sand fractions.

Carbonate gravel and sand fractions are mostly highly angular and of extemely poor sphericity. Exceptions occur in zones of strong currents, where thick shells of bivalves like oysters and scallops may be reworked into fairly rounded fragments.

(iii) Surface Textures:

Only surface textures of rounded, glacially derived pebbles are of interest, since angular fragments of local source normally show few imprints of a transporting agent or the sedimentary environment.

Pitting is very common, caused by preferential erosion of the mafic minerals in diorites or of phenocrysts in some of the volcanic rocks. Percussion marks, resulting from collisions between pebbles, are fairly rare and were observed only in a few cases on very fine-grained volcanic rocks. Glacial striations may be expected as a common feature here, but were found only on very few pebbles and cobbles, even among those collected directly from glacial drift.

Encrusting organisms are abundant throughout the area, with pink algae and bryozoans common in the strong-current zones of the two guts and the mouth of Useless Inlet, and calcareous worm tubes occurring along most rocky sections of the inlet perimeters and around the islands (see Photograph 18).

8. Effects of the Fauna upon Sedimentation

As discussed in a previous chapter, the olive-green muds in Fatty Basin show a lack of stratification, which was attributed to the activities of burrowing organisms like Ophiuroids, Pelecypods, Holothurians, and Polychaete Worms, as well as to the decay processes initiated by bacteria within the mud. The lack of stratification here seems to be in contrast to the laminations Carter (1970) found in the muds of Effingham Inlet. Perhaps, the bottom waters of Effingham Inlet are truly stagnant and deficient in dissolved oxygen and prevent any infauna except anaerobic bacteria, which then may result in remnants of laminations to be still preserved within the mud. Another suggestion is, that Carter observed the laminations only on X-ray photographs of his cores, which revealed laminations otherwise hidden from observation. No such procedure was followed with the Fatty Basin cores, and it may be well possible that they also reveal remnants of laminations, if subjected to X-ray photography. This question is left unanswered here, since more relevant importance is seen in the basic fact, that the effects of infauna and bacteria upon the stratification are very strong indeed, which is easily confirmed by ordinary observation methods.

Faecal pellets, believed to be the waste products of filter-feeding organisms, were found only in two samples from Useless Inlet and Rainy Bay (92 and 122). The pellets, egg-shaped and of about 1 millimeter length, are very soft and break easily during handling, which may be one reason for their lack in most of the collected samples. However, similar faecal pellets seem to be common in the sediments of Barkley Sound (Carter), although samples collected there have undoubtedly undergone extensive handling as well. This observation suggests, therefore, that filter feeding organisms actually are far more abundant in the open waters of the Sound than in the restricted environments of Useless Inlet and Fatty Basin.

In some areas of the Basin, notably on shell deposts just off reef 4, large starfishes, in their search for buried clams, dig through surface sediments and turn over considerable amounts of material. The same species is also common on sandy and gravelly sediments, wherever colonies of clams live buried beneath the surface. In general, however, the effect of these starfishes upon the sedimentation may be regarded as very minor.

Small hermit crabs are abundant in Fatty Basin and Useless Inlet. They seem to favour as their portable homes empty shells of univalves like the Red Turban and the Spindle Shell, and consequently unbroken shells of these species are rarely found in a sediment sample. Because of their considerable abundance, the hermit crabs clearly have some influence upon the distribution of shell debris, and commonly fragments of univalve shells are found in unlikely places, where they were transported by the crabs.

In conclusion, it is apparent that the influence of shell-bearing organisms upon the sedimentation is of major importance, as has been discussed in previous chapters on sediment distribution, since they are responsible for a large percentage of the total sediments, but other organisms contribute only negligible amounts of debris. The effects of the fauna upon distribution of sediments are minor in comparison to other factors like currents and bottom topography, but stratification of sediments may be largely destroyed, as is well exemplified by organisms within the olive-green mud zone.

9. Organic Carbon Distribution

Eighteen samples (Table 6) were analysed for their total carbon contents by Can Test Laboratories of Vancouver, where the combustion furnace method was used. All samples had been previously treated with hydrochloric acid for carbonate removal, and organic carbon is therefore considered to provide the total carbon content of these samples. Carbon in the form of carbonates was disregarded in this study, since random occurrences of shell fragments are often inconclusive in reference to transporting agents and types of sediments, largely because of the abundant shell-bearing fauna throughout most of the inlets.

The organic carbon content of a sediment is strongly influenced by the sedimentary environment, and the dominant factors are (i) the particle size of the sediment, (ii) the influx of organic relative to terrestrial debris, and (iii) the bottom topography and currents. Figure 19 illustrates the distribution pattern of organic carbon throughout the area of interest.

Highest concentrations are found along the north-western shore of the Central Section in Useless Inlet and at the south-eastern end of Fatty Basin, coinciding with locations of rapidly advancing deltas (type B; see chapter on "Delta Developments"). Large amounts of organic debris are transported by rapidly flowing creeks and added to the inlet sediments here, which results in maxima of over 11% of organic carbon within the mud fraction.

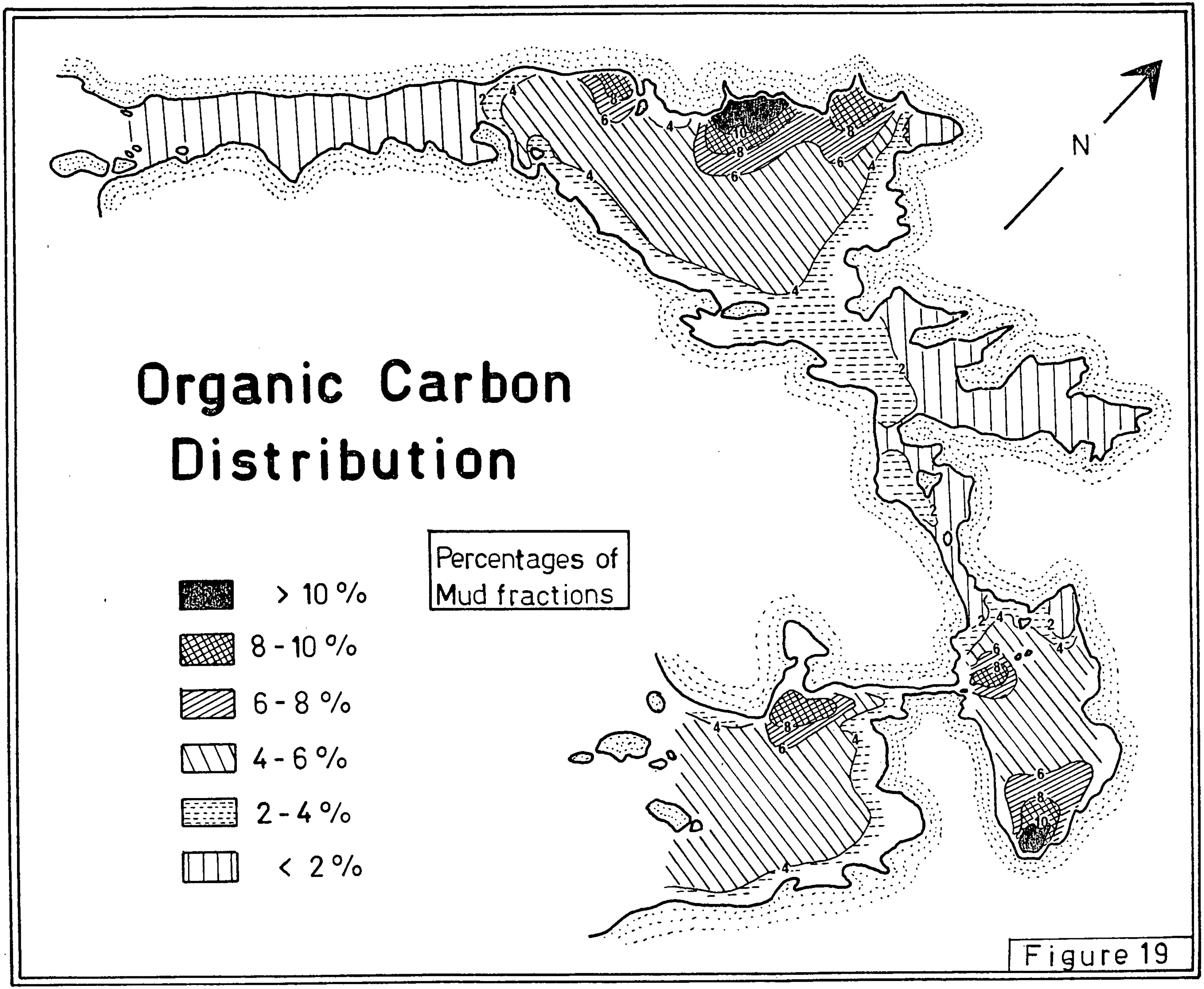

Organic Carbon Distribution
Percentages of Mud fractions
> 10 %
8 - 10 %
6 - 8 %
4 - 6 %
2 - 4 %
< 2 %
N
Figure 19

Table 6 : Organic Carbon Contents (in percentages of mud fractions)

Sample No.	Organic Carbon (%)
1	1.85
7	1.45
18	5.50
27	6.70
33	11.20
49	8.75
71	5.25
75	5.45
87	1.95
88	2.50
90	1.25
91	1.05
92	3.35
99	1.50
102	11.10
109	4.70
125	5.30
R.B. off Small Gut	8.45

Other high concentrations of over 8% were found in the "holes" of Fatty Basin and off the Small Gut in Rainy Bay. Coarse organic debris, swept through the gut by strong tidal currents, tends to settle immediately upon entering the relatively quiet-water conditions in both Fatty Basin and Rainy Bay. Decomposition of the coarse debris then results in high percentages of organic carbon within the mud fraction.

Most of the green mud zones are characterized by concentrations between 5 and 6%, dominantly the result of excess production through deposition of fine-grained phytoplanktonic debris upon the mud with its reducing environment. pH-measurements of the water column and the near-surface mud were taken by Seki (unpubl.) on June 12, 1969. The data are plotted on Figure 20 , and it is evident that the mud may have either slightly higher or lower pH-values than the bottom waters. If destruction of organic carbon within the mud is exceeding its production through photosynthesis in the bottom water, the pH-value of the mud seems to be lower (more acidic) than in the water immediately above. If there is more production in the bottom water as compared to destruction of organic carbon in the mud, the pH-value of the mud appears to be higher than that of the immediately overlying bottom water. Slight variation of organic carbon contents in the mud may be caused by these factors, but is probably minor relative to the total quantities of organic carbon produced by photosynthesis in the whole water column.

Low concentrations of organic carbon occur in areas dominated by grey mud, notably near deltas of type A. The water here is generally very shallow, and deposition of organic debris is minor compared to the vast amounts of fine-grained terrestrial material derived from glacial clayey silts.

Low concentrations are also found in zones of strong currents, notably the two guts and the Outer Section of Useless Inlet, where the sediments are without appreciable mud fractions.

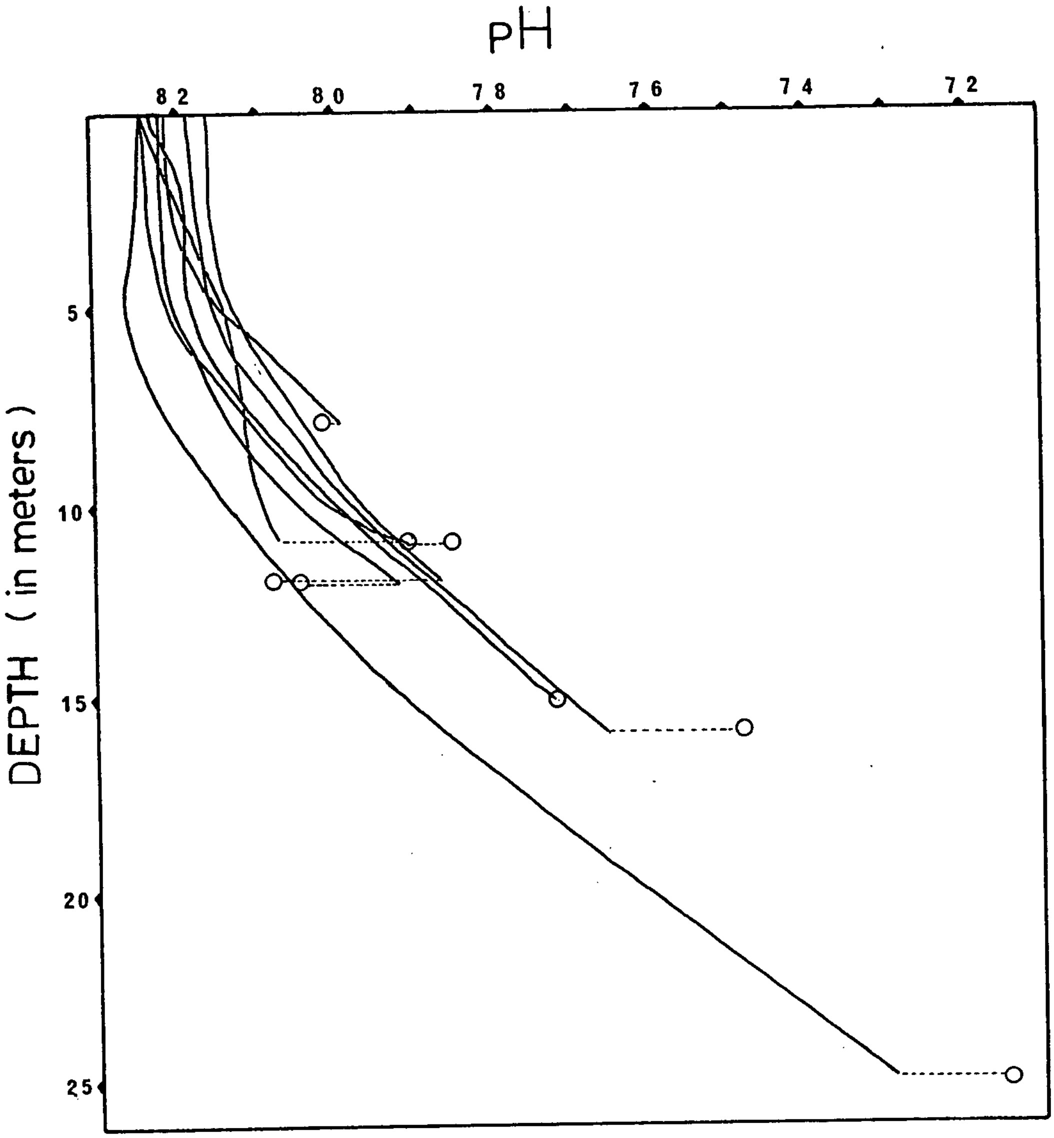


Figure 20

Variation of pH - values with depth at 8 stations in Fatty Basin on June 12, 1969.
(Data from Seki, 1969)

o = bottom sediment (mud)

10. Nature and Distribution of the Shell-bearing Fauna

The relatively restricted environment of Useless Inlet and especially Fatty Basin reflects upon the shell-bearing fauna of these inlets. The shells of many organisms are much smaller than those found in the more open waters of Barkley Sound, notably molluscs such as *Mytilus*, *Chlamys*, *Donax*, *Humilaria*, *Astrea*, *Ocenabra*, and *Tegula*. A few genera are entirely absent (e.g. *Haliotis* and *Olivella*), but others seem to prefer the inlet environment and are more common here, notably *Nassarius*, *Saxidomus*, and a Rhynchonellid-Brachipod (genus not identified). A complete list of the shellfish genera found in Fatty Basin and Useless Inlet is presented in Table 7.

Distribution of the various genera is entirely dependent upon the sedimentary environments. Within the mud zone, few shell-bearing organisms are found; these are mostly bivalves such as *Mya* and *Yoldia*. Muddy sands and gravels in bays and on delta tops are inhabited by *Venerupis*, *Saxidomus*, *Clinocardium* and, occasionally, *Ostrea*. Only few genera occur in the strong-current zones; they are mostly restricted to that environment and include *Glycimeris*, *Humilaria*, and *Felaniella*.

The vast majority of shell-bearing organisms is found on bedrock and boulder slopes along the inlet perimeters and around islands. Barnacles and calcareous worm tubes are by far most abundant and provide the bulk of the shell debris accumulating below the slopes, but most of the molluscan univalves (gastropods) and all of the brachipods are also restricted to this environment.

Table 7 : Bivalves and Univalves in Fatty Basin and Useless Inlet

Species or generic names are listed in approximate order of abundance of the organisms; in one case (Rhynchonellida) only the order was identified. Among the univalves, the first 8 species are common, but all others are very rare.

Whenever known, popular names for the shells are presented in brackets.

Bivalves

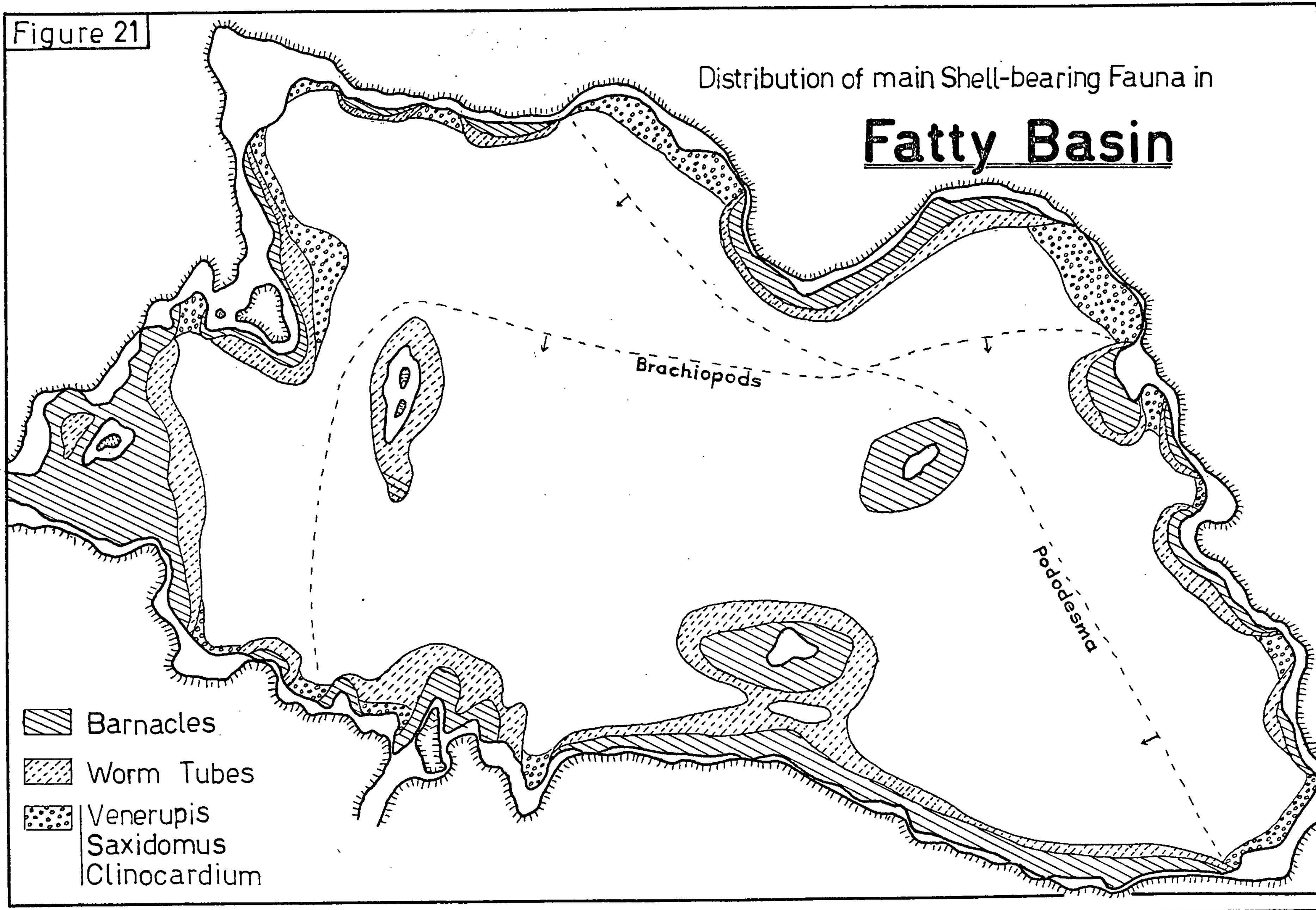
1. Venerupis japonica		(Little Neck Neck Clam)
2. Saxidomus giganteus		(Butter Clam)
3. Mytilus edulis		(Common Blue Mussel)
4. Clinocardium nuttalli		(Cockle)
5. Ostrea lurida		(Native Oyster)
6. Pododesma	(?)	(Jingle Shell)
7. Rhynchonellida (Order)		
8. Mya arenaria		(Mud Clam)
9. Chlamys	(?)	(Scallop)
10. Ostrea	(?)	(Japanese Oyster)
11. Donax	(?)	(Sunset Shell)
12. Glycimeris	(?)	(?)
13. Humilaria	(?)	(?)
14. Felaniella	(?)	(?)
15. Yoldia	(?)	(?)
16. Nuculana	(?)	(?)
17. Solen	(?)	(?)

Table 7 Continued

Univalves

1.	Nassarius fossatus	(Channelled Dog Whelk)
2.	Searlesia dira	(Spindle Shell or Dire Whelk)
3.	Crepidula lingulata	(Wrinkled Slipper Shell)
4.	Astrea gibberosa	(Red Turban)
5.	Bittium eschrichtii	(Threaded Bittium)
6.	Acmaea persona	(Mask Limpet)
7.	Acmaea testudinalis	(Plate Limpet)
8.	Ocenabra interfossa	(Sculptured Rock Shell)
9.	Lacuna variegata	(Variegated Chink Shell)
10.	Homalopoma carpenter	(Carpenter Dwarf Turban)
11.	Tegula pulligo	(Dusky Turban)
12.	Littorina sitkana	(Sitka Littorine)
13.	Mitrella gansapata	(Dove Shell)
14.	Ceratostoma foliata	(Leafy Hornmouth)
15.	Tegula funebralis	(Black Top Shell)
16.	Crepidula nummaria	(White Slipper Shell)
17.	Margaritus pupillus	(Puppet Margerite)
18.	Margaritus lirulatus	(Lirulate Margerite)
19.	Thais emarginata	(Short-spired Purple)
20.	Acteocina culcitella	(Pillowed Lathe Shell)
21.	Polinices (?)	(Lewis Moon Snail)
22.	Megatebennus bimaculatus	(Spotted Keyhole Limpet)
23.	Diodora aspera	(Rough Keyhole Limpet)
24.	Acmae mitra	(Whitecap Limpet)
25.	Puncturella (?)	(?)

Figure 21


Distribution of main Shell-bearing Fauna in
Fatty Basin
Brachiopods
Pododesma
Barnacles
Worm Tubes
Venerupis
Saxidomus
Clinocardium

The distribution of the most common shell-bearing organisms is illustrated on Figure 21.

Foraminifera were identified by Dr. Bruce Cameron of the Geological Survey of Canada and are listed on Table 8. No significant distributional pattern was recognized within the inlets, but in Fatty Basin, Elphidiella hannai (Cushman, Grant) appears to strongly predominate over other species. Elphidium fax (Nicol) is common throughout Useless Inlet and Rainy Bay, but rare in the Basin, and Quinqueloculina sp. seems to concentrate near the strong-current zone of the Big Gut.

The foraminifera population is far more varied in the more open waters of Useless Inlet and especially Rainy Bay than in Fatty Basin, and all species found are also common on relatively shallow sections of the continental shelf off Vancouver Island (Cameron, personal communication). The relatively restricted nature of Useless Inlet, therefore, appears to have little effect upon the foraminifera assemblage, whereas the strongly restricted environment of shallow Fatty Basin is favoured by the shallow-water species, Elphidiella hannai (Cushman, Grant).

Table 8 : Foraminifera in Fatty Basin, Useless Inlet, and Rainy Bay (listed in approximate order of abundance).

1. *Elphidiella* hannai (Cushman, Grant)
2. *Elphidium* fax (Nicol)
3. *Quinqueloculina* sp.
4. *Discanomalina* japonica (Asano)
5. *Cibicides* lobatulus (Walker, Jacob)
6. *Eponides* repandus (Fichtel, Moll)
7. *Cribrostomoides* crassimargo (Norman)
8. *Floribus* basispinatus (Cushman, Moyer)
9. *Cribroelphidium* frigidum (Cushman)
10. *Glabratella* ornatissima (Cushman)
11. *Dyocibicides* biserialis (Cushman, Valentine)
12. *Rotalia* columbiensis (Cushman)
13. *Planorbulina* sp.
14. *Elphidium* sp.

Note: "sp." = species not identified.

Identification by Dr. Bruce Cameron, Geological Survey of Canada.

17

Small shear zone on the shore of Rainy Bay. The greenish material in the zone consists dominantly of chlorite minerals and is relatively soft and friable.

18

5 ft-wide glacial groove on reef 1 in Fatty Basin (view is towards north-east).

Photograph No. 19: Base of Bedrock-Slope, Reef 1

Photograph No. 20: Surface of olive-green mud. Few shells of Mya.

15

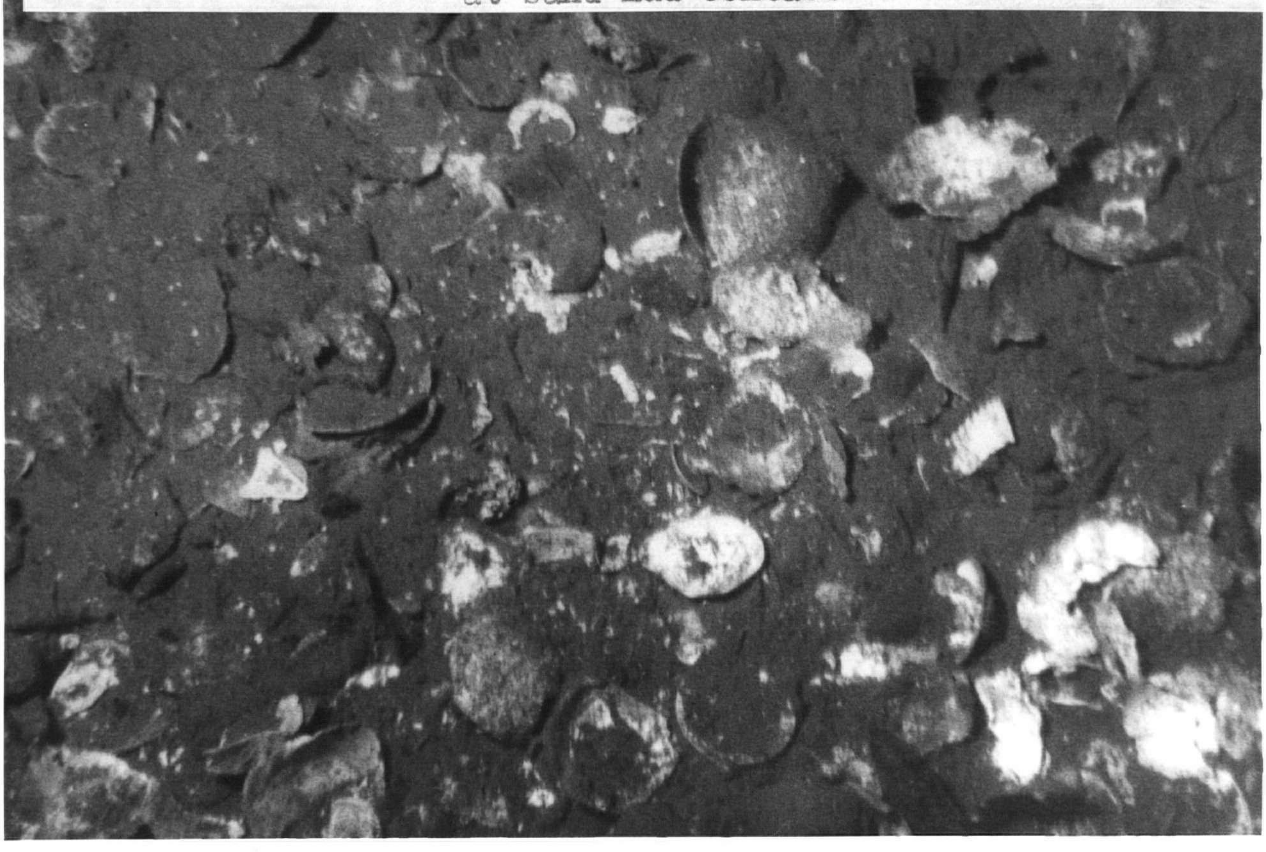
Gravelly sand of sediment type 6, exposed at a very low tide on the north-eastern perimeter of Fatty Basin. Glacial drift deposits occur above the boulder zone to the left of the picture.

Typical deposit of shell debris (sediment type 12) below bedrock slopes, exposed during an exceptionally low tide. Barnacles cover most of the intertidal rock faces, and their shell debris accounts for more than 80 percent of the sediment here.

16

Photograph No. 21: Gravel of Sediment No. 3

Photograph No. 22: Accumulations of mostly unbroken shells at sand-mud contact



SUMMARY AND CONCLUSIONS

In many aspects, notably physiography and sedimentology, Useless Inlet is probably typical for many inlets with shallow sills at their mouths, whereas Fatty Basin, at first observation, appears to represent an exceptional environment, because of small size, shallow water, and highly restricted connection with the ocean. Comparison of structures and sedimentation characteristics, however, reveals much similarity in the geology of these two inlets, and in this study, Fatty Basin is considered to be a small-scale model of many inlets with restricted entrances on a mountainous, glaciated coast. Because of ready accessibility of most sections of the Basin, accuracy in detail is believed to be good, notably with respect to the distribution of sediments, and general conclusions regarding the geological environment may be applicable to many similar, if larger inlets on this type of coast.

1. The Setting

Useless Inlet consists of three different parts, the (i) Outer Section, a straight channel with irregular bottom topography, sandy sediments, steep sides, and a relatively restricted entrance with a shallow, rocky sill; the wide (ii) Central Section with strongly embayed shorelines and muddy sediments on a smooth bottom topography; and the (iii) Inner Section, which is shallow and narrow and has a highly irregular bottom topography. Fatty Basin appears as an elongate, shallow bowl of

104 ft (32 m) maximum depth, with two very narrow and shallow entrance passages, the "guts". The bottom topography is generally smooth and dominated by muddy sediments, but several bedrock exposures rise up above the Low-tide Level.

The geology of the area is dominated by the Bonanza Subgroup (Upper Triassic to Lower Jurassic), which consists mainly of dark-greenish to reddish andesite flows, and by sporadic occurrences of massive limestones or limestone breccias of the Quatsino Formation (Upper Triassic). Hornblende diorite (West Coast Diorite) is found in extensive exposures on Tzartus Island, but only in two small outcrops in Fatty Basin and at the mouth of Uchucklesit Inlet. Granodiorites of the Island Intrusions (Middle to Late Jurassic) occur west of the area of interest, where they are widespread throughout the central section of the Barkley Sound Region. North of Uchucklesit Inlet, basaltic lavas of the Karmutsen Formation (Lower to Upper Triassic) form very extensive exposures; they are probably a major source for the glacial sediments found in the Fatty Basin area.

Although their present shapes are largely the results of scouring by glacial ice flows, both Fatty Basin and Useless Inlet are thought to be of structural origin, because directional trends of the many faults and fracture zones are also followed by the major shorelines. On the west coast of Vancouver Island and the B.C. mainland, fjords commonly trend at large angles to the general directions of Pleistocene ice flow, and similar to the limited area under consideration in this study, inlets in most regions of this coast tend to follow two preferred directions. A structural origin, with subsequent erosion by water and ice, is therefore suggested for most of the coastal depressions in British Columbia.

Similar views were presented by Peacock in 1935, and it is proposed here that statistical evaluation of attitudes of all known major faults on the B.C. coast and of directional trends of fjords and inlets be undertaken, in order to possibly confirm this suggestion.

Uplift of the land, probably due to isostatic response after glaciation, was at least 20 ft here during the last 7000 years, if a eustatic sea level rise of about 10 ft is assumed. This latter figure, however, represents a minimum, and much larger values have been proposed by some workers (e.g. Kennedy, Hopkins; from diagram by Mathews, 1970, page 694). Obviously, the evidence in different localities is conflicting, and the true amount of eustatic sea level rise is still largely uncertain. Consequently, the value of 20 ft for uplift of the land in this area is tentative, and any excess over 10 ft in absolute rise of the sea level during the last 7000 years will increase the total uplift by the same amount.

Within Fatty Basin, the physical oceanography is strongly affected by the restricted nature of the entrance passages, where currents generated by tidal exchange and head difference in water level are exceptionally strong. As a result, stratification of inflowing waters is destroyed, and good exchange of the entire water column takes place during most of the year. Salinity and temperature gradients are consequently always less in the Basin than in the outside waters, and stagnant, de-oxigenated bottom water appears to be rare, even in the deepest sections.

The water entering the Basin over the shallow sills is mostly surface water from the euphotic zones, where concentration of phytoplankton is much higher than in deeper waters. Great amounts of organic debris are therefore swept into Fatty Basin during each upcoming tide and are well distributed throughout the entire water column by the strong currents. Outgoing water during the ebb tide carries only part of this phytoplanktonic debris, and as a result, Fatty Basin appears to be a large trap for suspended organic matter.

Inlets with restricted entrances are common on the B.C. coast, because glacial scour tends to be more intense in the upper sections of a fjord than near its mouth, which results in entrance sills of bedrock or glacial drift. In many such inlets, tidal flushing is probably very effective in preventing development of truly stagnant waters during most of the year, but fjords of great length and depth may have extensive sections entirely unaffected by the strong tidal currents generated over the shallow entrance sill.

2. The Sediments

Rate of Sedimentation

Deposition of terrestrial and organic debris from suspension is in the order of 900 grams per square meter and year in Fatty Basin, but daily rates of sedimentation may vary considerably with the seasons. They reach a maximum of over 10 $g/m^2/day$ during late summer, when phytoplanktonic debris from the euphotic zone is deposited in great quantities, and minima of less than 2 $g/m^2/day$ in fall and spring. In late winter, a small increase in sedimentation rate to about 3 $g/m^2/day$ is probably caused by increased precipitation and resultant runoff during that time of the year.

These variations in sedimentation rates, largely caused by abundance or lack of phytoplankton in the water column, demonstrate the great influence of fine-grained organic debris upon the muds in Fatty Basin. These are therefore always rich in organic matter, except when glacial clayey silts in nearby shore deposits provide abundant fine-grained terrestrial material.

Clays and Heavy minerals

The clay minerals in Fatty Basin and Useless Inlet are almost exclusively members of the chlorite group, associated with only minor amounts of illite. Other minerals, such as kaolinite, smectite, and vermiculite, are either absent or present only in traces not detectable by ordinary X-ray diffraction methods.

The heavy mineral suite is generally dominated by epidote, clinopyroxene (augite), and abundant opaque minerals (magnetite). Hornblende, which is widespread in sediments of most of the Barkley Sound region (Carter, 1970), was common only in few of the samples, and accessory minerals, mostly sphenes, are rare. Chlorite was always present, but never in significant quantities, and appears to concentrate in the silt and clay fractions rather than in the fine sand fractions used for heavy mineral analysis.

Both clays and heavy minerals clearly reflect the nature of the source rocks, which are mainly Bonanza andesites and Karmutsen basalts. These units are very rich in chlorite, and both, especially the Karmutsen basalts, contain abundant clinopyroxene and epidote. No other rock unit in the central section of Vancouver Island carries all these minerals in similar abundances, or is exposed to any significant extent in the probable glacial passage from the Henderson Lake region to Fatty Basin. Karmutsen and Bonanza volcanics, therefore, constitute the ultimate source for the fine sands, silts, and clays within the area under consideration, where these materials are derived from glacial drift and clayey silt deposits.

Nature and Distribution of Sediments

Least sorted sediments are usually mixtures of shells, terrestrial gravel, sand, and mud. Such assemblages may vary greatly in mean size, even if other statistical parameters are similar, because slight changes in abundance of any one of these individual materials may result in distinct shifts of the mean size of the sediment as a whole. Best sorting, on the other hand, is found in well-washed terrestrial sand and gravels, where mixing of different sedimentary materials is insignificant.

Since most of the sediments contain at least some mud, positive (fine) skewness is very common, except for some of the terrestrial sands, where strong currents have removed most of the mud fraction. Even if present in only small amounts, silts and clays strongly influence the skewness of any sediment.

Shell fragments commonly introduce a poor sorting into coarse and medium size-fractions, but are rare in the silt-size range. Mixtures of shells and terrestrial material, therefore, are usually platykurtic, because of less sorting in the coarse fractions as compared to the fine silts and clays. Relatively homogeneous carbonate or terrestrial sands with appreciable mud fractions, however, are generally leptokurtic, because here the bulk of the coarse debris is better sorted than the fine-grained material.

Eight groups of sediments were defined on the basis of statistical parameters. Further subdivision as to relative contents of carbonate versus terrestrial debris and of rounded versus angular material resulted in recognition of thirteen different sediment types, which are shown on two accompanying distribution maps. Total bottom surface areas for each of these sediment types, as well as for bedrock exposures and angular boulders, which are regarded as an additional sediment type, are presented on Table 5. These figures refer to true surface areas, determined from width and length of exposures and from the approximate angle of slopes.

Below, short descriptions of the sediments, their general mode of occurrence within the inlets, and their extent in percentages of total bottom surface in Fatty Basin and Useless Inlet are presented. They may be roughly grouped into (A) boulders,(B) pebbles and gravels, (C) terrestrial sand, (D) shell debris, (E) muds, and (F) coarse gravel-shell mixtures.

(A) Boulders (Sediment No. 2):

Large, angular boulders form steeply sloping accumulations along extensive sections of the inlet perimeters, usually below highly fractured bedrock. (3.4% in Fatty Basin, 1.3% in Useless Inlet)

(B) Pebbles and Gravels

(i) Mostly angular, coarse gravel with few shell fragments (Sediment No. 3):

This gravel is common on some delta tops in the near-shore zone of some bays, and occasionally below strongly fractured bedrock faces. (0.6% in Fatty Basin, 4.3% in Useless Inlet)

(ii) Rounded pebbles and gravel (Sediment No. 7)

This coarse, rounded material is characteristic for the strong-current zones of the two guts and the mouth of Useless Inlet; it is mostly derived from glacial drift deposits. (1.2% in Fatty Basin, 3.2% in Useless Inlet)

(C) Terrestrial Sands

(i) Medium to fine sand (Sediment No. 4):

These sands occur in zones of medium-strong currents (velocity up to 5 knots) and are particularly extensive in the Outer Section of Useless Inlet. They are also found in many bays below the near-shore gravels, from which they were removed through winnowing by surface currents and, to a lesser degree, waves. (1.4% in Fatty Basin, 12.9% (!) in Useless Inlet)

(ii) Coarse sand with abundant gravel and pebbles (Sediment No. 6):

This sediment is usually confined to the near-shore zone of bays with abundant sediment supply, as the result of winnowing action that removes the fine and medium sands. (2.8% in Fatty Basin, 1.7% in Useless Inlet)

(iii) Coarse sand with some gravel, pebbles, and shells (Sediment No. 5):

Relatively uncommon, this sediment occurs near gravel or sand deposits and is evidently a mixture of both. No size-gradation as in sediment No. 6 between the coarse and the finer fractions was observed. (0.5% in Fatty Basin, 1.1% in Useless Inlet)

(D) Shell Debris

(i) Coarse shell debris with few terrestrial fragments (Sediment No. 12):

These shell deposits occur mostly in a narrow zone along the base of steep bedrock and boulder slopes, and in hollows between boulders and on bedrock. Most of the debris is derived from barnacles, which are very abundant in the intertidal zone. (2.8% in Fatty Basin, 3.6% in Useless Inlet)

(ii) Medium-sized shell debris, very muddy and with abundant terrestrial gravel (Sediment No. 10):

The sediment is usually found below deposits of coarse shell debris (No. 12), or where steep rock slopes reach down directly to the mud zone. (4.4% in Fatty Basin, 3.8% in Useless Inlet)

(iii) Fine to very fine shell hash (Sediment No. 11):

This sediment is rare and occurs only in few patches below coarser shell deposits near the mud zone, where the fine-grained shell fragments were concentrated after winnowing of the coarser shell material. (0.1% in Fatty Basin, uncommon in Useless Inlet)

(E) Muds

(i) Olive-green mud rich in organic matter (Sediment No. 15):

This mud is the most common sediment throughout the inlets, and accumulates in areas of weak bottom currents, usually the central parts of the inlets. It is generally rich in organic carbon (average 5 - 6%) and receives abundant organic matter in the form of phytodetritus from the euphotic zone. (70.6% in Fatty Basin, 49.5% in Useless Inlet)

(ii) Olive-green mud with abundant small shell fragments (Sediment No. 14):

This sediment is a mixture of green mud with numerous small shell fragments, which are winnowed out of deposits of coarse shell debris. It usually occurs in narrow zones below shell deposits along the base of rocky slopes. (2.2% in Fatty Basin, 1.9% in Useless Inlet)

(iii) Grey Mud (Sediment No. 13):

This mud is mostly derived from glacial clayey silts, and it is restricted to bays with exposures of these silts on the shore or on the banks of an inflowing creek. (2.0% in Fatty Basin, 7.6% in Useless Inlet)

(F) Coarse Shell-Gravel Mixtures

(i) Coarse, muddy mixture of shells with gravel and sand (Sediment No. 8):

This sediment occurs in a few isolated areas near deposits of gravelly sand and is never very extensive. (0.7% in Fatty Basin, uncommon in Useless Inlet)

(ii) Muddy, very coarse angular gravel - shell mixture (Sediment No. 9):

This mixture is similar to sediment No. 8 and is found near deposits of angular gravel. (0.2% in Fatty Basin, 1.1% in Useless Inlet)

Bedrock occurs extensively along the inlet perimeters, around the islands, and in several exposures that rise only slightly above the muddy bottom. About 40% of it is strongly fractured, whereas 60% is without significant joints and has glacially smoothened, rounded surfaces. Bedrock exposures amount to about 6.8% of the bottom surface area in Fatty Basin, and 8.0% in Useless Inlet.

Sedimentary Environments

From the distribution of sediments, five sedimentary environments are defined for Useless Inlet and Fatty Basin; they are the mud zone, the rock slopes, the beaches, the deltas, and the strong-current zones, all the results of variations in currents, topography, and availability of sediments; wave action is generally of minor influence. Relative importance of these factors varies with each of the sedimentary environments.

The mud zone is characterized by olive-green muds with a reducing environment and relatively high contents of organic carbon. It is restricted to areas with weak bottom currents, and most of the organic debris is derived from phytoplankton in the euphotic surface waters. The infauna consists of a few genera of mud dwellers, such as polychaete worms, ophiuroids, yoldia, and mya, which may be locally common.

Steep bedrock and boulder slopes are extensive along the perimeters and around the islands. Sedimentation here is dominated by shell debris, notably barnacle plates and calcareous worm tubes, which accumulate along the base of the slopes and in hollows on bedrock and between boulders. The zone is generally well-washed by currents and hosts most of the inlet fauna.

Beaches here include all sections of the inlet perimeters not dominated by bedrock and boulder slopes or by delta developments. They are generally located in bays with shore exposures of glacial drift, where the inflow consists only of small trickles. Pebbly sediments characterize the intertidal zone, and gravels or gravelly sands are found at and below low-tide level. Towards depth, a gradation to fine sand occurs as the result of winnowing of the near-shore gravels. The sand finally dips beneath the ubiquitous green mud of the mud zone.

The fauna here consists dominantly of sand-burrowing bivalves, such as venerupis, saxidomus, and clinocardium. Abundant unbroken shells of these genera accumulate near the contact with the mud zone, where they cause extremely poorly sorted mixtures of sediments.

Deltas are common in the area under consideration, and two types may be distinguished. Type A is built by sluggish creeks, where abundant fine-grained material is derived from glacial clayey silt deposits. The dominant sediment is a grey, silty mud, and top- and foreset slopes are indistinct because of slow deposition. Type B, on the other hand, is built by turbulent creeks of steep gradient, and abundant coarse debris is provided from glacial drift deposits. These deltas have a rapid rate of advance, and top- and foreset slopes are well developed.

Strong-current zones with very high flow velocities are found in the two guts and at the mouth of Useless Inlet. Fine-grained material is removed, and the dominant surface sediment consists of rounded gravel and pebbles, probably the coarse, immobile fraction of glacial drift. In areas of medium-strong currents (about 4 knots), most notably the Outer Section of Useless Inlet, terrestrial sands form the predominant surface sediment. The limited shell-bearing infauna in these zones consists of genera such as glycimeris, humilaria, and felaniella.

Lithology of the Sediments

The colours of terrestrial sediments coarser than very fine sands are dominated by dark-grey to greenish hues, caused by the great abundance or exclusive presence of andesitic rock fragments. Fine-grained sediments, notably those of the mud zone in the central parts of the inlets, are mostly of dark olive-green colours, due to high concentrations of organic matter. Grey muds are derived from shore exposures of glacial clayey silt of the same colour and mineralogy. Deposits of shell debris appear in various shades of very light grey, and overgrowths by shell-secreting organisms commonly give light colours to otherwise dark, coarse terrestrial particles.

Sphericity and roundness values for terrestrial pebbles and gravel are dependent upon the origin of the material, whether it is derived from local bedrock exposures or from glacial drift. Coarse glacial debris is usually rounded and of good sphericity, whereas fragments from local sources are highly angular and of irregular shapes. The angular material appears to be much more abundant among the coarse fractions, and a predominant influence of locally derived debris is suggested. Coarse fragments, therefore, are mostly of local origin, whereas fine sands, silts, and clays are derived dominantly from glacial deposits, as was discussed earlier.

Pitting is the most common feature in regard to surface textures of rounded pebbles; percussion marks and glacial striations are rare. Encrusting organisms are very abundant on the coarse sediments of the strong-current zones, but may also be found along most rocky sections of the inlet perimeters.

Organic carbon

Organic carbon contents of the mud fractions in sediments reach maxima of over 11% near the mouths of turbulent creeks, where abundant fine-grained organic debris is deposited on delta fronts. Throughout most of the central sections of the inlets, however, where the sediments are dominated by olive-green mud, the content in organic carbon is between 5 and 6%. Similar values for related sediments throughout the Barkley Sound region were reported by Carter (1970), and a content of 5 to 6 % appears to be a characteristic value for most of the green muds. The organic matter in these sediments is primarily derived from phytoplankton in the euphotic zone.

Low values of less than 2% of the mud fraction were found in the grey muds on deltas of type A, where the supply of terrestrial silts and clays greatly exceeds that of organic debris.

The organic carbon content within a sediment is direcly related to the size of the mud fraction, which is a function of the current strength, and to the supply of organic debris. Because of its molecular nature, most of the organic carbon is associated only with very fine-grained sediment fractions and is uncommon in sands and coarser materials, unless silts and clays are present as well. Consequently, zones of medium and strong currents, where the mud fraction is largely removed, have characteristically low contents of organic carbon, whereas high contents are commonly found in muddy sediments. Within the muds, the distribution of organic carbon is primarily dependent upon the supply of organic detritus, as was shown above for Fatty Basin and Useless Inlet.

Shell-bearing fauna

Most of the shell-bearing fauna of the west coast of Vancouver Island is also found in Useless Inlet and Fatty Basin. The relatively quiet water conditions in these restricted inlets, however, result in shell-size reduction of many genera. A few species of shellfishes, which require the strongly agitated waters of the open coast, are entirely absent, whereas others appear to favour the inlet environment.

Apart from a few mud dwellers, such as mya and yoldia, the mud zone is sparsely inhabited by shellfishes. Sand-burrowing bivalves, mostly venerupis, saxidomus, and clinocardium, predominate the beaches and some of the deltas, and only few genera, such as glycimeris and humilaria, occur in the zones of strong currents. The majority of the shell-bearing fauna is found in the rock-slope environment along the inlet perimeters, where currents and steep gradients prevent significant accumulations of mud. Barnacle plates, derived from the intertidal zones, and calcareous worm tubes are the predominant constituents of the shell debris deposited on and below the slopes.

3. General Conclusions

The fjords and inlets on the west coast of Vancouver Island and the British Columbia mainland are mostly of structural origin; their present shapes are the results of subsequent erosion by water and ice.

Uplift of the land in the Fatty Basin area was in excess of 20 ft during the last 7000 years, probably due to isostatic response; upward movements appear to continue at present at a very slow rate.

Useless Inlet and especially Fatty Basin act as traps for phytoplanktonic debris because of shallow entrance sills. Phytoplankton is particularly abundant during summer, when it constitutes most of the fine-grained material deposited from suspension, and organic-rich sediments are consequently widespread within the inlets.

The strong currents generated over the shallow sills cause good exchange of the entire water column, and stagnant water conditions are very rare in the inlets. Despite well-oxigenated bottom waters, the organic-rich muds always form a strongly reducing environment.

Fine-grained terrestrial debris is derived mainly from glacial deposits, whereas local bedrock exposures provide the majority of coarse sands, gravel, and pebbles. The source area for most of the glacial sediments is to the north of Fatty Basin, in the Henderson Lake region, where the geology is dominated by Karmutsen basalts. A wide, U-shaped valley extends from that area to Uchucklesit Inlet and Fatty Basin; it probably was a major glacial passage during the Pleistocene.

Five sedimentary environments in Fatty Basin and Useless Inlet determine the distribution of sediments. They are defined as the mud zone, bedrock and boulder slopes, beaches, deltas, and strong-current zones.

The mud zone is the most extensive environment and accounts for about 73% and 57% of the total bottom surface in Fatty Basin and Useless Inlet, respectively. It is characterized by olive-green muds and occurs in the central parts of the inlets, where bottom currents are weak. Terrestrial sands, gravel, and pebbles predominate the beach environment (5% of the bottom surface in Fatty Basin, 4% in Useless Inlet), the deltas (3% in Fatty Basin, 5% in Useless Inlet), and the strong-current zones (1% in Fatty Basin, a large 16% in Useless Inlet). The rock-slope environment is characterized by deposition of shell debris, notably barnacle plates, along the base of the slopes, and it accounts for approximately 18% of the bottom surface in both Fatty Basin and Useless Inlet. The thick shell deposits are steadily buried by mud and may possibly be preserved in the geologic record, resulting in lenses of a rather unusual barnacle limestone.

Accumulations of boulders as well as exposures of strongly fractured bedrock provide shelter for large crustaceans, such as lobsters and crabs, and sections of the rock-slope environment therefore constitute a preferred habitat for these organisms. Beaches offer little shelter, but may provide sufficient food, whereas the entire mud zone, the deltas, and the strong-current zones are essentially unfavorable environments for crustaceans.

On the basis of these assumptions, the bottom surface area suitable as a lobster habitat in Fatty Basin amounts to about 7% (38,000 m^2) of the total area, with an additional 13% (70,000 m^2) available to the search for food. In Useless Inlet, the figures are 5% (135,000 m^2) for the favorable lobster habitat, and 11% (300,000 m^2) for the additional areas.

BIBLIOGRAPHY

Blatt, H.; 1967:
"Provenance Determinations and Recycling of Sediments"
J. Sed. Petr., v. 37, pp. 1031-1044.

Bremner, J.M.; 1970:
"The Geology of Wreck Bay, Vancouver Island"
MSc-Thesis, University of British Columbia.

Brindley, G.W.; 1961:
"The X-Ray Identification and Crystal Structures of Clay Minerals"
Mineralog. Soc. Great Britain

Carter, L.; 1970:
"Surficial sediments in Barkley Sound, Vancouver Island, British Columbia"
PhD-Thesis, University of British Columbia.

Clapp, C.H.; 1912:
"Southern Vancouver Island"
Geological Survey of Canada, Mem. 13.

Cockbain, A.E.; 1963:
"Distribution of Foraminifera in Juan de Fuca and Georgia Straits, British Columbia"
Contr. Cushman Found. for Foram. Research, v. XIV, Part 2.

Cushman, J.A.; 1947:
"Foraminifera From The Coast of Washington"
Cushman Lab. for Foram. Research, Spec. Publ. No. 21

" " ; 1959:
"Foraminifera - Their Classification and Economic Use"
Harvard University Press, Cambridge, Mass.

Curray, J.R.; 1965:
"The Quaternary History, Continental Shelves of the United States", in "The Quaternary of the United States"
Princeton University Press, pp. 723 - 735.

Deer, W.A., Howie, R.A., Zussman, J.; 1967:
"An Introduction to the Rock Forming Minerals"
Wiley, New York, 528 p.

Mathews, W.H., Fyles, J.G., Nasmith, H.W.; 1970:
"Postglacial Crustal Movements in Southwestern British Columbia and Adjacent Washington State"
Can. J. Earth Science, v. 7, pp. 690 - 702.

Muller, J.E., Carson, D.J.T.; 1969:
"Geology and Mineral Deposits of Alberni Map Area, British Columbia"
Geological Survey of Canada, Paper 68 - 50.

Peacock, M.H.; 1935:
"Fjord-Land of British Columbia"
Geol. Sock. Am. Bull., v. 46, pp. 633 - 696.

Pettijohn, F.J.; 1957:
"Sedimentary Rocks"
Harper, New York, 718 p.

Pierce, J.W., Siegel, F.R.; 1969:
"Quantification in Clay Mineral Studies of Sediments and Sedimentary Rocks"
J. Sed. Petr., v. 39, pp. 187 - 193.

Prokopovich, N.P.; 1969:
"Deposition of Clastic Sediments by Clams"
J. Sed. Petr., v. 39, pp. 891 - 901.

Quayle, D.B.; 1960:
"The Intertidal Bivalves of British Columbia"
Handbook No. 17, B.C. Prov. Museum, 104 p.

Seki, H.; 1968:
"Relation Between Production and Mineralization of Organic Matter in Aburatsubo Inlet, Japan"
J. Fish. Res. Bd. Canada, v. 25, pp. 625 - 637.

Shepard, F.P.; 1963:
"Submarine Geology"
Harper & Row, N.Y., 557 p.

Stephens, K., Sheldon, R.W., Parsons, T.R.; 1967:
"Seasonal Variations in the Availability of Food for Benthos in a Coastal Environment"
Ecology, v. 48, No. 5.

Sutherland-Brown, A.; 1966:
"Tectonic History of the Insular Belt of British Columbia", in "Tectonic History and Mineral Deposits of the Western Cordillera"
Canadian Inst. Mining and Metallurgy, pp. 83 - 100.

Degens, E.T.; 1965:
"Geochemistry of Sediments"
Prentice-Hall, N.J., 342 p.

Douglas, R.J.W. (edit.); 1970:
"Geology and Economic Minerals of Canada"
Geological Survey of Canada, Economic Geology Report No. 1.

Folk, R.L.; 1965:
"Petrology of Sedimentary Rocks"
Hemphill's, Texas, 159 p.

Fyles, J.G.; 1963:
"Surficial Geology of Horne Lake and Parksville Map Area. Vancouver Island"
Geological Survey of Canada, Mem. 318

Griffith, L.M.; 1967:
"The Intertidal Univalves of B.C."
Handbook No. 26, B.C. Prov. Museum, 101 p.

Grim, R.E.; 1968:
"Clay Mineralogy"
McGraw - Hill, Toronto, 596 p.

Herlinveaux, R. H.; 1966:
"Oceanographic Phase of the Fatty Basin Study for a Lobster Transplant"
Manuscript Report Series, No. 228,
Fisheries Research Board of Canada.

Holland, S.S.; 1964:
"Land forms of B.C. - A Physiographic Outline"
B.C. Dept. Mines Petr. Res., Bull. No. 48.

Keen, M.A.; 1963:
"Marine Molluscan Genera of Western North America"
Stanford University Press, Calif.

Koldijk, W.S.; 1968:
"On Environment-Sensitive Grain-Size Parameters"
Sedimentology, v. 10, pp. 57-69.

" " ; 1968:
"Bottom Sediments of the Ria de Arosa"
PhD-Thesis at Rijks-University, Leiden, Netherland.

Krumbein, W.C., Pettijohn, F.J.; 1938:
"Manual of Sedimentary Petrography"
Appleton-Century-Crofts, N.Y., 549 p.

APPENDICES

Appendix 1 - Laboratory Methods

Methods used for analysis of the sediment and rock samples are briefly outlined. Details of the procedures followed are discussed in standard textbooks, all listed in the bibliography.

(i) Size analysis

125 sediment samples from Fatty Basin, Useless Inlet, and Rainy Bay were analysed, using sieving and hydrometer methods for the coarse and the fine fractions, respectively (fine fractions = silt and clay).

Sieve intervals of 1/2 phi were considered sufficient for most samples, except when the bulk of a sediment appeared to be concentrated in a few size fractions; 1/4 phi intervals were then used for those fractions. Wet-sieving was done on muddy sediments, in order to separate most of the fine fractions from the coarse material before dry-sieving.

Silts and clays were analysed by standard hydrometer methods. Previous to analysis, all samples were treated with hydrogen peroxide for removal of organic carbon, because in water, the untreated muds always coagulated into tiny "balls", despite the use of dispersant. Size analysis of those muds, therefore, would give results totally irrelevant to the true size distribution of suspended particles at the time of deposition. Errors induced by omission of the organic material are therefore considered less severe than those inherent in an analysis of untreated, organic-rich muds.

Results from the size analysis were processed by an IBM 360/67 computer, which calculated statistical parameter values and also drew cumulative and frequency curves.

(ii) Heavy minerals

The fine sand fractions between 2.5 and 4 phi of 30 samples were analysed for their heavy mineral content, using bromoform (specific gravity = 2.89) as separating agent. Thin sections for heavy and light grains were prepared, and relative percentages of individual minerals were determined by grain-count methods.

(iii) Clay minerals

Clays were analysed using a Phillips diffractometer with Ni-filtered K_α radiation. Preparation of the samples involved several steps, including

- removal of $CaCO_3$ with hydrochloric acid,
- removal of organic carbon with hydrogen peroxide,
- removal of iron with sodium dithionite,
- Mg- and K-saturation of some of the samples.

Additional treatment of clays, in order to determine individual mineral groups, included

- heating to 200° C and 540° C, to recognize the presence of vermiculite and kaolinite,
- exposure to ethylene glycol fumes, to expand smectite and vermiculite lattices, and
- washing in warm hydrochloric acid, to remove chlorite minerals.

(iv) Organic carbon

Mud samples selected for organic carbon analysis were first treated with hydrochloric acid, in order to remove all carbonates. Due to prolonged equipment-breakdown in the laboratory, the carbon analyis was done by Can Test Ltd. in Vancouver, where the combustion furnace method was used.

(v) Rocks

Rock samples from all major units exposed in the area under consideration were studied in polished and thin sections. Grain count methods were used to determine relative percentages of the main constituent minerals.

(vi) Shell-bearing Fauna

Shells were collected and identified, using reference volumes listed in the bibliography. Foraminifera tests were separated from the sediments with carbon tetrachlorite and identified by Dr. B. Cameron of the Geological Survey of Canada.

Appendix 2 - <u>Tables</u>

Table 9 : Dates of exchange of sampling bowls (positions shown on Map No. 1), dry weight of samples (after removal of $CaCO_3$), and rates of sedimentation as calculated.

Samples bowls were first put into position on July 15, 1969.

Date	Position	Dry Weight (g)	Rate of Sed. (g/m^2/day)
Aug. 15, '69	1	1.890	14.60
	2	1.000	7.65
	3	1.095	8.43
	4	.170	1.33
Sept. 16, '69	1	lost	-
	2	.330	2.46
	3	.663	4.94
	4	.190	1.43
Oct. 15, '69	1	.052	.43
	2	.121	1.00
	3	.091	.74
	4	.320	2.63
Nov. 15, '69	1	.107	.81
	2	lost	-
	3	.311	2.39
	4	.209	1.60
December samples not collected			
Jan. 7, '69	1	4.435 (?)	-
	2	.150	.69
	3	.512	2.36
	4	.269	1.24
Feb. 13, '69	1	.252	1.62
	2	.198	1.29
	3	18.410 (?)	-
	4	lost	-

Table 9 Continued

Date	Position	Dry Weight (g)	Rate of Sed. ($g/m^2/day$)
Mar. 24, '69	1	.438	2.75
	2	.171	1.08
	3	.286	1.79
	4	6.502 (?)	-
Apr. 15, '69	1	.013	.14
	2	.122	1.43
	3	.091	.98
	4	.191	2.08
May 20, '69	1	.103	.69
	2	17.404 (?)	-
	3	.144	.98
	4	lost	-
June 17, '69	1	2.562	21.80
	2	lost	-
	3	lost	-
	4	lost	-
July 18, '70	1	.572	4.42
	2	1.064	8.19
	3	.118	.91
	4	.038	.29

Note: (?) refers to abnormally large samples, which probably were contaminated with bottom mud during retrieval.

Table 10: Statistical parameters and percentages of gravel, sand, and mud. The samples are arranged in groups defined from cumulative curves (see chapter "Types of Sediments")

	Sample No.	Graph. Mean (phi)	Inc. Gr. Std. Dev. (phi)	Inc. Gr. Skewn.	Graph. Kurt.	Gravel (%)	Sand (%)	Mud (%)
Group	2	- 2.947	1.116	.367	1.504	91	8	1
No. 1	26	- 2.395	1.438	.408	.977	96	4	-
	44	- 2.990	.711	.127	.871	98	2	-
	58	- 2.840	1.649	.639	.968	99	1	-
	84	- 3.192	2.157	.770	1.025	81	17	2
	100	- 2.606	1.086	.230	.912	90	10	-
	114	- 2.658	1.324	.546	.995	86	14	-
	119	- 2.212	1.504	.452	.939	77	22	1
Group	3	- 1.150	1.828	.387	1.290	66	31	3
No. 2	8	- 1.095	1.359	.131	1.466	57	42	1
	17	- 1.308	1.635	.304	1.053	59	38	3
	20	.471	1.244	.026	.928	12	87	1
	23	- .838	1.344	.331	1.396	54	44	2
	24	- 1.429	1.365	.197	1.231	70	30	-
	25	- .913	1.532	.216	1.261	58	41	1
	39	- .633	1.769	.221	1.072	45	52	3
	45	.409	1.521	.086	1.147	15	82	3
	51	.038	1.894	.063	1.101	28	69	3
	61	- 1.812	1.453	.363	1.735	79	18	3
	62	- .452	1.486	.239	1.114	39	59	2
	65	- .041	1.692	.143	.916	32	65	3
	76	- .774	2.024	.141	1.135	48	48	4
	83	- .396	1.763	.215	1.058	40	57	3
	89	- .895	1.856	.185	.902	51	47	2
	92	- .905	1.847	.342	1.129	53	46	1
	103	- .970	1.947	.333	.710	54	45	1
	104	- .920	1.619	.359	1.448	56	43	1

Table 10 Continued

	Sample No.	Graph. Mean (phi)	Inc. Gr. Std. Dev. (phi)	Inc. Gr. Skewn.	Graph. Kurt.	Gravel (%)	Sand (%)	Mud (%)
	112	- .714	1.454	.300	1.239	46	53	1
	117	- .367	1.727	.113	1.455	33	66	1
	122	- .383	1.612	.328	.933	43	55	2
	124	- 1.275	1.709	.281	1.050	62	37	1
Group No. 3	14	2.402	1.243	- .012	1.243	-	91	9
	79	1.273	1.160	.030	1.414	5	92	3
	86	2.481	.775	- .265	1.203	1	98	1
	90	2.539	.890	- .240	.901	4	94	2
	96	1.718	1.535	- .292	.849	5	93	2
	98	2.679	1.319	.198	1.844	-	91	9
	101	1.715	1.570	- .187	.863	3	96	1
	105	1.776	1.260	- .179	.923	3	95	2
	107	1.898	.982	- .179	.963	-	99	1
	111	1.565	1.432	- .198	.937	6	93	1
	113	1.724	.992	- .148	.984	1	98	1
	115	2.010	.914	- .242	.958	1	99	-
	116	1.941	1.160	- .409	1.177	4	95	1
	121	1.465	.994	- .050	.904	1	98	1
Group No. 4	1	5.024	3.132	.294	1.903	2	27	71
	6	5.738	3.143	.392	1.063	1	15	84
	7	5.145	1.444	.447	1.435	-	12	88
	10	6.521	2.455	.321	.857	-	2	98
	11	5.782	1.569	.271	.708	-	-	100
	18	5.780	2.037	.406	.931	-	1	99
	19	6.950	2.680	.311	.847	-	-	100
	27	4.984	3.010	.287	.953	2	6	92
	31	5.139	1.739	.315	.868	-	4	96

Table 10 Continued

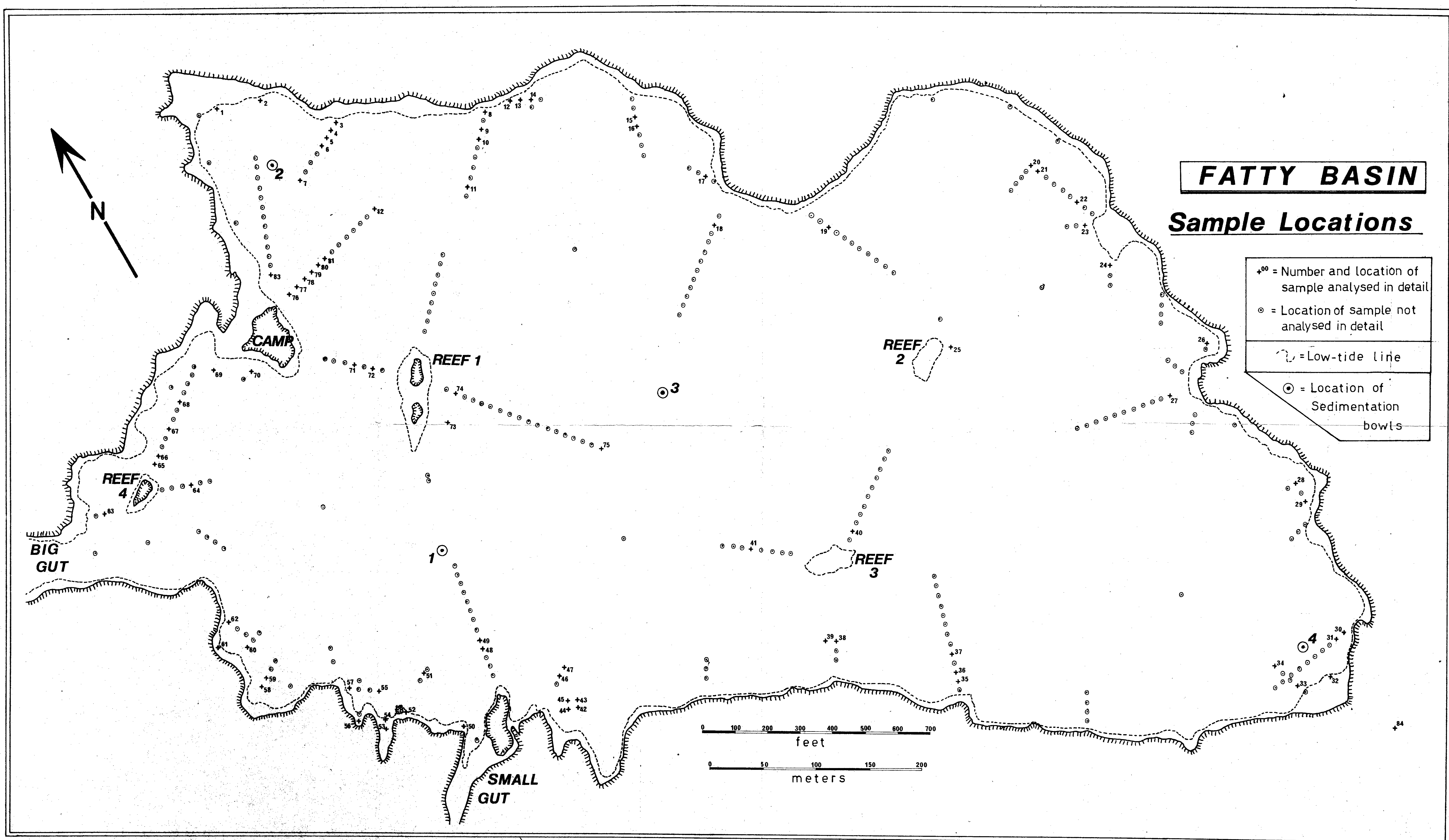
	Sample No.	Graph. Mean (phi)	Inc. Gr. Std. Dev. (phi)	Inc. Gr. Skewn.	Graph. Kurt.	Gravel (%)	Sand (%)	Mud (%)
	34	5.981	2.074	.299	.795	-	2	98
	36	5.074	3.148	.287	1.923	-	15	85
	37	6.063	3.349	.661	2.147	-	12	88
	41	5.378	1.935	.289	.713	-	4	96
	47	5.842	3.245	.103	1.125	1	24	75
	49	5.739	2.683	.326	.853	-	3	97
	71	5.061	2.489	.427	1.383	2	11	87
	72	4.808	1.239	.647	1.983	-	17	83
	75	6.037	1.870	.294	1.864	-	9	91
	82	6.705	2.959	.512	.985	-	5	95
	85	5.686	3.141	.439	1.151	-	29	71
	91	6.342	3.424	.759	2.139	-	14	86
	93	4.982	3.145	.268	1.836	-	11	89
	123	5.671	2.096	.305	1.695	1	8	91
Group	4	- .103	1.900	.036	.691	35	62	3
No. 5	12	- .033	1.862	.122	.967	32	66	2
	21	- .026	1.876	.124	.959	34	63	3
	22	- 1.638	2.198	.383	.698	63	36	1
	28	.035	1.712	- .230	.919	26	73	1
	29	- 1.433	2.127	.419	.912	64	33	3
	32	- 1.563	2.493	.428	.782	63	34	3
	38	.063	2.257	.313	.919	37	57	6
	42	.205	2.663	- .008	.945	30	63	7
	50	- 1.593	2.282	- .034	.633	54	45	1
	52	- 1.120	2.313	.140	.811	62	35	3
	53	- 1.038	2.174	.175	.714	53	46	1
	54	- 1.686	1.960	.233	.903	67	32	1
	56	- 1.579	2.148	.303	.951	65	33	2
	66	- .277	2.111	.079	.944	45	52	3

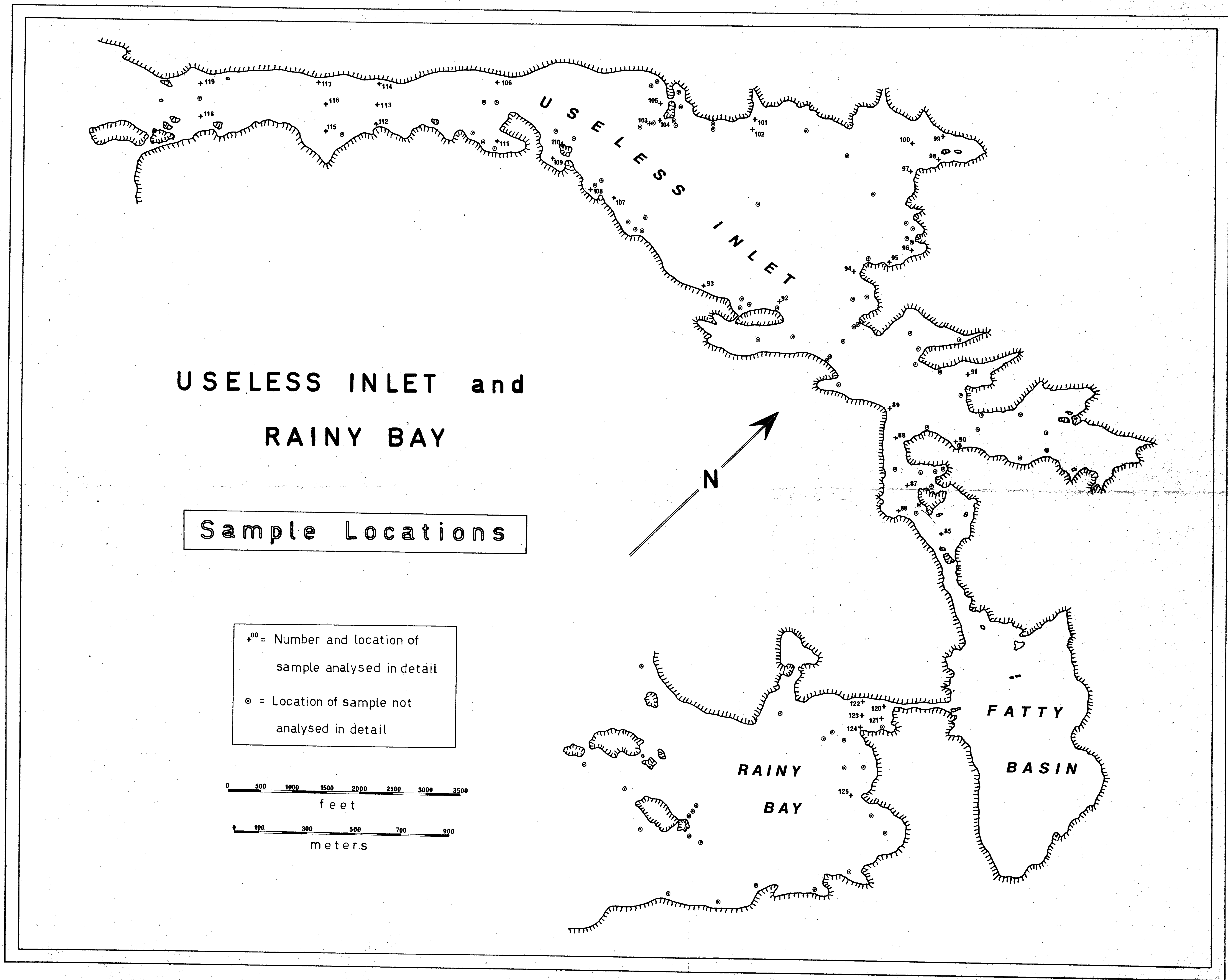
Table 10 Continued

	Sample No.	Graph. Mean (phi)	Inc. Gr. Std. Dev. (phi)	Inc. Gr. Skewn.	Graph. Kurt.	Gravel (%)	Sand (%)	Mud (%)
	68	- 1.615	2.061	.418	.929	67	31	2
	69	- .374	2.418	- .338	.751	32	65	3
	77	- 1.992	2.204	.497	.681	69	30	1
	118	- 1.706	1.627	- .065	.716	59	40	1
	125	.214	1.887	.036	1.023	26	70	4
Group	5	2.385	1.883	.207	.898	1	74	25
No. 6	13	1.888	1.648	.087	1.124	3	86	11
	15	.696	1.502	.012	.721	19	80	1
	35	2.038	1.603	.277	1.583	2	79	19
	43	2.275	2.312	.433	2.155	1	82	17
	55	2.002	2.879	.244	1.748	8	73	19
	57	.805	2.721	.625	1.611	22	63	16
	60	1.764	2.105	.047	1.093	3	89	8
	78	1.595	1.867	.263	1.718	6	82	12
	95	1.100	1.855	- .214	1.158	14	82	4
	97	1.880	2.228	.055	1.189	8	78	14
	99	2.687	1.652	- .111	1.070	2	77	21
	106	.224	1.640	.048	.946	23	75	2
	108	.593	1.576	- .018	.999	15	84	1
	109	2.509	1.830	.027	1.931	2	85	13
	120	1.043	1.439	.084	.926	7	90	3
Group	33	4.340	3.738	.341	1.192	7	45	48
No. 7	87	3.936	4.564	.291	1.197	12	43	45
	88	4.836	2.894	.436	1.178	-	47	53
	102	5.051	2.620	.439	.906	1	36	63

Table 10 Continued

	Sample No.	Graph. Mean (phi)	Inc. Gr. Std. Dev. (phi)	Inc. Gr. Skewn.	Graph. Kurt.	Gravel (%)	Sand (%)	Mud (%)
Group	9	3.628	4.739	.341	1.043	18	46	36
No. 8	30	.833	4.207	.352	1.273	41	34	25
	46	2.972	5.242	.374	.813	27	33	40
	48	3.710	4.838	.319	1.063	21	39	40
	59	2.308	4.839	.573	1.033	24	37	39
	63	2.873	.397	.377	.984	19	43	38
	64	1.822	4.670	.318	.928	32	39	29
	67	.232	4.060	.622	1.109	53	26	21
	70	- .847	3.063	.162	.935	50	40	10
	73	1.826	5.271	.358	.699	44	17	39
	74	4.833	4.717	.518	.993	14	34	52
	80	4.714	4.668	.107	1.359	12	28	60
	94	1.005	4.131	.477	1.193	35	38	27


FATTY BASIN
Sample Locations
+00 = Number and location of sample analysed in detail
⊙ = Location of sample not analysed in detail
= Low-tide line
⊙ = Location of Sedimentation bowls
N
CAMP
REEF 1
REEF 2
REEF 3
REEF 4
BIG GUT
SMALL GUT
feet
meters



USELESS INLET and
RAINY BAY
Sample Locations
USELESS INLET
RAINY BAY
FATTY BASIN
N
+00 = Number and location of sample analysed in detail
⊙ = Location of sample not analysed in detail
0 500 1000 1500 2000 2500 3000 3500
feet
0 100 300 500 700 900
meters


FATTY
BASIN
BATHYMETRY
0 200 400 Feet
0 100 Meters
Contour Interval = 6 feet
High-tide line
Low-tide line
North Delta
South Delta
Camp
Reef 1
Reef 2
Reef 3
Reef 4
Big Gut
Small Gut
N

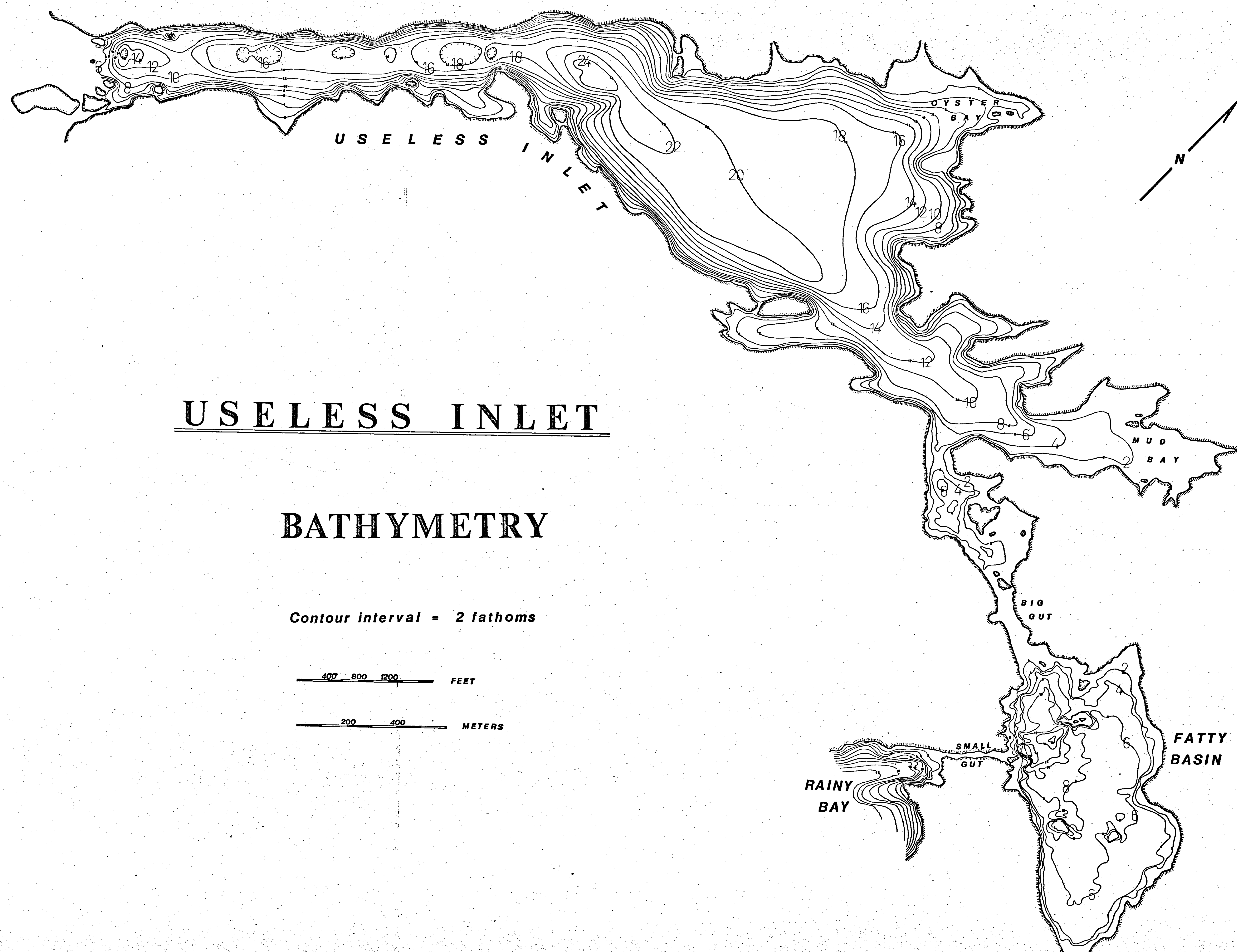
USELESS INLET

BATHYMETRY

Contour interval = 2 fathoms

400 800 1200 FEET

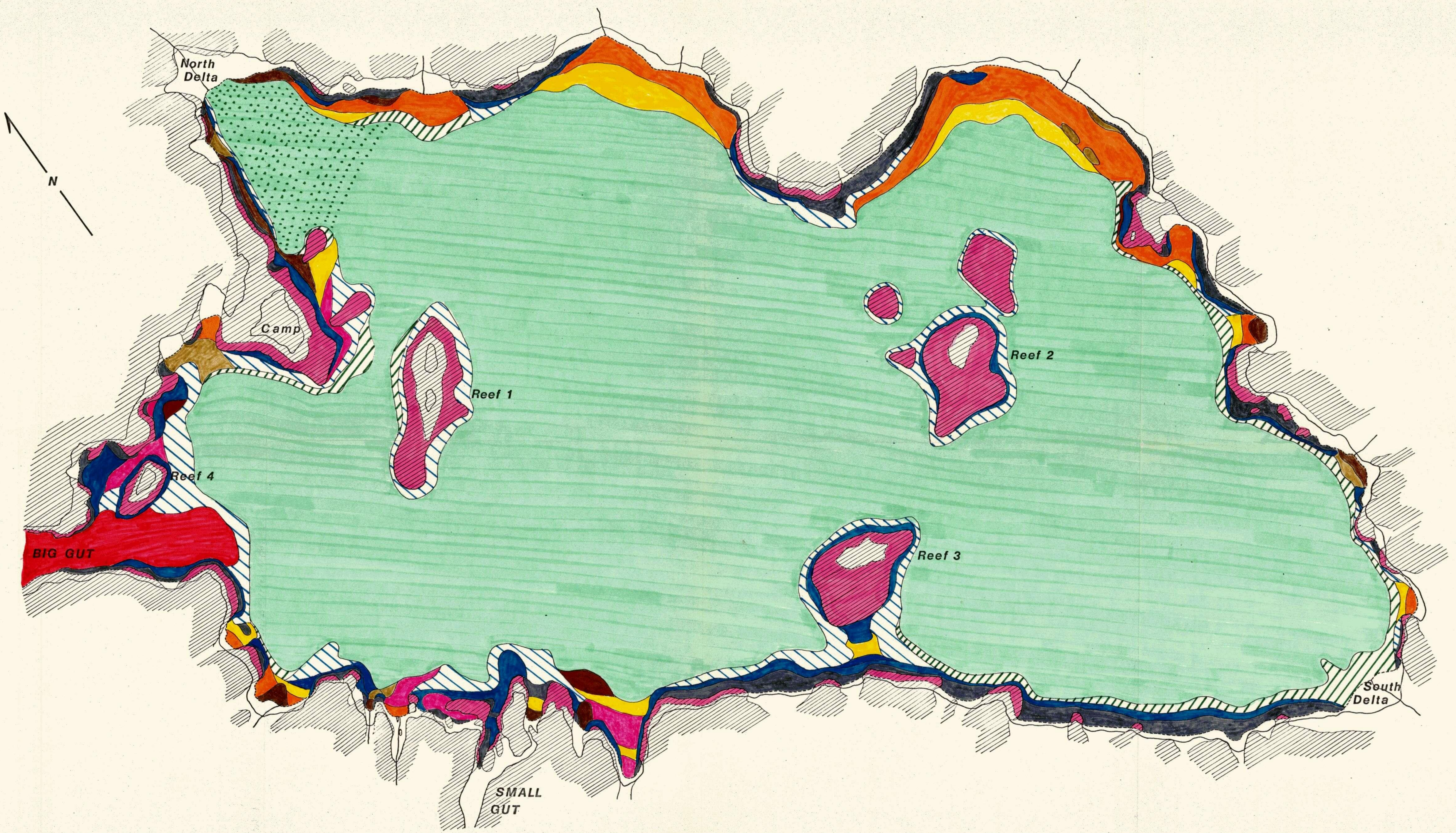
200 400 METERS



FATTY BASIN

SCALE = 1 : 2000

DISTRIBUTION OF SEDIMENTS

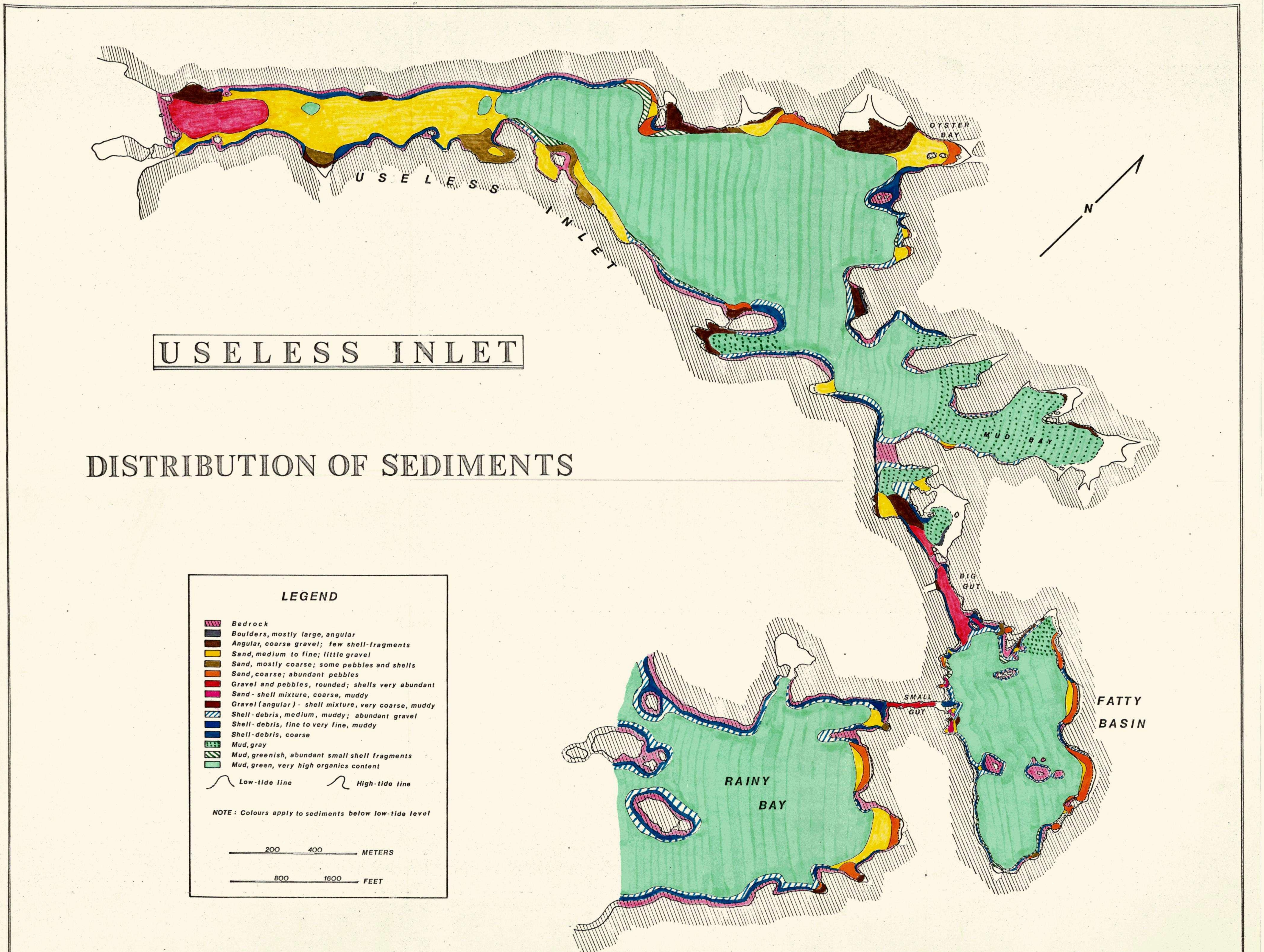


LEGEND

1. Bedrock
2. Boulders, mostly large, angular
3. Angular, coarse gravel; few shell-fragments
4. Sand, medium to fine; little gravel
5. Sand, mostly coarse; some pebbles and shells
6. Sand, coarse; abundant pebbles
7. Gravel and pebbles, rounded; shells very abundant
8. Sand-shell debris mixture, coarse, muddy
9. Gravel (angular)-shell mixture, very coarse, muddy
10. Shell-debris, medium, muddy; abundant gravel
11. Shell-debris, fine to very fine, muddy
12. Shell-debris, coarse to very coarse
13. Mud, gray
14. Mud, greenish, abundant small shell fragments
15. Mud, green, very high organics content

= Low-tide line   = High-tide line

NOTE : Colours apply to sediments below low-tide level only


USELESS INLET
DISTRIBUTION OF SEDIMENTS
U S E L E S S
I N L E T
OYSTER BAY
N
MUD BAY
BIG GUT
SMALL GUT
FATTY BASIN
RAINY BAY
LEGEND
Bedrock
Boulders, mostly large, angular
Angular, coarse gravel; few shell-fragments
Sand, medium to fine; little gravel
Sand, mostly coarse; some pebbles and shells
Sand, coarse; abundant pebbles
Gravel and pebbles, rounded; shells very abundant
Sand - shell mixture, coarse, muddy
Gravel (angular) - shell mixture, very coarse, muddy
Shell - debris, medium, muddy; abundant gravel
Shell - debris, fine to very fine, muddy
Shell - debris, coarse
Mud, gray
Mud, greenish, abundant small shell fragments
Mud, green, very high organics content
Low-tide line
High-tide line
NOTE : Colours apply to sediments below low-tide level
200 400 METERS
800 1600 FEET