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Marine Environmental Assessment of Mine Waste Disposal into Rupert Inlet, British Columbia

Surveillance Report
Report EPS PR-77-11

Pacific Region
December 1977

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MARINE ENVIRONMENTAL ASSESSMENT OF MINE WASTE DISPOSAL INTO RUPERT INLET, BRITISH COLUMBIA

by

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Environmental Protection Branch
Environmental Protection Service
Pacific Region

December, 1977

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ABSTRACT

In 1968 plans were announced to construct a 33,000 T.P.D. open pit copper-molybdenum mining complex on the north shore of Rupert Inlet, British Columbia. Coincident with this proposal was the necessity to develop a mill tailings and waste rock disposal system which was environmentally acceptable to existing regulatory agencies.

Land disposal of the mine wastes was one of the alternatives considered during pre-operational studies but was rejected in preference to a marine tailings disposal system. Characteristics of the ore indicated that the tailings if stored on land, could be subject to bacteriological leaching.

The mining company predicted that tailings solids discharged directly into Rupert Inlet would generally remain below 100 metres and would flow as a density current down the sloping bed of the inlet to settle in the deeper portions. It was also predicted that high current velocities in the area would remain above 60 metres and would not influence tailings deposits on the floor of the inlet. These predictions were presented by the proponent in a brief to the British Columbia Pollution Control Branch in 1971. A permit was subsequently issued for marine disposal, including a provision for an environmental monitoring program to be carried out under the direction of an independent agency.

During the initial years of mine production, the Environmental Protection Service conducted a surveillance and monitoring program to assess the behaviour of the wastes in relation to the mining company's pre-operational predictions.

Present studies have shown that the waste discharge from the copper mine has resulted in the anticipated obliterative effects on deep benthos and an unpredicted widespread deposition of tailings which has affected the shallower, highly productive regions of the system. Strong

tidal currents along the floor of Rupert Inlet are believed to be the major cause of the unpredicted spread of tailings. In a number of areas this deposition has resulted in a permanent alteration of the native habitat and the smothering of resident benthic biota. Both surface and subsurface turbidity levels have also greatly increased.

RÉSUMÉ

En 1968, on annonçait la construction d'un complexe minier à ciel ouvert d'une capacité de 33 000 tonnes par jour sur la rive nord de l'inlet Rupert en Colombie-Britannique. À cette occasion, il fallut aussi mettre au point un système de mise en décharge du roc inutilisé et des résidus satisfaisant aux exigences réglementaires.

Bien que les études préliminaires aient entre autre porté sur la mise en décharge terrestre des résidus, on a préféré disposer des déchets miniers par immersion. Les caractéristiques du minerai laissaient croire, en effect, que son accumulation sur terre donnerait libre cours à unlessivage bactériologique.

La société minière prévoyait que les résidus solides déversés directement dans l'inlet Rupert demeureraient en deçâ de 100 mètres de la surface le long de la pente du fond de l'inlet, suivent un gradient de densité, pour s'accumuler en profondeur. On prévoyait aussi que le fort courant du secteur demeurerait au-dessus de 60 mètres et n'influerait pas sur le dépôt des résidus au fond de l'inlet. Le demandeur exposait ces prévisions à la British Columbia Pollution Control Branch, en 1971, après quoi on lui délivra un permis d'immersion des résidus. Le permis prévoyait qu'une agence indépendante serait chargée de surveiller le milieu.

Un programme de surveillance, mis en oeuvre par le Service de la protection de l'environnement, a permis d'évaluer le comportement des résidus au cours des premières années d'exploitation et de le comparer aux prévisions de la société minière.

Les études actuelles démontrent que l'immersion des déchets cupriques, comme on l'avait prévu, a fait disparaître en partie le benthos des profondeurs. De plus, contrairement aux prévisions, les résidus se sont répandus un peu partout, affectant les zones peu profondes où l'activité benthique est particulièrement élevée. On attribue cette dispersion à des courants intenses que les marées feraient naître au fond de l'inlet. En divers endroits, le dépôt a altéré l'habitat originel de façon permanente et détruit le biome benthique. Le taux de turbidité, tant à la surface que sous la surface, a également augmenté considérablement.

TABLE OF CONTENTS

		PAGE
TABLE OF CONTENTS		v
LIST OF FIGURES		viii
LIST OF TABLES		ix
LIST OF PLATES		x
CONCLUSIONS		xii
1	INTRODUCTION	1
1.1	Study Objectives	1
2	BACKGROUND	3
2.1	Description of Study Area	3
2.1.1	Geographical Aspects	3
2.1.2	Oceanographic Features	3
2.2	Island Copper Mine	6
2.2.1	Production Data	6
2.2.2	Tailings Disposal System	7
2.2.3	Waste Rock Disposal	9
2.3	Environmental Programs	9
2.3.1	Pre-Operational Studies	9
2.3.2	Post Start-Up Studies	12
2.3.2.1	By federal agencies	12
2.3.2.2	By independent agents	12
3	MATERIALS AND METHODS	13
3.1	Areas of Surface Turbidity	13
3.2	Depth of Subsurface Turbidity	13
3.2.1	Transmissometer Profiles	13
3.2.2	Underwater Observations	14

		PAGE
3.3	Particle Size Analysis	14
3.4	Distribution and Biological Impact of Mine-Derived Sediment Deposits	15
3.4.1	Ponar Grab Sampling	15
3.4.2	Underwater Observations	16
3.5	Heavy Metal Analysis	16
3.5.1	Biological Samples	16
3.5.2	Sediment Samples	17
4	RESULTS AND DISCUSSION	19
4.1	Deleterious Effects of Turbidity and Sedimentation	19
4.2	Surface Turbidity	20
4.3	Subsurface Turbidity	23
4.3.1	Transmissometer Surveys	23
4.3.1.1	1973 and 1974 test results	23
4.3.1.2	Comments	26
4.3.2	Submersible Observations	29
4.3.2.1	Rupert Inlet	29
4.3.2.2	Holberg Inlet	32
4.3.2.3	Quatsino Sound	32
4.4	Particle Size Analysis	33
4.4.1	Water and Sediment Particle Samples	33
4.4.2	Particle Suspension Criteria	33
4.5	Tidal Currents	37
4.6	Sources and Distribution of Suspended Solids	38
4.7	Mine Sediment Deposition	41
4.7.1	Ponar Grab Sampling Data	41
4.7.2	Observations by SCUBA Divers	44
4.8	Biological Impact of Mine Waste Disposal	47
4.9	Biological Impact in Intertidal and Shallow Subtidal Zones	48
4.9.1	Aquatic Habitat and Marine Life	48
4.9.2	Impact on Intertidal and Shallow Subtidal Benthos	48

PAGE

4.10 Biological Impact in the Deep Benthic Zone 50
4.10.1 Aquatic Habitat and Marine Life 50
4.10.2 Impact on Deep Benthos 51
4.11 Heavy Metal Contamination - Shellfish 53
4.12 Commercial Fisheries 56
4.13 Relationship to Other Studies 60

PLATES 71 to 88

REFERENCES 89

ACKNOWLEDGEMENTS 93

APPENDIX I PERCENT TRANSMISSIBILITY AND TIDAL CURVES FOR TRANSMISSOMETER SURVEYS

APPENDIX II SUBMERSIBLE DIVING OBSERVATIONS - PISCES IV

APPENDIX III COULTER COUNTER ANALYSIS

APPENDIX IV MINE SEDIMENT DEPOSITION - GRAB SAMPLES

APPENDIX V QUALITATIVE SCUBA DIVING OBSERVATIONS, 1970 - 1975

APPENDIX VI TISSUE HEAVY METAL ANALYSIS

LIST OF FIGURES

FIGURE		PAGE
1	NORTHERN VANCOUVER ISLAND	4
2	STUDY AREA	5
3	TYPICAL SIZE DISTRIBUTION OF TAILINGS SOLIDS DISCHARGED INTO RUPERT INLET	8
4	AREA OF WASTE ROCK DUMP AND FORESHORE LEASE - 1976	10
5	AREA OF SURFACE TURBIDITY - August 3, 1973	22
6	TRANSMISSOMETER STATIONS	24
7	TRANSMISSOMETER PROFILES - November 8, 1973	27
8	TRANSMISSOMETER PROFILES - April 23 and 24, 1974	28
9	TRANSMISSIBILITY CHANGES DURING A TIDAL CYCLE AT STATION T-2 - July, 1976	30
10	SUBMERSIBLE DIVING LOCATIONS	31
11	TRANSMISSOMETER PROFILES AT STATION T-2 - 1974	40
12	TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - November 3, 1971	42
13	TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - March 7, 1972	42
14	TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - October 6, 1973	43
15	TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - May-June, 1974	43
16	SCUBA DIVING STATIONS - 1970 - 1975	45
17	COPPER CONCENTRATION IN MARINE SEDIMENTS (μg/g Dry Wt.)	57

LIST OF TABLES

TABLE		PAGE
1	TYPICAL MINERAL COMPOSITION OF TAILINGS SOLIDS DISCHARGED INTO RUPERT INLET	8
2	PARTICLE SIZE ANALYSIS - WATER SAMPLES	34
3	PARTICLE SIZE ANALYSIS - BENTHIC SEDIMENT SAMPLES	35
4	TERMINAL VELOCITIES OF QUARTZ AND GALENA FREE SETTLING IN WATER AT 20°C	36
5	HEAVY METAL CONCENTRATIONS - INTERTIDAL SEDIMENT - DECEMBER,1975	55
6	ESTIMATES OF SALMON SPAWNING ESCAPEMENT FOR MARBLE RIVER, 1935 to 1976	58
7	OUTLINE OF ENVIRONMENTAL CONTROL MONITORING PROGRAM (Marine Program 1977)	61

LIST OF PLATES

PLATE		PAGE
1	SURFACE TURBIDITY AROUND THE NORTHERN END OF QUATSINO NARROWS AND THE MOUTH OF RUPERT INLET, August 3, 1973	72/73
2	"TURBIDITY CLOUDS" OFF THE MOUTH OF RUPERT INLET, August 3, 1973	72/73
3	TURBIDITY FIELD OFF HANKIN POINT, August 3, 1973	72/73
4	REDUCTION IN SURFACE TURBIDITY WEST OF MINE SITE, RUPERT INLET, August 3, 1973	74/75
5	SURFACE TURBIDITY AROUND THE WASTE DUMP AND EMERGENCY TAILING IMPOUNDMENT, August 3, 1973	74/75
6	SHORELINE, EAST OF THE WASTE DUMP, August 3, 1973	74/75
7	SURFACE TURBIDITY IN THE WESTERN PORTION OF QUATSINO NARROWS, August 3, 1973	76/77
8	SURFACE TURBIDITY IN QUATSINO SOUND OFF DRAKE ISLAND, August 3, 1973	76/77
9	EXTENSION OF TURBIDITY FROM NORTHERN END OF QUATSINO NARROWS DURING EARLY FLOOD TIDE, May 8, 1974	78/79
10	TURBID "BOILS" OFF HANKIN POINT DURING THE LATE FLOOD TIDE, May 8, 1974	78/79
11	WASTE DUMP TURBIDITY, May 8, 1974	78/79
12	MUSSEL BED ON RED ISLAND SHOWING WASTE DUMP SEDIMENT DEPOSITS	80/81
13	MUSSEL BED ON RED ISLAND, SURFACE SEDIMENT REMOVED	80/81
14	HANKIN POINT SHOWING TAILINGS DEPOSITS IN THE INTERTIDAL ZONE	80/81
15	KELP COATED IN FINE SILT, KOKWINA COVE, QUATSINO NARROWS	82/83
16	TAILINGS DEPOSITS AT HANKIN POINT	82/83

PLATE		PAGE
17	TAILINGS BUILD-UP, HANKIN POINT	82/83
18	TYPICAL EXAMPLES OF MARINE LIFE AND BOTTOM CONDITIONS IN QUATSINO SOUND [(A) to (F)]	84/85
19	BARNACLES WITH A COVERING OF MINE SEDIMENT, HANKIN POINT	86/87
20	ROCK SURFACE BLACKENED UNDER FINE SEDIMENT	86/87
21	DEGENERATION OF ENCRUSTING ALGAE	86/87

CONCLUSIONS

1. A re-evaluation of the Island Copper Mine tailings disposal system is warranted to ensure that the best environmental solution to the present waste disposal problem has been achieved. This conclusion is based on the present and anticipated environmental impact of mine sediment deposition and the spread of these sediments into waters shallower than 100 metres and out into Quatsino Sound proper. This is contrary to the predicted tailings dispersion patterns.

2. Since tailings dispersion is primarily related to the action of tidal currents on the benthic deposits, alternate disposal methods should be considered. Changes to the design or location of the present underwater outfall system are unlikely to reduce or eliminate undesirable tailings dispersion.

3. In relation to the tailings discharge, sediment loading from the waste rock dump is considered to be less significant. However, this additional sediment loading plus filling approximately 700 acres of Rupert Inlet with waste rock, is of sufficient magnitude, that alternate methods of waste disposal should be considered, limiting further extension into the inlet.

These conclusions are based on the following considerations:

a. Pre-operational predictions concerning the movement of mine tailings discharged into Rupert Inlet, made by Utah Mines Ltd. in their brief to the British Columbia Pollution Control Branch (Utah, 1971) indicated that tailings solids would generally remain in the deeper portions of the inlet (below a depth of 100 metres) and would not contaminate the shallower, more biologically productive zones.

b. Results of the studies reported herein show that the pre-operationally predicted extent of effluent solids dispersion has been greatly exceeded, following 5 years of Island Copper Mine operation.

c. Submersible observations made during the present study, as well as experimental trawl studies conducted by others suggest that a much more diverse deep-water benthic community was naturally resident in Rupert Inlet than that reported by Utah Mines Ltd. (Utah, 1971). The company reported that deep-water benthos, consisted primarily of polychaete worms, small clams, shrimp-like animals, and a number of other relatively minor groups.

d. Evidence of lateral and vertical movement of tailings solids into areas and at depths shallower than the predicted 100 metres is demonstrated by: 1) a substantial increase in both surface and subsurface turbidity; 2) rapid and widespread mine sediment deposition over a considerable portion of the Rupert Inlet system; and 3) heavy sediment deposition on much of the original substrate and resident biota in some intertidal and shallow subtidal areas.

e. Three years of qualitative observations in Rupert Inlet have established that mine sediment deposition along portions of the shoreline has had, and is continuing to exert, a progressively detrimental effect on the benthic biota by altering native habitat and smothering resident species.

f. It is anticipated that the impact of solids deposition on resident biota in the shallower regions and the simultaneous obliterative effects on deep-water benthos will ultimately impair the biological productivity of Rupert Inlet by reducing species diversity and abundance.

g. The anticipated reduction of biological productivity will undoubtedly spread to adjacent waters as existing oceanographic influences continue the outward movement of mine sediment deposition.

h. The shoreline in the Quatsino Sound area is mostly bedrock, while the deeper areas around Quatsino Narrows consists of bedrock, coarse sand and gravel. These areas support a diverse benthic community. In many regions, this native habitat has become permanently altered due to the build up of mine sediment which will preclude rehabilitation by organisms that require a relatively sediment-free substrate for survival.

i. Based on the evidence of increased heavy metal concentration in the marine sediment and the potential bioaccumulation into marine organisms, particularly molluscan bivalves, the authors of the present report anticipate that the concentration of certain heavy metals will increase in marine biota exposed to mine sediment deposition.

1 INTRODUCTION

In 1968, Utah Mines Ltd. announced plans to construct the Island Copper Mine, a large open pit copper-molybdenum mining complex, to be located on the north shore of Rupert Inlet, northern Vancouver Island.

Following discussions with what was then the Federal Department of Fisheries and presentation of a brief to a Provincial Pollution Control Board public inquiry (January, 1971), Utah Mines Ltd. was granted permission to discharge both mill tailings and waste rock into Rupert Inlet.

Construction of the Island Copper Mine was completed in 1971 and the first ore had been processed by October of that year. During the first two years of mine operation, Environment Canada (now Fisheries and Environment Canada) carried out periodic monitoring surveys to determine if tailings distribution conformed to pre-operational predictions made by Utah Mines Ltd. Subsequently, in 1973, the range of studies was increased following evidence of surface turbidity in Rupert Inlet.

1.1 Study Objectives

The principal goal of the study reported herein, was to monitor and evaluate the effects of underwater unconfined copper mine tailings disposal and waste rock shoreline dumping on the marine environment. Specific objectives were as follows:

(a) monitor the level of turbidity within the receiving waters to determine the distribution of mine-derived suspended solids;

(b) monitor the benthic distribution and movement of mine tailings and waste rock materials in relation to pre-operational predictions;

(c) evaluate the influence of oceanographic conditions on the distribution and deposition pattern of mine tailings and waste rock sediment;

(d) determine the deleterious effects of mine sediment deposition on indigenous marine organisms in the intertidal, shallow subtidal and deep benthic zones;

(e) assess the degree of heavy metal contamination (Cu, Zn) in resident bivalves.

2 BACKGROUND

2.1 Description of Study Area

2.1.1 Geographical Aspects. Quatsino Sound, located in the northwestern portion of Vancouver Island, leads into three major inlets, Rupert and Holberg inlets to the north, and Neroutsos Inlet to the south (Figures 1 and 2). Rupert and Holberg inlets are connected to Quatsino Sound by Quatsino Narrows, a narrow and often very turbulent tidal channel.

Rupert Inlet is the smallest of the three inlets, being 10.2 km long with a mean width of 1.8 km. The mean center channel depth is 110 metres. The maximum depth of 165 metres is located near the mouth of the inlet in the vicinity of Quatsino Narrows (Pickard, 1963).

Holberg Inlet is 34.2 km long and has a mean width of 1.3 km. The mean center channel depth is 80 metres; the deepest portion, 170 metres, is located near Quatsino Narrows (Pickard, 1963).

Neroutsos Inlet, including Quatsino Sound proper, is 59.2 km long with a mean width of 2.2 km. The mean center channel depth is 150 metres (Pickard, 1963). The Rayonier Canada (B.C.) Ltd., Port Alice Pulp Mill, in operation since 1917, is located near the head of the inlet.

Drinkwater (1973) reported the volumes of Rupert and Holberg inlets as 2,000 x 10^6 m^3 and 3,400 x 10^6 m^3, respectively.

2.1.2 Oceanographic Features. The most active tidal currents are in the vicinity of Quatsino Narrows. The Canadian Hydrographic Service (1972) reported that surface-current velocities in Quatsino Narrows can reach 7.0 to 7.5 knots (360 to 386 cm sec^{-1}) during large tidal changes. During a floodtide, considerable turbulence and upwelling can develop between Hankin Point and Quatsino Narrows (Figure 2) (authors' observation).

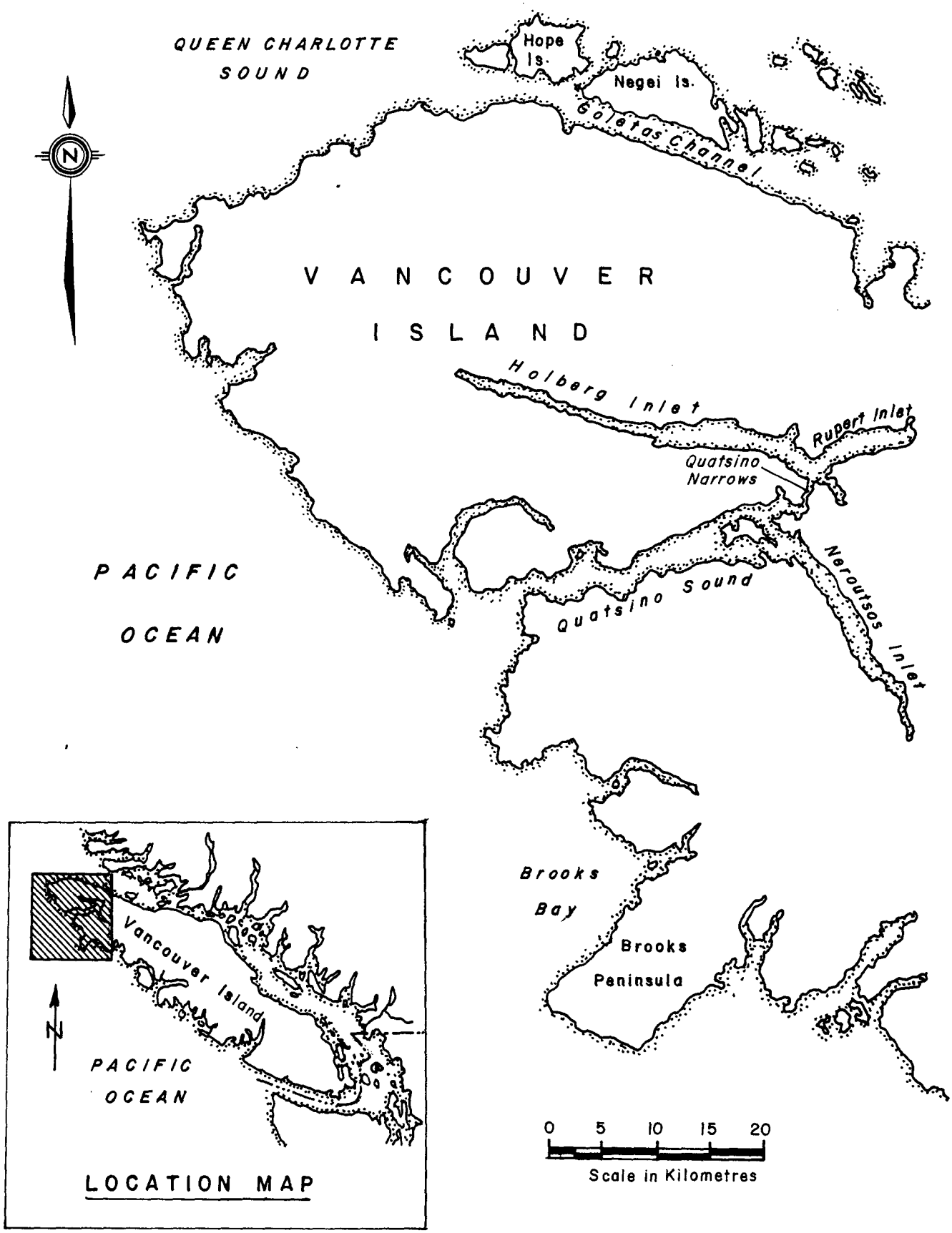


FIGURE I NORTHERN VANCOUVER ISLAND

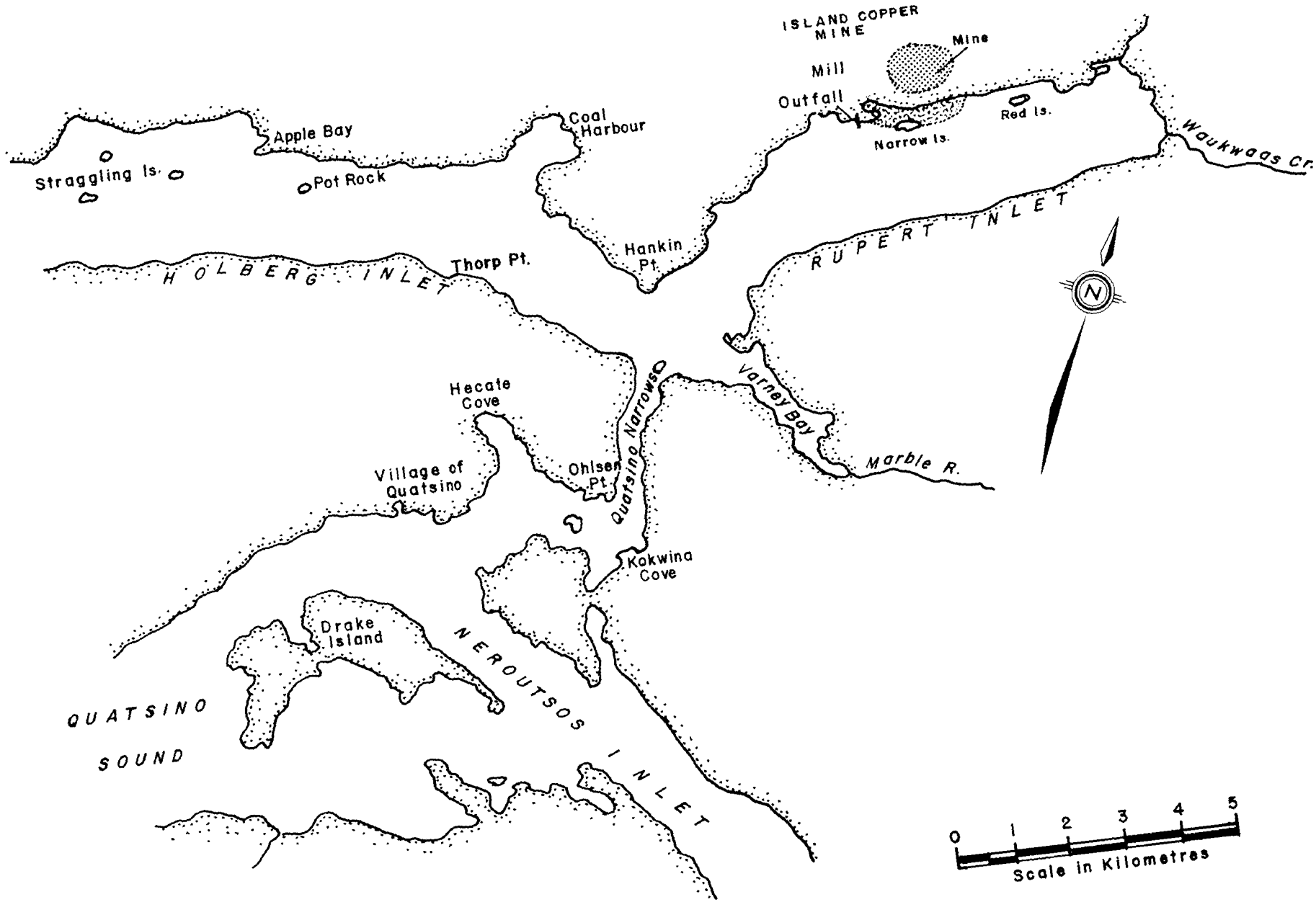


FIGURE 2 STUDY AREA

The tidal range at Coal Harbour, near the mouth of Holberg Inlet, is 0.18 m to 4.2 m with a mean of 2.8 m.

From the limited data available, Drinkwater (1973) estimated the total daily freshwater input into Rupert and Holberg inlets to be about 12 x 10^6 m^3 and 40 x 10^6 m^3 under maximum conditions. Based on the drainage area, he estimated that half of this volume comes from the Marble River, the major river system in the area. However, in relation to the tidal input through Quatsino Narrows, the flow from the Marble River is comparatively minor, estimated by Johnson (1974) to be about 5% of the total input.

The Marble River, which enters near the mouth of Rupert Inlet (Figure 2), is relatively short and drains several large lakes. According to Johnson (1974), the Marble River is not a significant contributor to the total sediment load into Rupert Inlet. The natural sediment input into both Rupert and Holberg inlets from other sources is also considered to be very low.

The vertical uniformity in temperature and salinity in the water column as shown by Pickard (1963) and Waldichuk et al (1968), indicates that considerable tidal mixing occurs in Rupert Inlet. In addition, benthal dissolved oxygen concentrations are usually high in Rupert Inlet, despite the existence of a shallow sill in Quatsino Narrows. Water circulation in Rupert Inlet and the influence of Quatsino Narrows on tidal mixing is discussed more fully by Drinkwater (1973), Drinkwater et al (1975), Johnson (1974), and Stucchi and Farmer (1976).

2.2 Island Copper Mine

2.2.1 Production Data. The Island Copper Mine has a designed capacity of 33,000 tons of ore per day, with an annual output of 230,000 tons of copper concentrate and 1,800 tons of molybdenum concentrate. The defined ore body has been estimated to have reserves of 280 million

tons of copper-molybdenum ore, with an average grade of 0.52% copper and 0.018% molybdenum. Based on the average production rate and known ore reserves, the life of the mine has been estimated to be 25 years. Daily production rates, however, have reached as high as 38,000 to 40,000 tons, presumably shortening the productive life span of the mine.

The mine configuration is a single open pit which is located east of the mill site. The final area of the pit is expected to be approximately 500 acres (202 ha) having surface dimensions of approximately 2,286 metres by 1,066.8 metres, and will extend to a depth of 304.8 metres, some 243.2 metres below sea level.

2.2.2 Tailings Disposal System. After crushing and grinding the ore to approximately 70% minus 200 mesh (74μm), the chalcopyrite ($CuFeS_2$) and molybdenite (MoS_2) mineral is removed by a flotation process. The waste material (mill tailings) from this process is passed through two large (375-foot diameter) thickeners to reclaim some of the process water and chemicals. The underflow or tailings effluent from the thickeners consists of 40% to 50% solids by weight. Characteristics of the discharged solids are shown in Table 1 and Figure 3 (Evans and Poling, 1975). Normally the effluent is disposed of via a marine outfall located immediately west of Narrow Island (Figure 2). Before discharge, the effluent is diluted with seawater drawn from a depth of 15 metres. The diluted effluent is then discharged at a depth of 50 metres.

In the event of a failure in the marine outfall system, Utah Mines Ltd. has constructed an emergency tailings impoundment by dyking off an area behind Narrow Island (Plate 5, see pages 74 and 75).

Since only a small portion of the ore is recovered as mineral concentrate (150 to 200 tons per day) most of the processed ore is discharged into Rupert Inlet as tailings (i.e., approximately 38,000 tons per day). To date, over 50 million tons of solids have been discharged into Rupert Inlet.

TABLE 1 TYPICAL MINERAL COMPOSITON OF TAILINGS SOLIDS DISCHARGED INTO RUPERT INLET (Evans and Poling, 1975)

Element	Heavy Metal Concentration (ppm)
Cu	700
Mn	650
Cr	140
Zn	80
Mo	40
Co	20
Ni	20
Pb	20
As	5
Cd	3
Hg	0.03

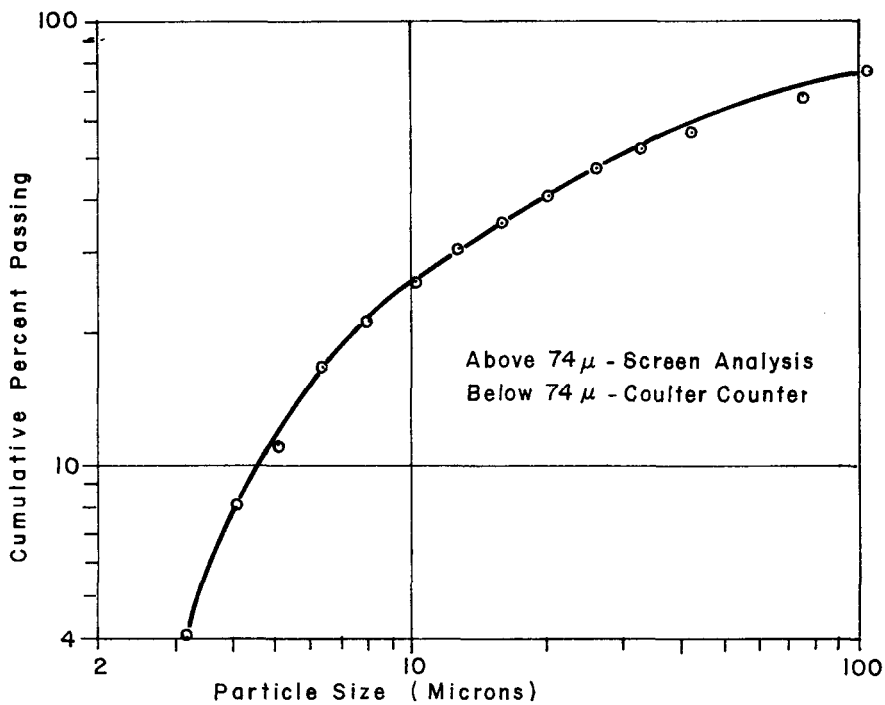


FIGURE 3 TYPICAL SIZE DISTRIBUTION OF TAILINGS SOLIDS DISCHARGED INTO RUPERT INLET (Evans and Poling, 1975)

In 1976 Utah Mines Ltd. increased the capacity of the marine outfall by installing a larger diameter pipeline and has obtained a Provincial Pollution Control Branch permit to increase the average annual daily effluent volume from 9.3 to 16.0 million Imperial gallons (82,000 m^3).

2.2.3 Waste Rock Disposal. With an open-pit operation, large quantities of waste material are generated during exposure of the ore body. At the Island Copper Mine, approximately 3.0 tons of waste material, comprised largely of crushed rock, fine sand, and silt are produced for every ton of ore mined. Most of this waste material (approximately 114,000 tons per day) is transported to a dump site located along the shore of Rupert Inlet adjacent to the pit. The present location and area of the waste dump is shown in Figure 4.

Utah Mines Ltd. has obtained a Provincial foreshore lease to extend the dump area into Rupert Inlet, to occupy some 700 acres (283 ha). The final dump crest and area of the foreshore lease are shown in Figure 4.

2.3 Environmental Programs

2.3.1 Pre-Operational Studies. On the basis of pre-operational studies, Utah Mines Ltd. concluded that marine tailings disposal was an acceptable method of disposal from an environmental standpoint and in the case of Rupert Inlet, the most preferable. In their brief to a Provincial Pollution Control Board public inquiry (Utah, 1971), the company maintained that: (1) tailings solids, if discharged directly into Rupert Inlet, would generally remain below a depth of 100 meters; (2) solids would flow as density current down the sloping bed of Rupert Inlet to settle in the deeper portions of the inlet, and; (3) by cessation of the mine operation, the total deposition would be about 1,600 acres (647 ha) and would equal one-tenth of the volume of Rupert Inlet. It was also understood that deposits would eventually extend into Holberg Inlet.

Although recognizing the strength of tidal currents through Quatsino Narrows, Utah Mines Ltd. concluded that the deposits of tailings

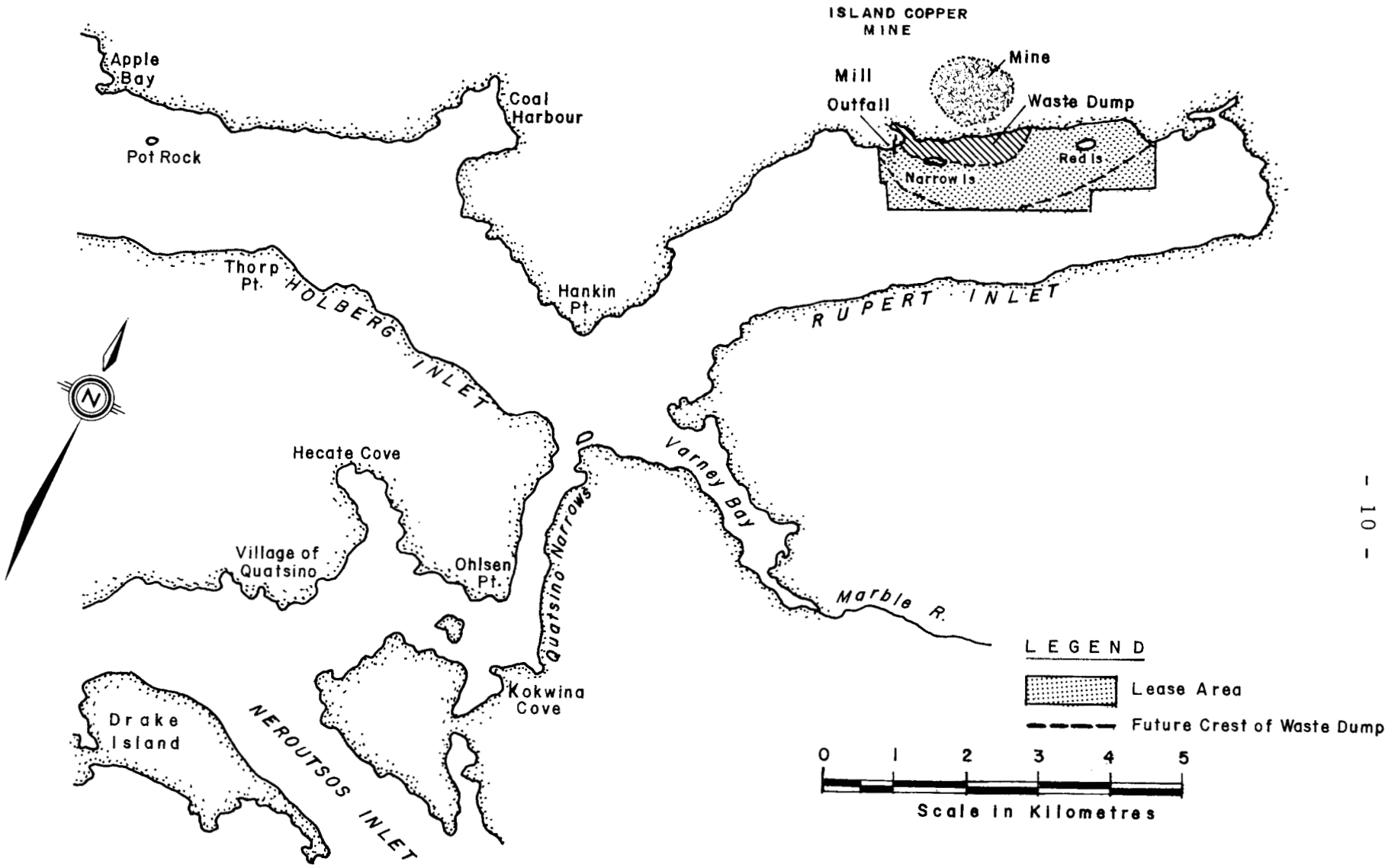


FIGURE 4 AREA OF WASTE ROCK DUMP AND FORESHORE LEASE - 1976

would be below any direct influence of these channel currents. Utah Mines Ltd. indicated that the greatest current velocity in Rupert Inlet would be above a depth of 60 metres and that a zone of vertical stability would exist from 60 metres to the bed of the inlet. This assessment was based on measurements taken by B.C. Research Council at two stations, one between Quatsino Narrows and Hankin Point, and the other near the mine site (Utah, 1971).

It was generally understood during discussions between Utah Mines Ltd. and the Federal Department of Fisheries that acceptance of marine tailings disposal would result in the reduction, if not total elimination, of many marine organisms living in the deeper portions of both Rupert and Holberg inlets. Utah Mines Ltd. stated in their brief that, "... the bottom fauna of the Rupert-Holberg system is dominated by marine worms. In the deeper portions they form over 70% of the animal population in numbers and the bulk of the biomass." It was also stated that, "...the balance of the animal populations on the bottom of Rupert Inlet consists of small clams, shrimp-like animals and a number of relatively minor groups."

Although recognizing that there would be some deleterious effects to the bottom fauna of Rupert Inlet, the Federal Department of Fisheries accepted Utah Mines Ltd.'s proposal to discharge directly into Rupert Inlet. This decision was undertaken to prevent the potential for biological leaching and subsequent run-off of toxic heavy metals into surface waters of the watershed, if the tailings solids had been stored on adjacent land. Earlier tests of Island Copper ore samples had indicated an acid generation potential, and the resultant biological release of toxic heavy metals would have presented a serious hazard to local salmon stocks and other resident biota. However, concurrence with Utah Mines Ltd.'s proposal was based on the belief that tailings solids would remain below the depth of 100 metres, as indicated by the company's environmental impact statements contained in their brief to the Pollution Control Board (Utah, 1971), and that the shallower, more productive areas would not be contaminated.

2.3.2 Post Start-Up Studies.

2.3.2.1 By federal agencies. Initially, following the mine start-up in 1971, Environment Canada carried out periodic surveys to monitor tailings distribution and movement in relation to pre-operational predictions. Observations indicated that suspended solids emanating from the mill outfall were not dispersing as predicted by Utah Mines Ltd., and that increased sediment deposition could result in detrimental impact on water quality and aquatic life forms in shallower more productive areas.

To test this proposition, emphasis during the studies was directed to determining the magnitude of turbidity within the water column and the resultant mine sediment deposition within the intertidal and shallow subtidal zones. Simultaneously, the physical impact on the resident biota and heavy metal contamination of intertidal shellfish were investigated.

In conjunction with this study, current measurements were taken in the area of Hankin Point by Ocean and Aquatic Sciences, Environment Canada, in April, 1974.

2.3.2.2. By independent agents. In accordance with the provisions of the Pollution Control permit, Utah Mines Ltd. is required to carry out an environmental monitoring program under the direction of an independent agent. In February, 1971, the role of independent agent was assumed by an interdisciplinary team of faculty members from the University of British Columbia and the University of Victoria. The objective of the program was to detect significant changes to the physical, chemical and biological conditions of the receiving environment attributable to the mining operation. An outline of the program is presented in the "Relationship to Other Studies" at the end of this report, see pages 60 to 69. Details of the program may be obtained from the Director of Pollution Control, Pollution Control Branch, Ministry of Environment, Province of British Columbia, Victoria, B.C. (Pollution Control Permit No. 379).

3 MATERIALS AND METHODS

3.1 Areas of Surface Turbidity

On August 3, 1973, and May 8 and 9, 1974, aerial visual observations and photographic recordings (using a Beaver floatplane) were carried out to determine the extent of surface turbidity. Flights were made over Rupert Inlet, Holberg Inlet and Quatsino Sound. A 35 mm Asahi Pentax camera equipped with colour film and polarizing filters was used to take oblique photographs of the affected areas. A number of these photographs appear as "Plates" (see pages 72 to 79) in this report.

In August 1973, flights were made during the latter part of a flood tide; on May 8, 1974, they took place during the early and late stages of a flood tide and on May 9, during the latter part of an ebb tide.

3.2 Depth of Subsurface Turbidity

3.2.1 Transmissometer Profiles. The vertical extent of subsurface turbidity was determined using a Hydro Products 612-S transmissometer. This instrument measures the attenuation of light passing through a column of water, and the values expressed as percent light transmission provide a relative measure of water clarity or turbidity. The transmissometer, equipped with a one-metre light path, was lowered toward the bottom by a hydrographic winch and held at 5-metre depth intervals for a standardize time interval, at each depth, before readings were obtained.

Transmissometer profiles were taken routinely at four test stations: two in Rupert Inlet; one near the northern end of Quatsino Narrows; and one in Holberg Inlet; on November 8, 1973, April 23, 1974, and May 22 to June 10, 1974.

On July 16, 1976, transmissometer profiles were taken in Rupert Inlet (Station T-2) specifically to determine any variability of turbidity during a tidal cycle.

The 5-metre depth interval technique was used for all measurements except those taken on November 8, 1973, when 10-metre intervals were used. Any significant changes in percent transmissibility which occurred between these depth intervals were also recorded. The instrument was cleaned and calibrated before each series of profiles.

In April, 1974, comparative tests were carried out using the Hydro Products 612-S transmissometer and a similar instrument employed by Dobrocky Seatech Ltd., a consulting firm retained by Utah Mines Ltd. Test results were similar for both instruments.

3.2.2 Underwater Observations. Visual observations of turbidity within the water column in Rupert Inlet, Holberg Inlet, and Quatsino Sound were made from the submersible, Pisces IV, in February, 1975. Visibility under 2 metres was estimated from known distances along exterior equipment mounted on the front of the submersible. In addition, estimates of water clarity along the shoreline were made during underwater SCUBA surveys carried out between 1970 and 1975, in various regions of Rupert Inlet and contiguous areas.

3.3 Particle Size Analysis

Particle size analysis was carried out on water samples collected during the April, 1974, transmissometer survey. Water samples were obtained from three depths at each transmissometer station: the water surface; the depth at which a marked reduction in transmissibility occurred, generally between 30 and 50 metres; and near the bottom of the inlet. Samples were shaken vigorously and passed through 44μm Nitex netting to remove detritus. Particles, assumed to be spherical for the calculations, were counted using a Model "B" Coulter Counter to determine the number and size of particles in each sample. A 50μm aperture was used for particle volumes ranging from $4\mu m^3$ to $60\mu m^3$, and a 100μm aperture for those ranging in volume from $58\mu m^3$ to $984\mu m^3$. The tubes were calibrated using latex particles and paper mulberry pollen as outlined in Sheldon and Parsons (1967).

Sediment samples for particle size analysis were collected by SCUBA divers from Hankin Point in July and December, 1975, and from Thorp Point (Holberg Inlet) in December, 1975. Analysis of the July samples from Hankin Point was conducted by B.C. Research Council using wet sieve (Wentworth - Udden Series) and Bahco micro-particle size analysis. The particle size range tested was from 3μm to 4,000μm. Samples obtained in December, 1975, were analyzed at Fisheries and Environment Canada, West Vancouver Laboratory using the U.S. Standard Sieve series between -43μm and +2,000μm.

3.4 Distribution and Biological Impact of Mine-Derived Sediment Deposits

3.4.1 Ponar Grab Sampling. Grab sampling has been conducted periodically since November, 1971, to monitor the distribution of mine sediment deposits in the deeper waters of Rupert and Holberg inlets. Samples were obtained with a 0.092 m^2 Ponar grab. Presence of tailings deposits was determined visually by comparing their light grey colour to the light brown/olive green colour of the natural sediment. This method of distinguishing mine-derived sediments from natural sediments has been employed effectively by other workers investigating submerged tailings deposits (Thompson and McComas, 1974; Thompson and Paton, 1975). Whenever possible, the thickness of the deposit was estimated after carefully unloading the grab sampler. Estimates are approximate since the force of impact by the Ponar grab tends to remove a portion of the surface layer before sampling.

Ponar grab sampling along the inshore areas proved to be ineffective in determining the area affected by mine-derived sediment deposition. Steep slopes and protruding bedrock often resulted in the instrument's failure to sample. In these areas, visual observations were found to be the most effective method in determining the area of mine sediment deposits.

3.4.2 Underwater Observations. SCUBA diving techniques have been employed in the study since July, 1970, to determine the extent of mine-derived sediment deposition in the intertidal and shallow subtidal zones. These SCUBA techniques were also employed for the qualitative determination of the effects of mine sediment deposition on the benthic marine biota inhabiting the inshore areas. Maximum depth of the dives was 20 metres. Underwater photographs were taken using a 35 mm Asahi Pentax camera and a Hasselbad 500 cm (with a 50 mm Zeiss Distagon lens) housed in underwater cases. Visibility permitting, underwater observations of mine sediment deposition and marine biota in the deep benthic zones were made from the submersible, Pisces IV, in February, 1975.

3.5 Heavy Metal Analysis

3.5.1 Biological Samples. Clams and mussels have been collected annually since 1971 from areas in Rupert and Holberg inlets. Species collected, were *Macoma irus*, *Saxidomus giganteus*, *Protothaca staminea*, *Mya arenaria*, and *Mytilus edulis*. Samples were frozen prior to analysis. The tissue heavy metal analyses were performed by the Fisheries and Environment Canada Laboratory in West Vancouver. Tissue samples were analyzed for copper (Cu) and zinc (Zn).

Copper and zinc analyses were performed on the whole body tissue as follows:

- whole tissue samples were dried for 48 hours at 110°C, then ground in a mortar and pestle;
- one-gram portions were then digested in 10 ml of concentrated nitric acid for approximately 6 hours;
- samples were made up to 100 ml by adding distilled water and were then analyzed with a Jarrell Ash atomic absorption spectrophotometer;
- results, with a precision of ±10 percent, were expressed on both a wet and dry weight basis.

3.5.2 Sediment Samples. Trace element analysis was conducted on intertidal sediment samples collected from Hankin Point and Thorp Point in December, 1975. Samples were air-dried under cover, disaggregated, and sieved through an 80-mesh nylon sieve (2.5 phi). These samples were forwarded to Dr. K. Fletcher (University of British Columbia) where they were digested in a 4:1 nitric-perchloric acid mixture, evaporated to dryness over an air-bath, taken up in 1.5 M HCl, and analyzed for the total concentration of copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), manganese (Mn), nickel (Ni), cobalt (Co), and iron (Fe) with a Perkin-Elmer 303 atomic absorption spectrophotometer.

4 RESULTS AND DISCUSSION

4.1 Deleterious Effects of Turbidity and Sedimentation

Some degree of ecological damage is unavoidable with any on-land or underwater system of mine waste disposal. B.C. Research Council (1970) after reviewing tailings disposal methods, points out that the ecological damage caused by underwater disposal can be much more extensive than that of a land application, because of the greater area involved and the existing potential for wider distribution of suspended solids. They concluded that the major problems associated with an underwater effluent discharge were turbidity and sedimentation, which may produce the following principal effects:

(a) turbidity can reduce the penetration of light through the water medium, thereby inhibiting the natural growth and productivity of light-dependent aquatic organisms, which can result in population depletion. This, in turn, disrupts the food chain of larger marine species which rely on these organisms as a food source. The deleterious effects of continued and increasing turbidity are therefore magnified;

(b) sedimentation, the physical deposition of suspended sediment and soil particles on the bottom, can be detrimental because benthic flora and fauna become buried beneath a layer of deposited materials, or because their habitat is altered.

Furthermore, B.C. Research Council indicated that underwater tailings disposal could result in a variety of other effects such as heavy metal contamination and resultant toxicity interfering with an organism's metabolic process, damage to the tissues and organs of marine species by particle abrasion, and disruptions to the spawning and/or feeding habits of resident species.

It is commonly recognized that the existence of suspended or deposited solid particles in a marine environment does not necessarily constitute a detrimental condition, as such circumstances often occur

naturally. However, if the introduction of a man-made effluent is prolonged and excessive, particularly in an area or at a depth where natural conditions normally produce low levels of suspended solids, the resultant heavy sediment loadings could have a serious impact on the existing ecosystem. For example, the loss of clean rocky substrate for the attachment and growth of resident biota, caused by excessive deposition, could make survival of some species impossible or may substantially alter species distribution and diversity.

4.2 Surface Turbidity

Surface visual observations by the authors, prior to the development of the Island Copper Mine, indicated that water clarity throughout the study area was normally very good. Secchi disc readings taken in Quatsino Narrows often exceeded a depth of 15 metres.

During the first two years of mine operation, no appreciable changes in water clarity occurred in the surrounding waters, except for some surface turbidity immediately offshore from the waste rock dump in Rupert Inlet. This turbidity was attributed to the effects of wave action along the shoreline of the waste dump and to the direct dumping of waste rock material into the inlet.

In the spring of 1972, surface turbidity was first noted around the northern end of Quatsino Narrows, plus a slight reduction in water clarity within the Narrows itself. Periodic in nature, the surface discolourations seemed to coincide with the latter portions of large flood tides, an observation which was supported by verbal reports from local residents.

The frequency and extent of surface turbidity sightings increased in the latter part of 1972 and the early months of 1973. Water clarity had deteriorated over a considerable portion of the study area. Aerial photography on August 3, 1973, carried out during the latter part of a

flood tide, confirmed affected areas throughout Rupert Inlet and Quatsino Narrows and in portions of Holberg Inlet and Quatsino Sound extending to the western tip of Drake Island. Figure 5 shows the area of the turbidity field on August 3, 1973, and Plates 1 to 8 (pages 72 to 77) present aerial views of turbidity discolourations taken on the same date. An example of heavy versus light turbidity referred to in Figure 5, can be identified by comparison of Plates 1, 7 and 8 (heavy turbidity) and Plates 4, 5 and 6 (light turbidity).

Surface waters in many regions had a distinct grey appearance, similar to the colour of mine tailings. As Plates 1, 2, and 3 indicate, the area around Hankin Point, the mouth of Rupert Inlet and the northern entrance to Quatsino Narrows, appeared to be the most heavily affected. Around the mouth of Rupert Inlet, large "turbidity clouds" rose periodically to the water surface (Plates 1 and 2). Off Hankin Point, surface discolourations were interspersed occasionally by striations of clear water, presumably caused by upwelling of deeper non-turbid water from Quatsino Narrows, or by the mixing of waters from the Marble River (Plates 2 and 3).

Toward the mine site from the mouth to the eastern end of Rupert Inlet, the intensity of surface turbidity declined, except for the waters immediately adjacent to the waste rock dump (Plates 4, 5, and 6).

Plates 7 and 8 show the extension of turbid surface waters into Quatsino Narrows and off Drake Island in Quatsino Sound. The demarcation line between turbid and comparatively clear waters in Quatsino Sound, shown on Figure 5 and Plate 8, is thought to be due to the intrusion of outflowing waters from Neroutsos Inlet during flood tide conditions.

Further photographic flights over the study area were completed on May 8 and 9, 1974, approximately nine months after the first series of flights. The resultant photography is shown on Plates 9, 10, and 11, see pages 78 to 79. Comparison of the total area of the turbidity field existing during the flood tide on both widely separated dates, indicates very little change in its overall extent.

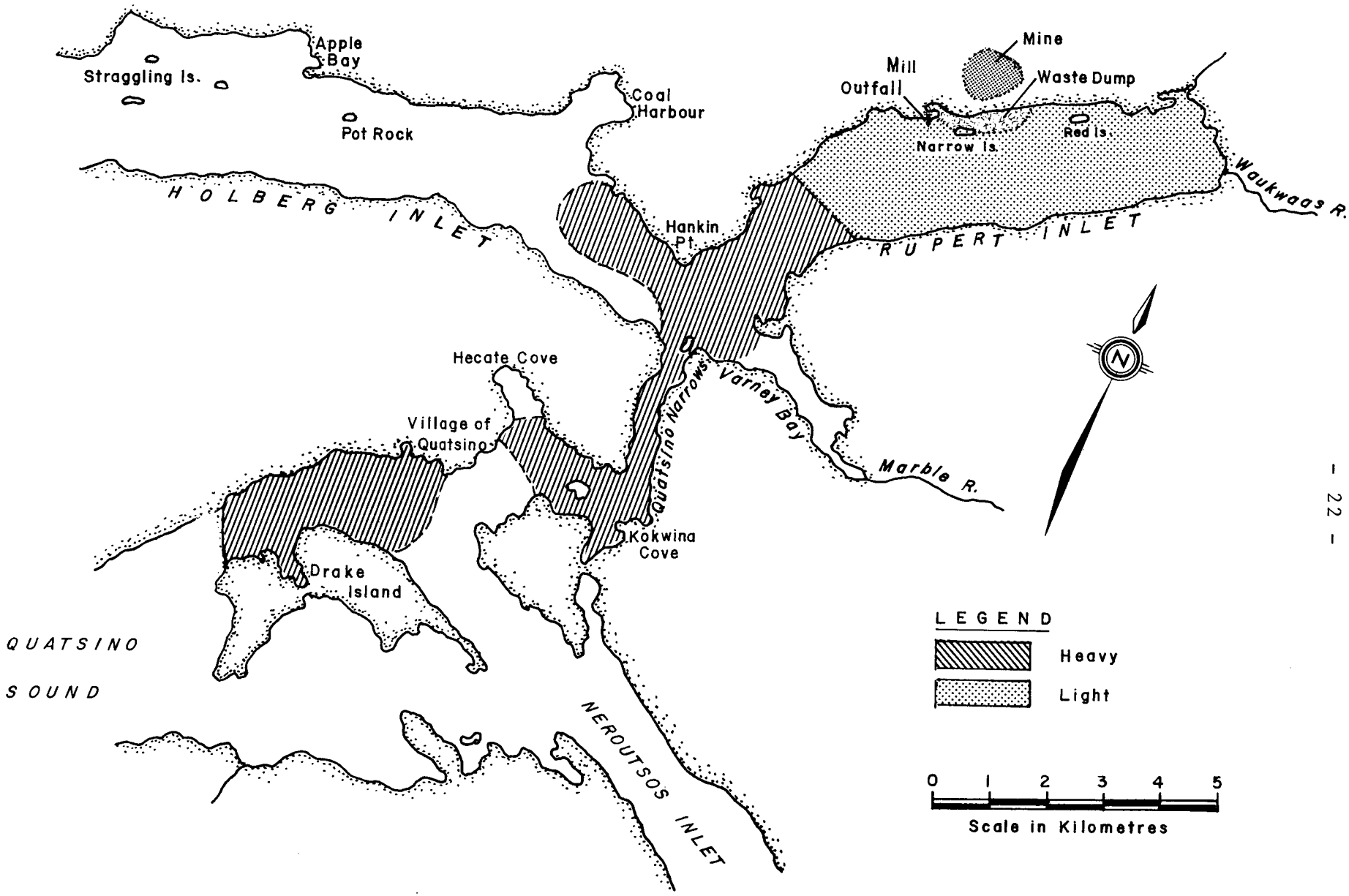


FIGURE 5 AREA OF SURFACE TURBIDITY - AUGUST 3, 1973

Plate 9, taken during the early stage of a flood tide, shows turbid waters, presumably from the previous tidal cycle, flowing back into Rupert Inlet from Quatsino Narrows. The turbid waters did not appear to flow northward along the surface towards Hankin Point during the early flood tide. During the latter part of the flood tide, large grey-coloured "boils" of turbid water appeared off Hankin Point (Plate 10), which gradually increased turbidity levels off the point and around the mouth of Rupert Inlet.

Johnson (1974) also reported "boils" off Hankin Point. He suggested that upward pressures below the Narrows caused by converging bottom currents are of sufficient strength so that as the flood tide begins to decay, turbid water is intermixed into the higher level water and first appears at the surface in turbulent "boils". He further suggested that this process would create a vertical sifting-winnowing action which would cause the fine material to enter the current flows of the water column, while the coarser material would remain captured in deeper waters until a dense inflow (i.e., high salinity water) scours the bottom and carries this material up the inlet.

Plate 11, taken on May 8, shows a large brown-coloured surface zone around the waste rock dump. This zone extended along the north shore towards the head of Rupert Inlet. On the following day, May 9, turbidity levels had markedly declined throughout the area, under the influence of an ebb tide.

4.3 Subsurface Turbidity

4.3.1 Transmissometer Surveys.

4.3.1.1 1973 and 1974 test results. Transmissometer profiles were obtained at four offshore stations located in Rupert and Holberg inlets during one series of tests in 1973, and five series in 1974. Figure 6 shows locations of the transmissometer stations. The percent

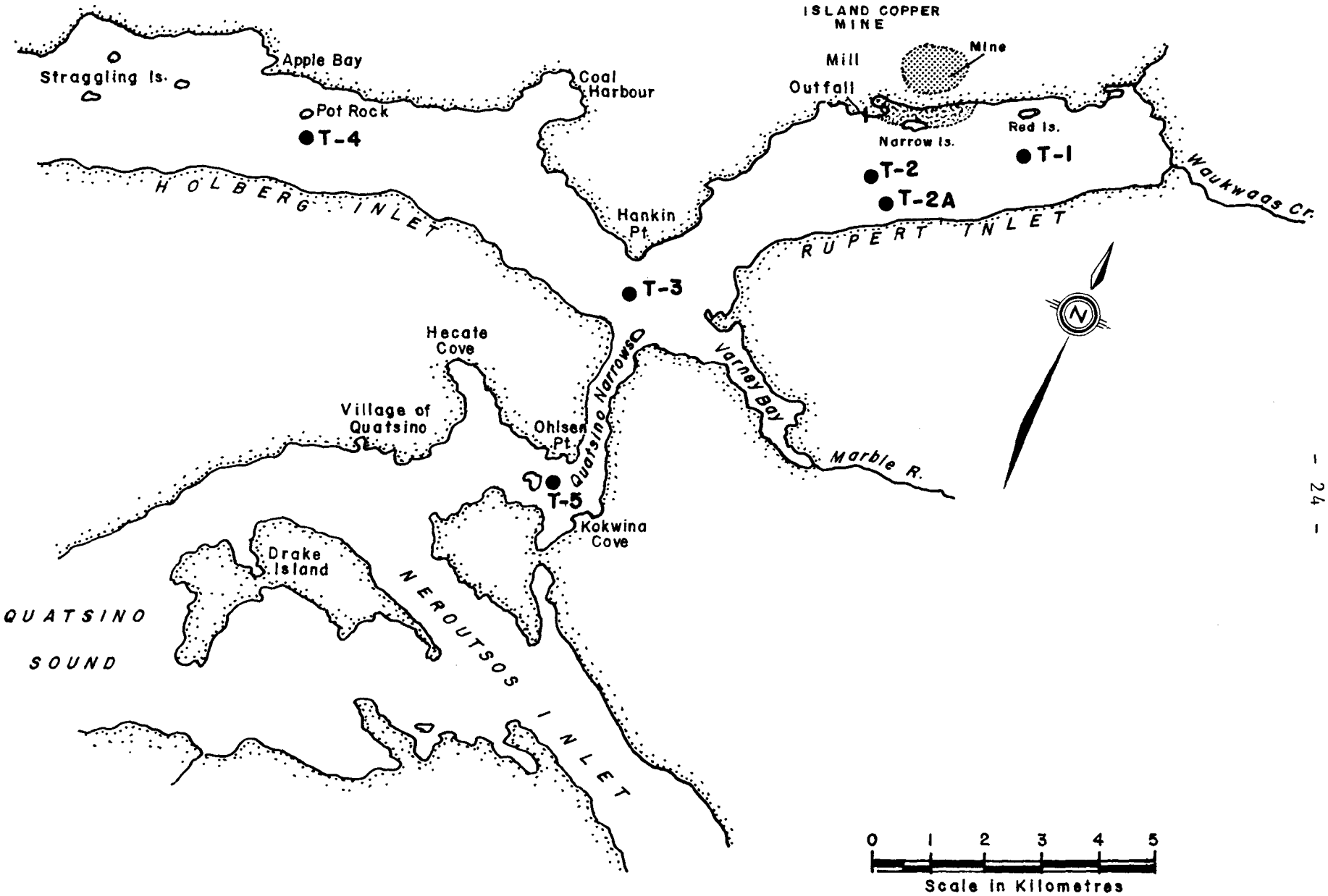


FIGURE 6 TRANSMISSOMETER STATIONS

transmissibility results for each series of tests are presented in Appendix I.

The results indicated that by 1973 a subsurface turbidity field had developed throughout most of Rupert Inlet. Transmissibility decreased sharply below a depth of 40 metres and decreased still further during the spring period.

Figure 7 summarizes the results obtained on November 8, 1973. At Station T-1, near the head of Rupert Inlet, transmissibility in the upper 40 metres ranged from 32% to 53%; but below 40 metres, it declined rapidly to 11% at 50 metres, and to 6% near the inlet bed at 90 metres.

At Station T-2, offshore from the mine site near the center channel of Rupert Inlet, transmissibility in the upper 60 metres ranged from 30% to 50%; but below 80 metres, readings dropped to 0% and remained at this value to the bottom at 118 metres.

At Station T-3, between Hankin Point and the mouth of Quatsino Narrows, a transmissibility of 40% was recorded at the surface; this gradually declined to 12% at 110 metres, approximately 30 metres above the maximum bottom depth in this region. Station T-3 is influenced by tidal currents from Quatsino Narrows, possibly accounting for a more gradual decline in transmissibility than that observed in Rupert Inlet.

At Station T-4, in Holberg Inlet, transmissibility tended to follow the same general pattern as at Station T-1 (Rupert Inlet) for the upper 40 metres; however, below 40 metres the readings were significantly higher than at Station T-1, 67% being recorded at a depth of 100 metres. Station T-4 has a depth of 115 metres at the inlet bed. Below 80 metres transmissibility was significantly higher than at corresponding depths at all stations in Rupert Inlet.

On November 8, 1973, a series of transmissometer readings at an additional test station (T-2A) was established off the south shoreline of Rupert Inlet opposite the mine site (Figure 6 and Appendix I). Readings

at this station were similar in pattern to those obtained at Station T-2 (Rupert Inlet), except that higher readings of 18% were recorded near the bottom at approximately 90 metres. This indicated that subsurface turbidity existing at the center of Rupert Inlet may extend to its southern shore.

Profiles obtained during the spring of 1974 (April 23 and 24), showed similar transmissibility patterns to those observed five months earlier. However, as Figure 8 and Appendix I demonstrate, the transmissibility levels of the entire water column in Rupert Inlet were much lower than in 1973.

4.3.1.2 Comments. Transmissibility reduction can be attributable to a number of natural influences: intrusion of organic materials or solids from stream runoff or wave action on beaches; scouring action of tidal currents; or the presence of plankton blooms. Alternatively, or simultaneously with some natural causes, man-made activities such as discharging mine tailings can reduce light penetration dramatically. In the case of Rupert Inlet, transmissibility at all stations at depths greater than 50 metres was consistently lower than the corresponding depths at the Holberg Inlet testing station.

Littlepage et al (1972) reported the presence of a suspended tailings field in Rupert Inlet between the depths of 50 and 100 metres, shortly after the Island Copper Mine had started operation.

Evans and Poling (1975) also reported the existence of fine, suspended mine-derived particles in the water column of Rupert Inlet. These particles produced "mist-like" turbidity layers which reduced the natural levels of water clarity. Measurements taken during a tidal cycle showed that light transmissibility between the mouth of Quatsino Narrows and Hankin Point had dynamic and highly variable characteristics (Evans and Poling, 1975).

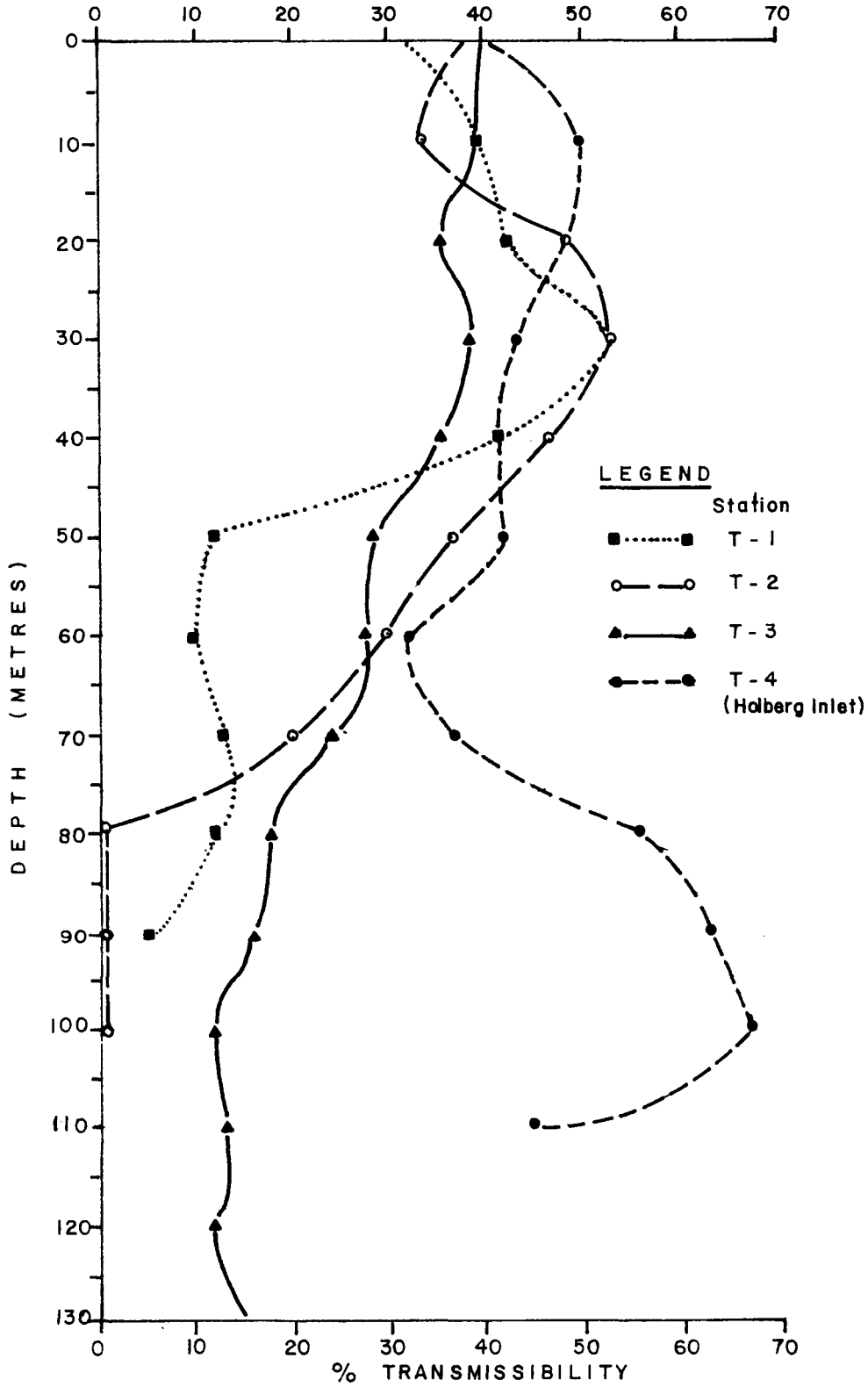


FIGURE 7 TRANSMISSOMETER PROFILES
November 8, 1973

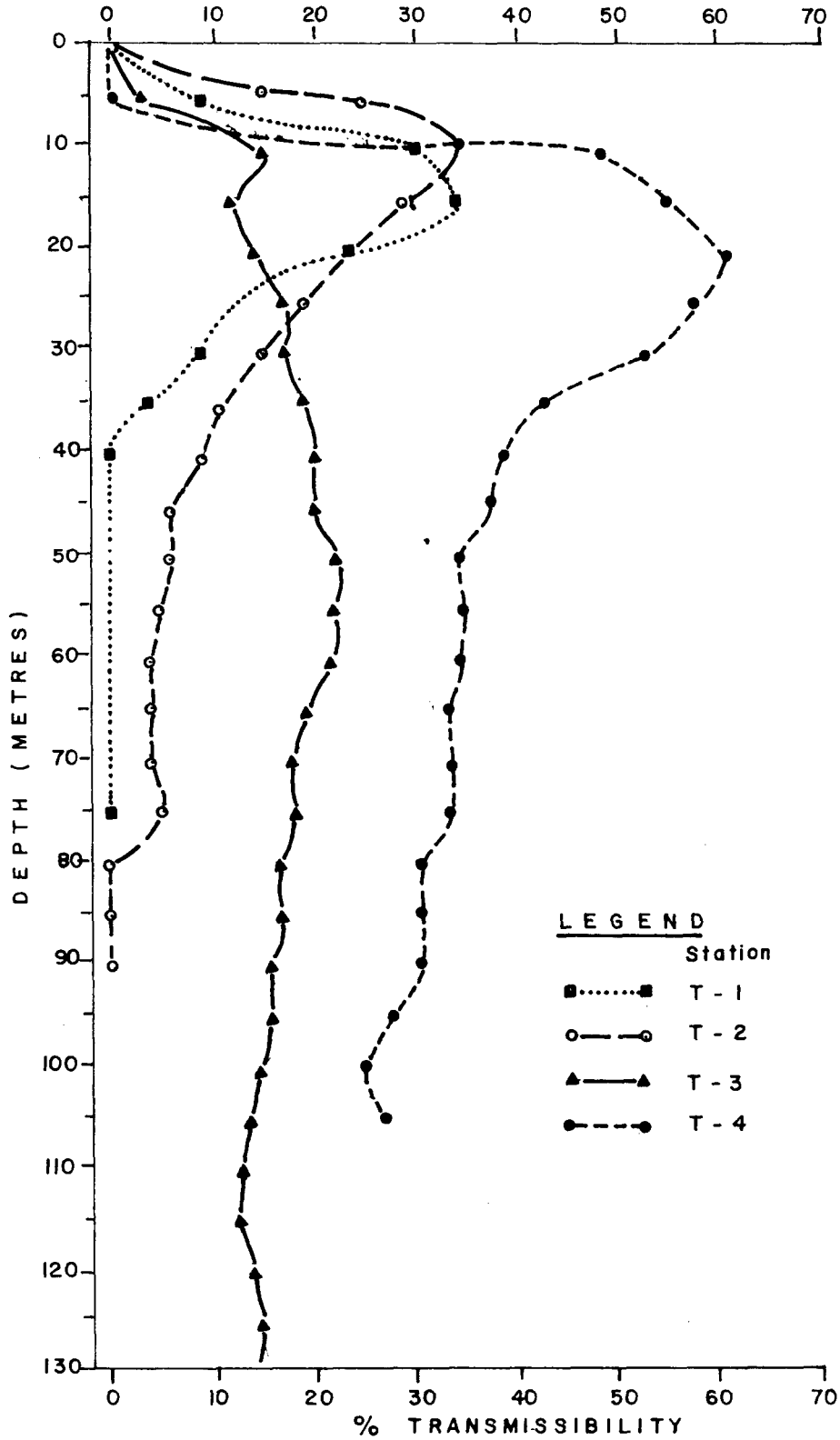


FIGURE 8 TRANSMISSOMETER PROFILES - April 23 and 24, 1974

However, during the present study, the results of tests carried out in July, 1976, indicated that transmissibility in deep water in the main body of Rupert Inlet (Station T-2) can remain relatively stable throughout a tidal cycle (Figure 9). From the measurements taken during the spring equinox tides (April, 1974), it would appear that seasonal fluctuations of transmissibility can occur, with maximum turbidity occurring during periods of large tidal changes.

4.3.2 Submersible Observations. During the period February 11 to 14, 1975, underwater visual observations of turbidity (and existing biota) were completed in a series of seven submerged traverses in Rupert Inlet, Holberg Inlet, and Quatsino Sound.

The submersible, Pisces IV, was used for all the dives, the locations of which are depicted in Figure 10. The observations are reported in Appendix II.

4.3.2.1 Rupert Inlet. Values obtained during transmissometer surveys in Rupert Inlet (1973-74) appeared to indicate that the upper 30 to 40 metres have not been significantly affected by the subsurface turbidity field. However, visual impressions obtained during submersible dives in February, 1975, revealed that extreme turbidity can exist throughout the entire water column.

Visibility near the surface during two separate dives (Numbers 295 and 297) at the head of Rupert Inlet was limited to approximately 2 metres and, below a depth of 60 metres, to about 0.5 metres. The poor visibility was caused by high concentrations of very fine, suspended particles, which gave the entire water column a grey-coloured appearance, best described as a "dense grey fog". On descent, visibility decreased gradually with no distinct layering of turbid water. A change in water density was noted at a depth of 25 metres. From 85 metres to the bottom, the number of larger suspended particles increased. Visibility remained the same during both flood and ebb tides. Similar conditions were encountered along the south shore of Rupert Inlet across from the Island Copper Mine.

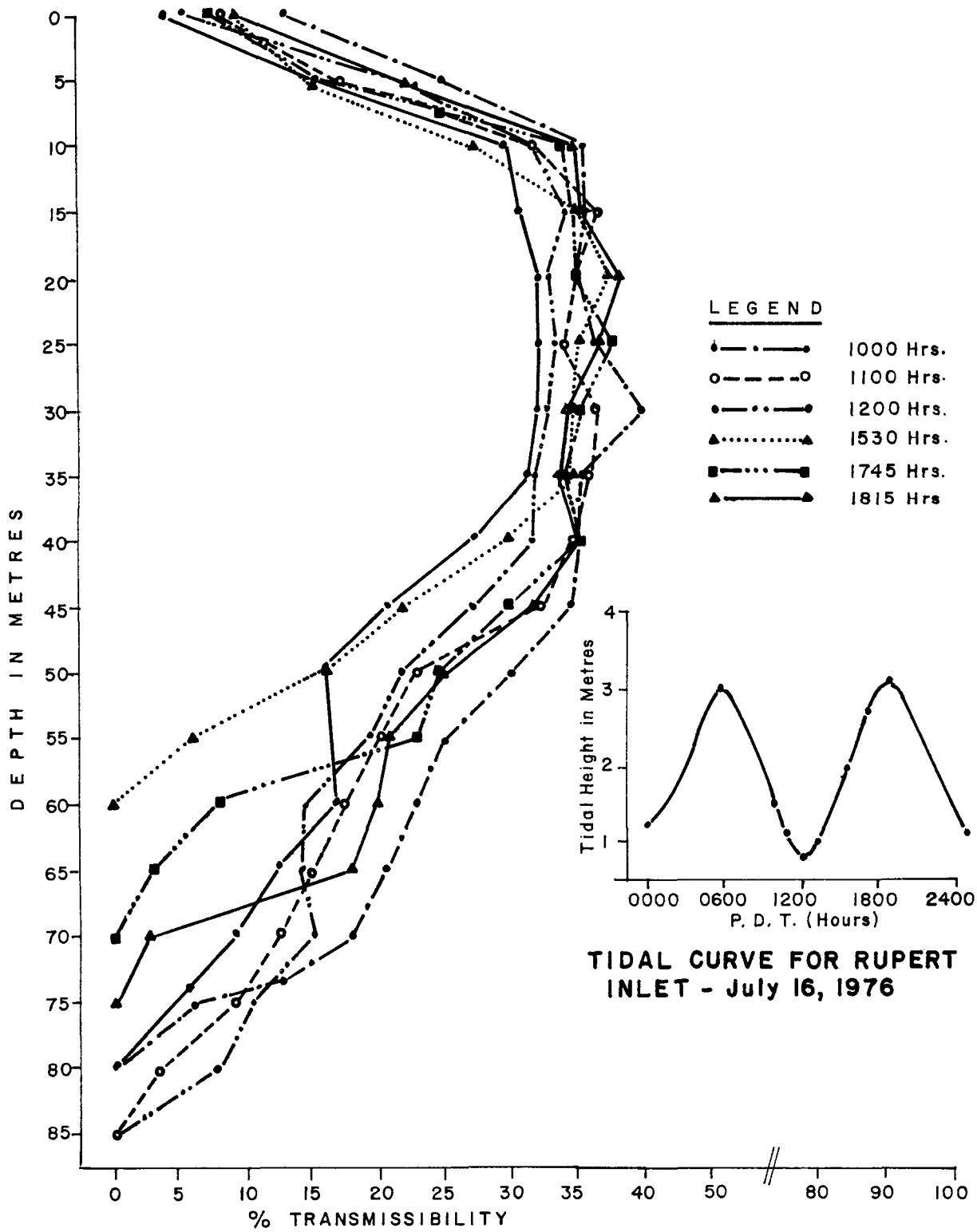


FIGURE 9 TRANSMISSIBILITY CHANGES DURING A TIDAL CYCLE AT STATION T-2 - JULY 1976

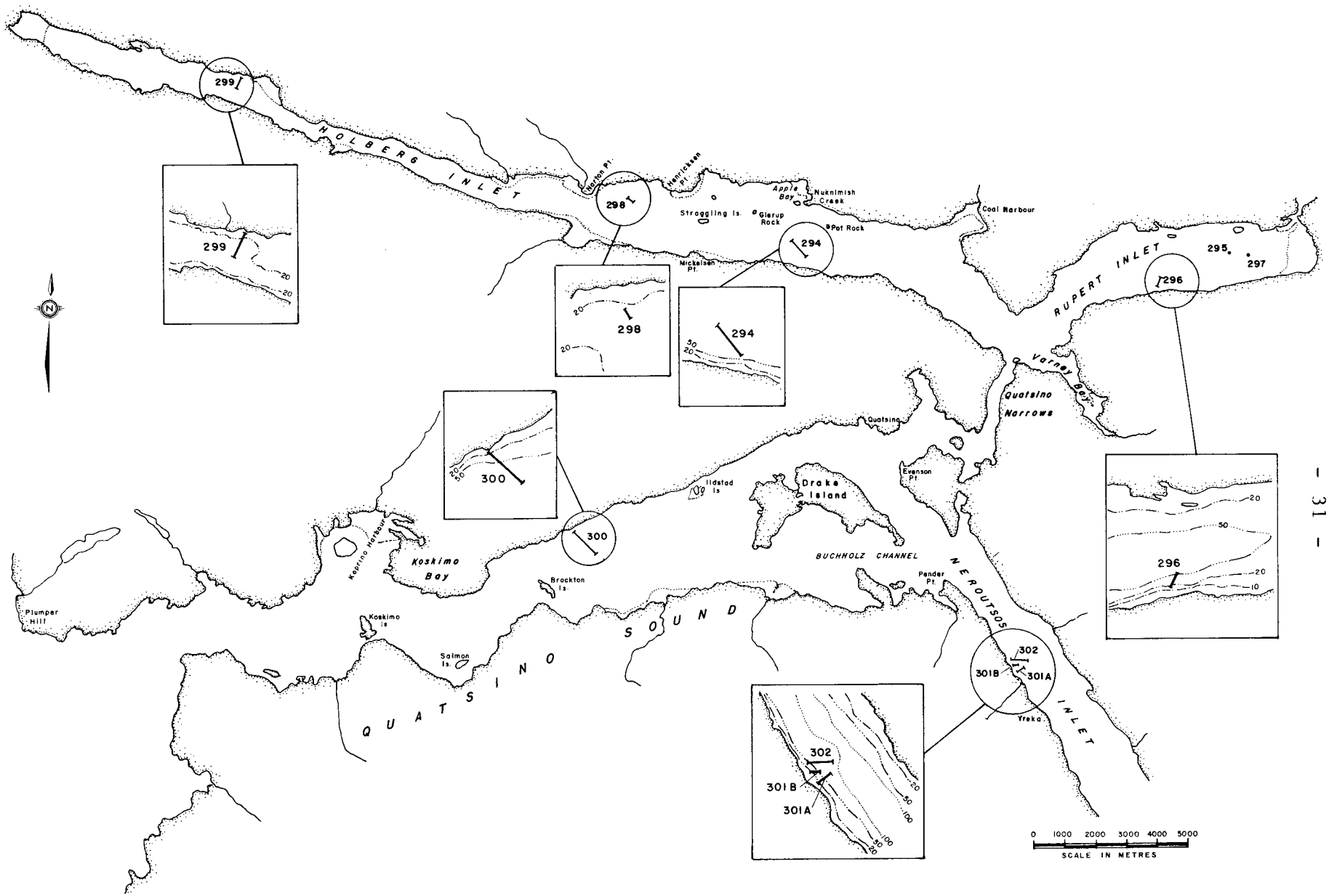


FIGURE 10 SUBMERSIBLE DIVING LOCATIONS

The presence of excessive turbidity throughout the water column does not appear to occur naturally, even under extreme conditions. In August, 1976, submersible observations were carried out near the head of Bute Inlet, which is fed by glacial rivers. Visibility near the surface was limited to a few centimeters. However, below 10 metres visibility improved dramatically and this condition persisted to the floor of the inlet.

Possible explanations for variations between turbidity observed from the submersible and transmissometer data include:

(a) as the tailings particles are mainly quartz, a certain concentration may reduce visibility but not significantly restrict light transmission;

(b) oceanographic conditions, such as strength of tidal current or density of incoming water may have varied during the time between the submersible and transmissometer surveys.

4.3.2.2 Holberg Inlet. Visibility in the Holberg Inlet waters was also very poor. In the area of Pot Rock (Dive No. 294) and Straggling Islands (Dive No. 298), visibility was restricted to about 2 metres at a depth of 30 to 50 metres, and 1 metre at depths from 90 metres to 115 metres near the bottom. Conditions improved slightly towards the head of the inlet where the bottom could be observed over a distance of about 3 metres (Dive No. 299). The suspended particles were brown in colour and larger than those observed in the upper portion of the water column in Rupert Inlet. The water column in Holberg Inlet lacked the grey-coloured appearance observed in Rupert Inlet. The origin of the suspended material could not be determined from visual observations; but, the presence of tailings deposits off Pot Rock suggests that some of the suspended material may have orginated from the Island Copper Mine discharge.

4.3.2.3 Quatsino Sound. In comparison to Rupert and Holberg inlets, the visibility in Quatsino Sound, west of Drake Island (Dive No. 300),

was very good throughout the entire water column. Visibility was estimated at times to be greater than 10 metres, despite the abundance of zooplankton and inert suspended material in the water. The "dense, grey fog" effect noted in Rupert Inlet was absent in the Quatsino Sound dive.

4.4 Particle Size Analysis

4.4.1 Water and Sediment Particle Samples. Johnson (1974) found that more than 50% of the particles by weight in the Island Copper Mine effluent, are less than medium silt size (<23.3μm), and of these, more than 50% are clay size (<2.0μm).

On April 23, 1974, water samples were collected for particle size analysis in conjunction with the transmissometer surveys at stations shown in Figure 6. Samples were taken at the water surface, near the bottom, and at a depth where a significant reduction in percent transmissibility was recorded. The complete results of the Coulter Counter analyses are tabulated in Appendix III. Table 2 summarizes the percentage distribution of particle sizes and indicates that 80% of the particles in all samples, except those from Station T-5 (Figure 6), were less than 5 m in diameter. At Station T-5, 80% of the particles were less than 6 m in diameter.

In July and November, 1975, benthic sediment samples were collected from Hankin Point and Thorp Point (control station) by SCUBA divers. Results of the particle size analysis are shown in Table 3. About 75% of the particles in the sediment from Hankin Point ranged in size from 63 m to 250 m. This sediment was light grey in colour compared to the light brown sediment from Thorp Point (see Figure 2). The brass-yellow colour of pyrite (FeS) particles in the -125 to 38 m size range was also noted.

4.4.2 Particle Suspension Criteria. Table 4 (abstracted from the Handbook of Mineral Dressing [Taggart, 1964]) shows the terminal velocity

TABLE 2 PARTICLE SIZE ANALYSIS - WATER SAMPLES

Station	Depth (m)	Diameter (μm)	Distribution (%)
T-1	0	1.9 - 4.8	81.4
T-1	30	1.9 - 4.2	87.3
T-1	70	1.9 - 4.8	85.4
T-2	0	1.9 - 4.8	82.8
T-2	50	1.9 - 4.2	82.8
T-2	90	1.9 - 4.8	80.5
T-3	0	1.9 - 4.2	84.7
T-3	20	1.9 - 4.2	82.7
T-3	150	1.9 - 4.8	79.8
T-4	0	1.9 - 4.2	80.7
T-4	40	1.9 - 4.2	89.9
T-4	100	1.9 - 4.8	87.6
T-5	0	1.9 - 6.0	82.8
T-5	30	1.9 - 6.0	81.8

TABLE 3 PARTICLE SIZE ANALYSIS - BENTHIC SEDIMENT SAMPLES

Particle Size Range (μm)	Weight Percent of Sample		
	Hankin Pt.[1]	Hankin Pt.[2]	Thorp Pt.[2] [3]
+2000	0.6	3.1	20.9
-2000+1000	0.4	2.4	19.3
-1000+500	0.5	1.1	18.9
-500+250	1.1	2.4	13.2
-250+125	28.5	42.4	12.4
-125+63	48.5*	30.8	7.4
-63+43	11.5	4.2	1.1
-43	8.6	13.6	6.8

[1] - Sample collected in July, 1975, analyzed by B.C. Research Council, sediment light grey colour

[2] - Sample collected in November, 1975, analyzed by Environmental Protection Service

[3] - Sediment light brown colour

* - Sample size between -125+38 m showed some pyrite colour

TABLE 4 TERMINAL VELOCITIES OF QUARTZ AND GALENA FREE SETTLING IN WATER AT 20°C

Terminal Velocity		Particle Diameter - μm	
cm sec^{-1}	knots	Quartz	Galena
0.01*	0.0002	10	5
0.05*	0.001	23	13
0.126	0.002	34	20
0.505	0.01	77	41
1.468	0.03	120	72
1.980	0.04	230	103
5.008	0.10	520	170
8.028	0.15	860	280
11.009	0.21	1230	360
15.031	0.29	1680	460
18.057	0.35	1970	580

*Extrapolated by Dr. C. Guarnaschelli, Environmental Protection Service.

of quartz and galena. Data on this table suggests that a vertical velocity of 0.0002 knots (0.01 cm sec^{-1}) will maintain tailings particles less than 10 m diameter in suspension. Moreover, vertical currents of 0.04 knots (1.98 cm sec^{-1}) will maintain all quartz particles less than 230 m in suspension. Thus silt and clay fractions similar to those found in the Island Copper Mill effluent (Johnson, 1974), will remain suspended by very slight current velocities.

4.5 Tidal Currents

Johnson (1974) reported that the "base" up-inlet current velocity near the bed of Rupert Inlet was 0.12 knots (10 cm sec^{-1}). Maximum up-inlet velocity was about 1.75 knots (90 cm sec^{-1}), approximately twice the maximum down-inlet velocity. Johnson postulated that up-inlet currents of up to 6 knots (300 cm sec^{-1}) could occur if the density of the incoming water from Quatsino Narrows exceeded the density of the water near the bottom of Rupert Inlet. Both Johnson (1974) and Drinkwater (1973) concluded that these unusually strong currents along the bottom of Rupert Inlet were caused by the intrusion of higher density water from Quatsino Narrows. The depth to which these currents penetrated was dependent upon the difference in density between the incoming water and that of Rupert Inlet. This being the case, bottom current velocities would vary according to the season and density of the water in Quatsino Sound.

Johnson (1974) also states: "Maximum winnowing of the tailing by bottom current occurs in Rupert gap while currents starting at Quatsino Narrows will continue to erode tailing from below the Narrows. An estimated 7.5% of the tailing have been moved up Holberg Inlet. These tailing are believed largely the result of turbulence below the Narrows raising tailing higher in the water column for transport up inlet by currents. Turbidity caused by very fine tailing is common through much of the water column and throughout the basin to beyond the Straggling Islands.... After mine activity ceases, bottom currents will continue to attempt to excavate the area beneath the Narrows to its present depth."

Recent current measurements (April-May, 1974) by Fisheries and Environment Canada (Stucchi and Farmer, 1976), recorded maximum current velocities of from 1 to 3 knots (51 to 154 cm sec^{-1}) within 5 metres of the bottom between Hankin Point and Quatsino Narrows. Bottom currents were often greater than those measured near the surface or at a depth of 70 metres.

The horizontal current velocities measured between Hankin Point and Quatsino Narrows are capable of lifting and re-suspending benthic deposits which move into the area. Observations of upwelling and the evidence of "turbidity clouds" off Hankin Point, suggest that the currents possess a strong vertical component in this region. On the basis of particle size distribution of recent deposits off Hankin Point, the vertical current velocity must have been at least 0.1 knots (5.1 cm sec^{-1}) for the particles to have been transported upward into the intertidal zone.

4.6 Sources and Distribution of Suspended Solids

Two sources of particulate matter from the Island Copper Mine which are capable of causing a substantial increase in turbidity in receiving waters are the waste rock dump and the mill effluent.

From visual observations, the suspended sediment from the waste rock dump appeared to be confined mainly to the north shore of Rupert Inlet. The more significant source appeared to be the mill effluent; more specifically, the benthic tailings deposits located off Hankin Point, where the surface turbidity field was centered.

Large "turbidity clouds" (Plate 2) at the mouth of Rupert Inlet suggested a direct relationship to the tidal currents from Quatsino Narrows. Both the colour and apparent concentration of materials in these "clouds" suggest that the suspended particles originate from benthic tailings deposits near Hankin Point. This observation was strengthened by noting that surface turbidity at the mouth of Rupert Inlet did not occur until benthic deposits had reached the area off

Hankin Point; and although a subsurface turbidity field developed shortly after commencement of mill operations (Littlepage et al, 1972), the "clouds" were not observed until August, 1973. Had the "clouds" originated from the subsurface turbidity field rather than the benthic deposits, they should have appeared much earlier.

A portion of the subsurface turbidity field in Rupert Inlet appears to come directly from the mine outfall. During the period May 10 to 22, 1974, the Island Copper Mine was shut down due to a labour dispute. The mine resumed production on May 22 using only the tailings discharge; waste rock was not dumped into Rupert Inlet until May 31. This afforded the opportunity to measure transmissibility during shut-down and start-up periods. Transmissometer results are shown in Figure 11 and Appendix I (transmissibility in Rupert Inlet [T-2]).

After twelve days of no effluent discharge (May 22), transmissibility at Station T-2 just offshore from the mine site had improved slightly in comparison to readings obtained in the previous month. Within six days following resumption of tailings effluent discharge, transmissibility had returned to the pattern observed previously during normal mine discharge, i.e., a marked reduction in transmissibility below 40 metres. This indicates that some of the tailings effluent had remained in suspension at the point of discharge and may have been responsible for a portion of the turbidity observed in the lower depths of Rupert Inlet. Upon resumption of the waste rock dumping, transmissibility in the upper portion of the water column at Station T-2 became highly variable.

It should be noted that turbid "boils" were observed off Hankin Point on May 22, after twelve days of no waste discharge. In all probability, turbidity will continue as long as benthic deposits are present in this region and possibly for a considerable time after the Island Copper Mine has closed its operation.

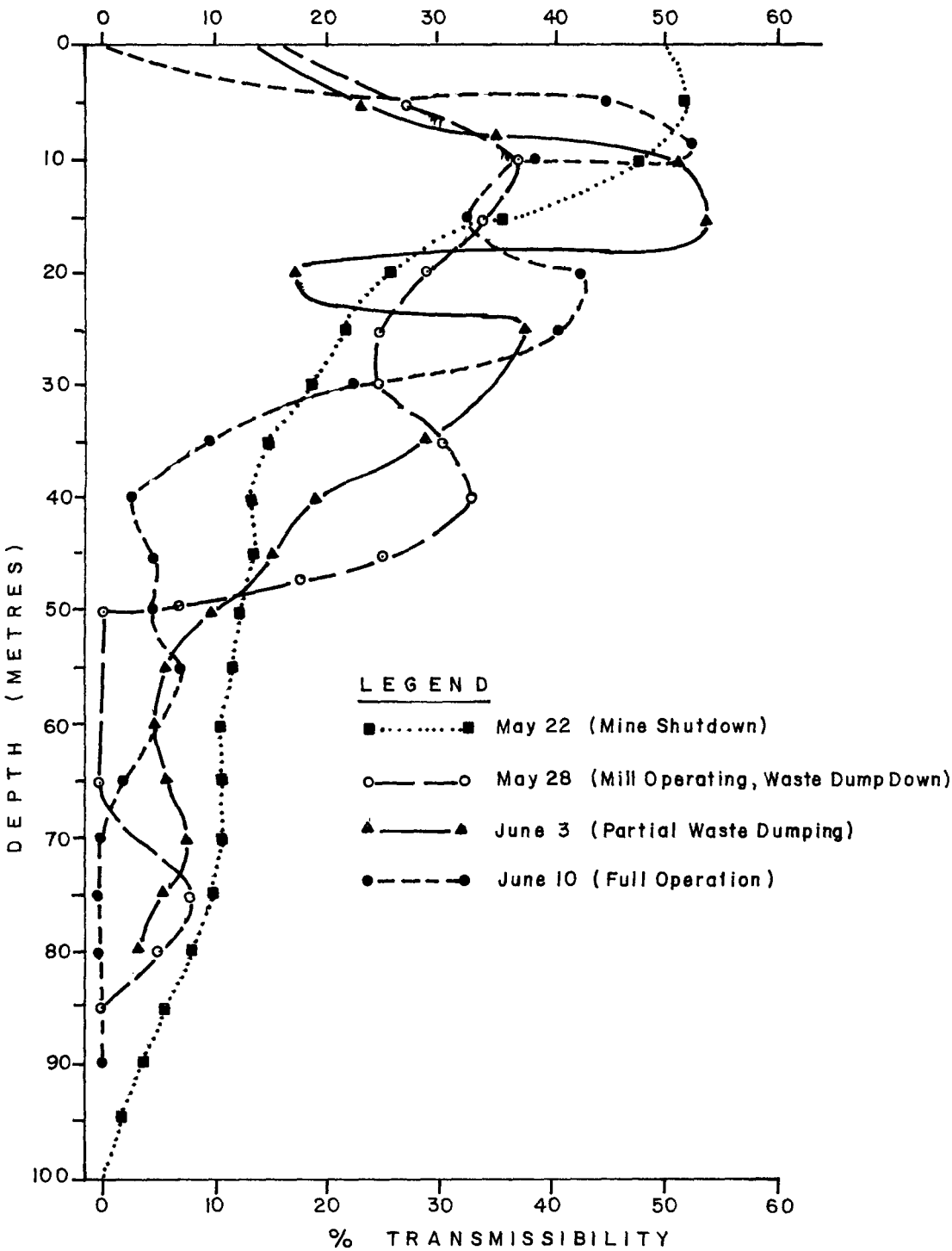


FIGURE 11 TRANSMISSOMETER PROFILES AT STATION T-2, 1974

4.7 Mine Sediment Deposition

4.7.1 Ponar Grab Sampling Data. Observations of surface turbidity revealed that mine sediments were being widely distributed by tidal currents. The presence of abnormally high concentrations of suspended sediment throughout the water column in Rupert Inlet suggested that deposition is taking place at all depths. The distribution of mine sediments on the bottom as determined by Ponar grab sampling since November, 1971, are shown in Figures 12 to 15. Results are presented in Appendix IV.

Mine sediment deposits greater than 2.5 cm in thickness have covered a considerable portion of both Rupert and Holberg inlets within a relatively short period. By October, 1973, deposits had covered most of Rupert Inlet to within 60 metres of the surface (Figure 14). In some regions of Rupert Inlet deposits extended to the shoreline. Ponar grab samples collected from a depth of 19 metres along the south shore near the mouth of Rupert Inlet contained tailings up to 2.5 cm in thickness. Sediment deposits from the waste rock dump were observed along the shoreline of Rupert Inlet near Red Island. In Holberg Inlet deposits extended past Thorp Point, a distance of approximately 11 km from the Island Copper Mine. In 1973, no evidence of tailings was found in grab samples taken from Quatsino Narrows or the mouth of Hecate Cove in Quatsino Sound. These sediment layers had increased in thickness by 1974, as shown in Figure 15. Tailings distribution has been extrapolated from grab sample data collected at 50 stations (not shown) in May, 1974, by Thompson and Patton, and at 19 stations occupied by the Environmental Protection Service in June, 1974. For additional station locations and chemical delineation of tailings deposits, see Thompson and Patton (1975).

Grab sampling surveys in 1973 and 1974, showed that the majority of deposits between Hankin Point and Quatsino Narrows were confined to a narrow area near center channel (Figures 14 and 15).

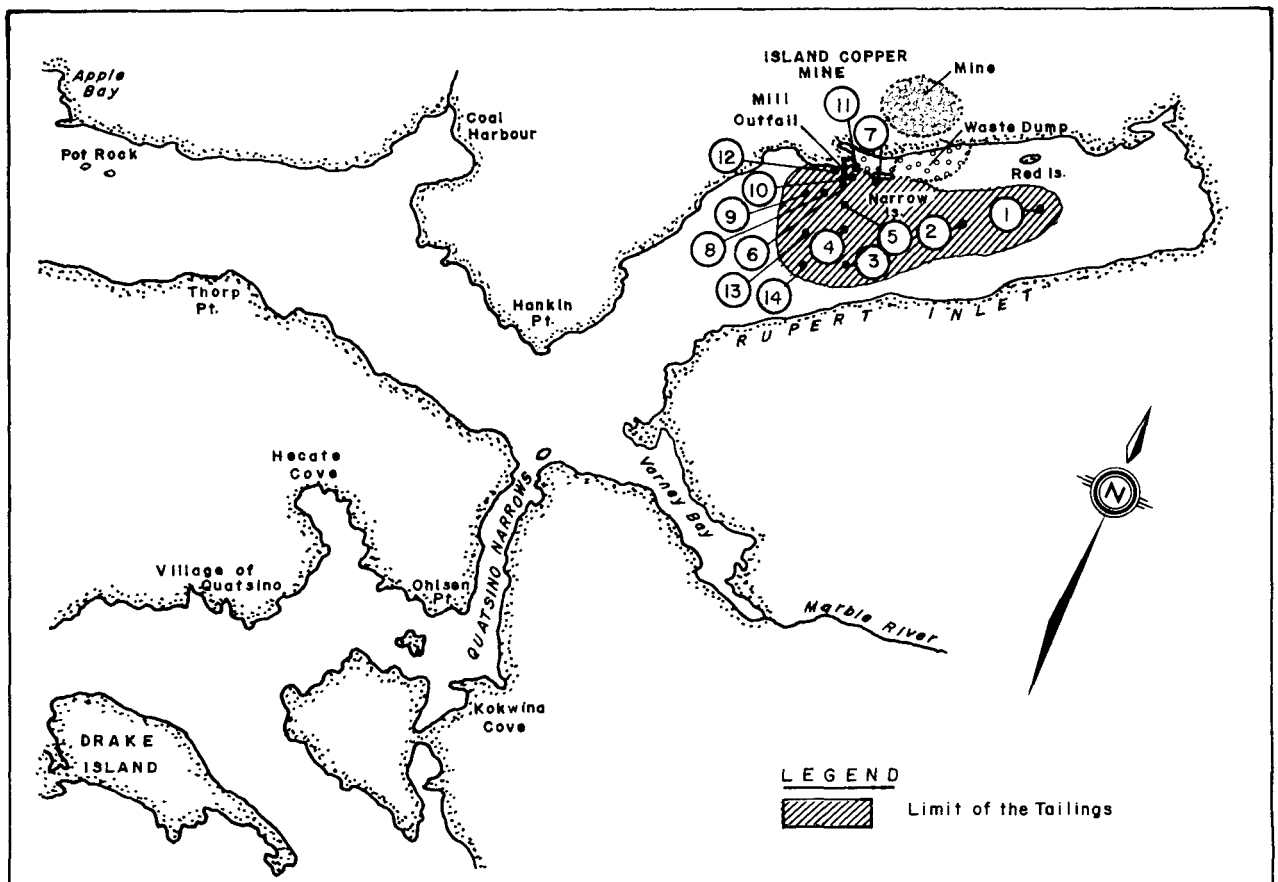


FIGURE 12 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - NOVEMBER 3, 1971

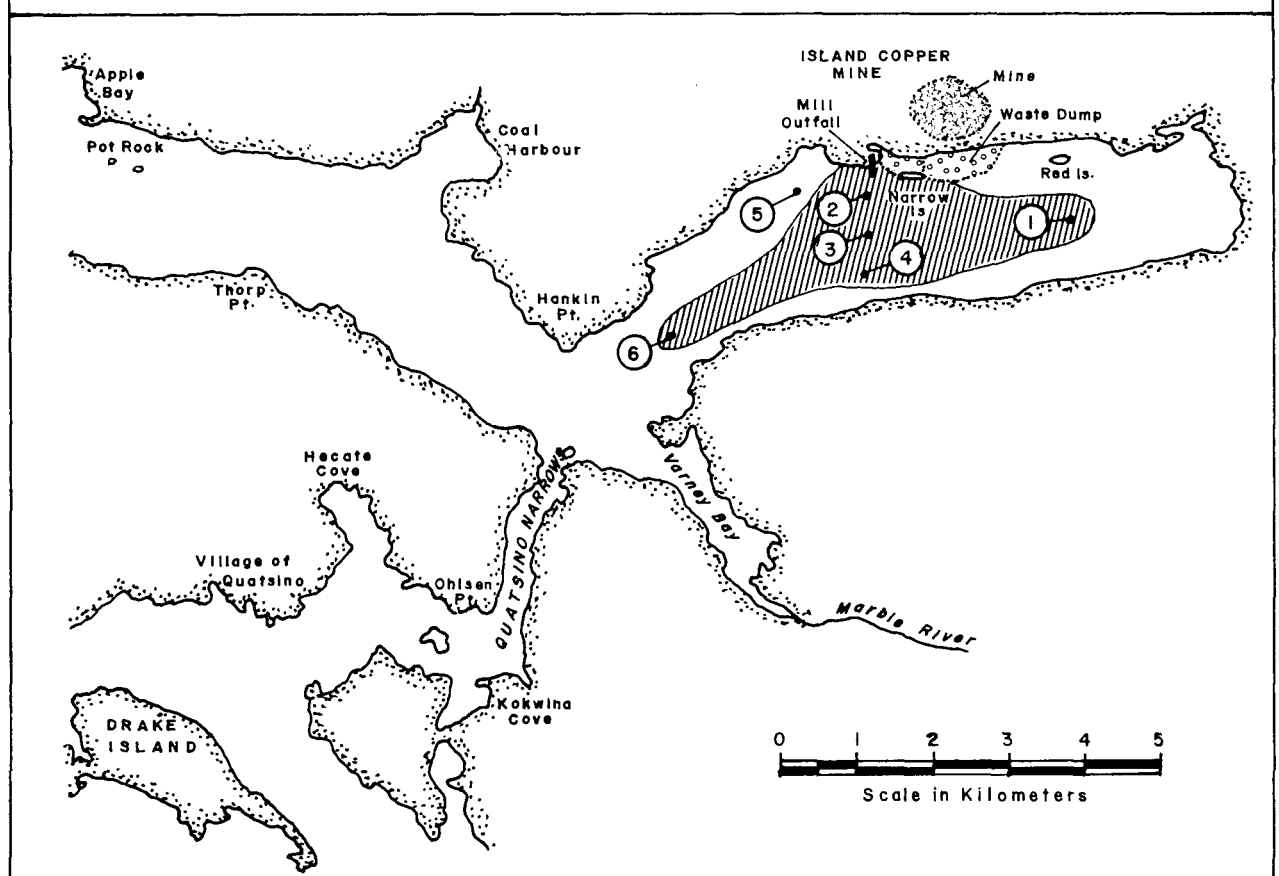


FIGURE 13 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - MARCH 7, 1972

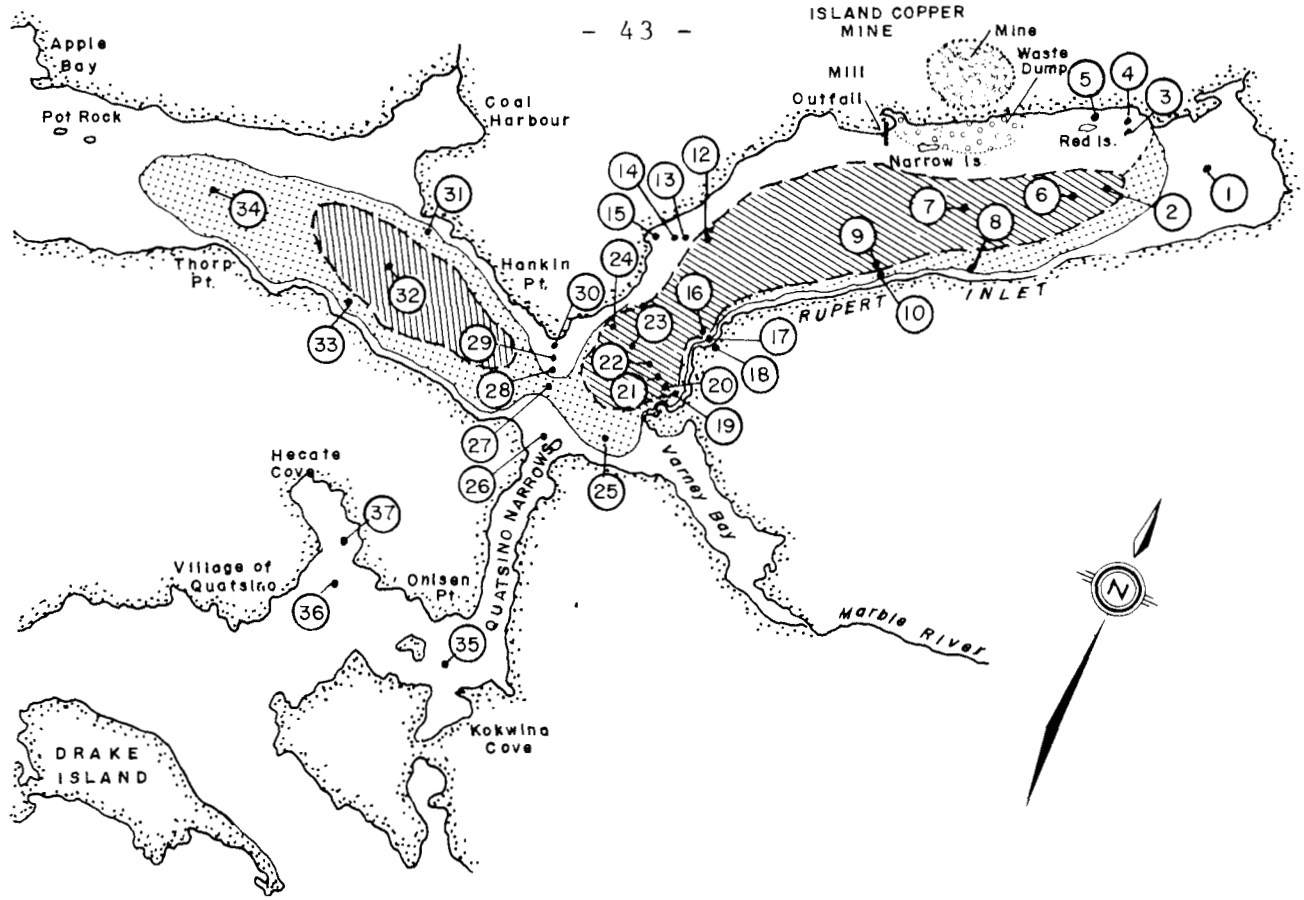


FIGURE 14 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - OCTOBER 6, 1973

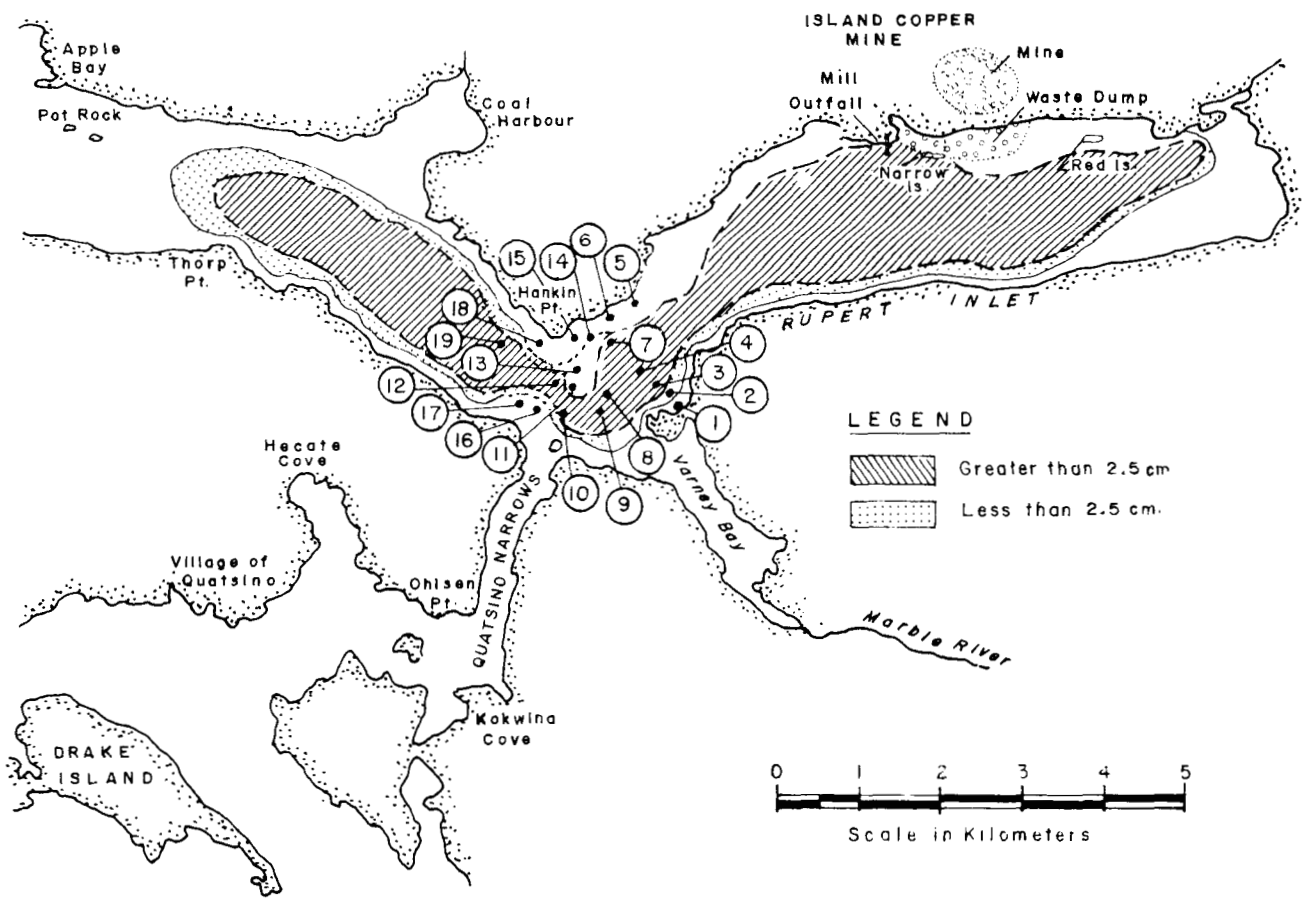


FIGURE 15 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - MAY-JUNE 1974

The channel bed on both sides of the narrow deposition area consisted of coarse sand, gravel or bedrock, with only a trace of tailings solids, thus providing evidence that tidal currents are scouring the bottom in this region.

Chemical analyses of sediments collected off the western end of Quatsino Narrows (Utah, 1973 and 1975) show an increase in the levels of copper (Cu), from 70 mg/l in 1973 to 235 mg/l in 1975. This suggests that tailings deposits now extend into Quatsino Sound. Similar analyses have also shown an increase in copper (Cu) concentrations in sediments near Straggling Island, Holberg Inlet, where levels have risen from 95 mg/l (Utah, 1973) to 167 mg/l (Utah, 1975). Further evidence of the spread of benthic deposits into Holberg Inlet was obtained by submersible, Pisces IV, observations (February, 1975), when light-grey coloured sediment was seen along the bottom from center channel (115 metres) to the south shore at a depth of 60 metres in the vicinity of Pot Rock.

4.7.2 Observations by SCUBA Divers. SCUBA observations since 1973, have revealed a marked increase in sediment deposition in the intertidal and shallow subtidal zones since the commencement of operations at the Island Copper Mine. SCUBA diving locations are shown in Figure 16 and observations (1970 to 1975) are summarized in Appendix V.

In 1973 and 1974, the most seriously affected areas were the north shore of Rupert Inlet and Hankin Point. Along the base of the emergency tailings dam, adjacent to Narrow Island, deposits were up to 1 metre in thickness. This may have been caused by seepage through the rock fill which forms part of the dam.

Sediment deposits had noticeably increased between Red Island and the waste rock dump, where the bottom was covered by a layer of brown mud up to 25 cm thick. Sediment in this area appeared to originate from the waste rock dump and pit runoff. An increase in sediment deposition was also observed in the intertidal zone along the eastern end of Red Island. Mussel beds (*Mytilus edulis*) in this area were partially covered

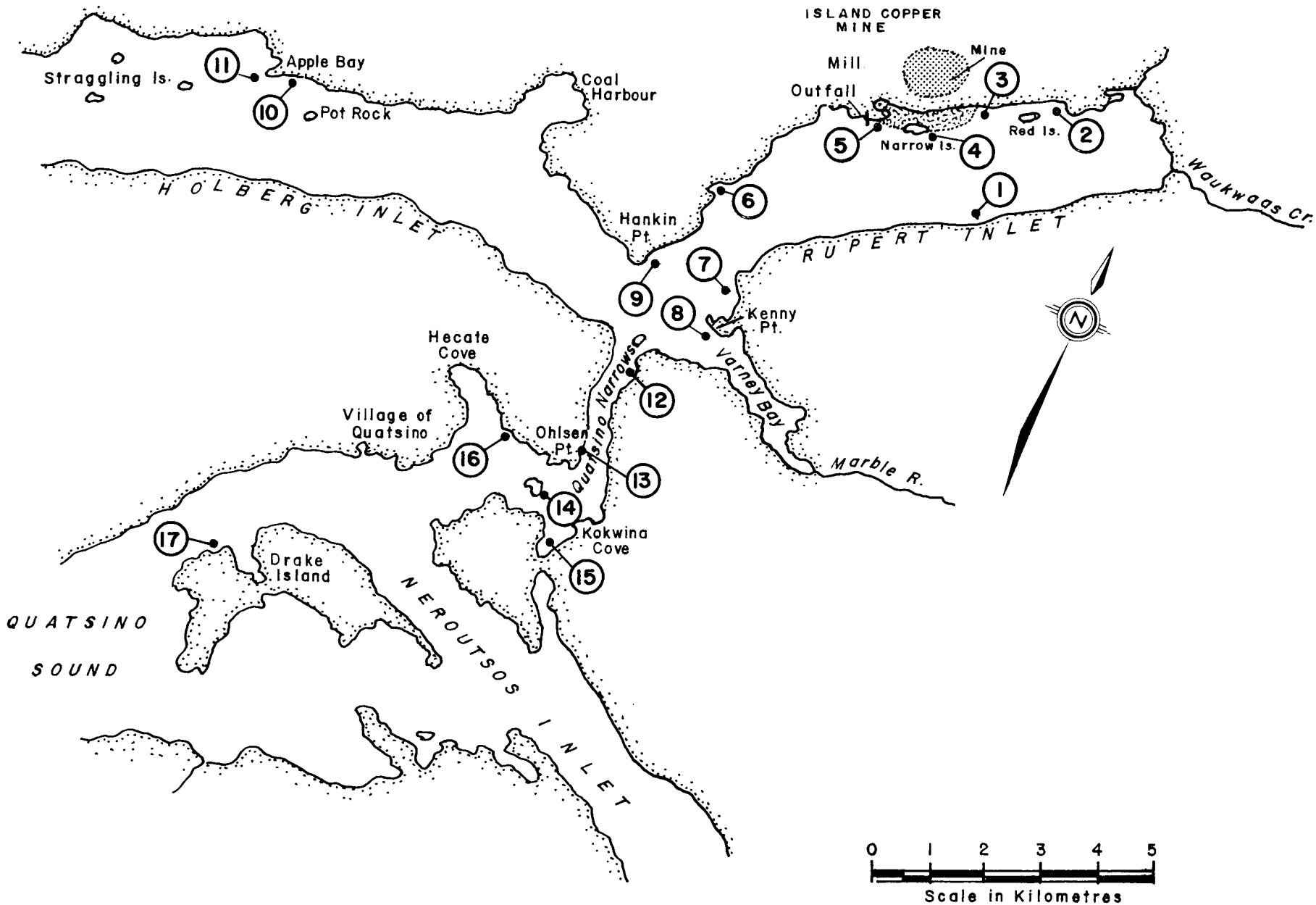


FIGURE 16 SCUBA DIVING STATIONS - 1970-1975

by new sediment deposits, in some places up to 8 cm thick (Plates 12 and 13, see pages 80 to 81). Beneath the surface layer, the sediment was black and had a strong smell of hydrogen sulphide when disturbed. This may have been due to the decomposition of organic material contained in the waste rock dump sediment.

Around Hankin Point, thick deposits of light-grey sediment covered much of the shoreline (Plate 14, see pages 80 and 81). In some areas deposits in the rock crevices and depressions were up to 2.5 cm thick. In Quatsino Narrows a layer of fine silt covered much of the substrate and marine vegetation along the shoreline (Plate 15, see pages 82 and 83), where back-eddies and lower current velocities occur. Light-grey sediment was observed in rock crevices around Ohlsen Point. In Kokwina Cove the bottom and vegetation was heavily silted with up to 2 cm of newly deposited sediment. The recent nature of these deposits was determined by removing the sediment and noting the presence of Lithothamnion sp., a red, encrusting algae which grows only on relatively sediment-free rock surfaces.

SCUBA diving observations in Holberg Inlet in 1973 and 1974, near Pot Rock showed no abnormal increase in sedimentation and the rock ledges were relatively free of sediment. Visibility along the shoreline in this area was very good in comparison to Rupert Inlet and Quatsino Narrows.

Diving observations were repeated in July, 1975, at additional stations located at Drake Island, and the south shore of Rupert Inlet (Figure 16 and Appendix V). Tailings deposited off Hankin Point had increased substantially by 1975. As shown in Plates 16 and 17 (see pages 82 to 83), much of the substrate had been covered by mine tailings. At Station 17 (Drake Island), "clouds" of grey sediment arose whenever the bottom, at a depth of 12 metres, was disturbed, and a light layer of sediment covered much of the vegetation along the shoreline. Along the south shore of Rupert Inlet, across from the mine, deposition remained minimal with only a trace of mine sediment at a depth of 10 metres.

However, at Station 7, east of Kenny Point, a noticeable build-up of fine grey sediment up to 2 cm thick had occurred since 1974. The surface turbidity field seen around Hankin Point often extended into this region.

It is apparent from the SCUBA diving observations that the total area of mine sediment deposition extends well beyond that shown by Ponar grab sampling. Intertidal and subtidal deposition is approximately equivalent to the area of surface turbidity noted during aerial surveys in 1973. The total area of mine sediment deposition determined by SCUBA diving observations and grab sampling represents approximately 9,500 acres (3,846 ha). This includes most of Rupert Inlet, Quatsino Narrows, and portions of Holberg Inlet and Quatsino Sound proper. The thickness of mine sediment deposits ranged from a light film to heavy deposits.

Mine deposits in intertidal and shallow subtidal zones particularly around the mouth of Rupert Inlet appear to be increasing rapidly.

4.8 Biological Impact of Mine Waste Disposal.

The effects of solid waste disposal on coastal seabed strata have been studied and reviewed by the US Army Corps of Engineers (1975). In summary, their findings on the effects of dredge spoil disposal indicate that solids deposition had a more deleterious physical impact on marine biota than did suspended solids. In the case of solids deposition, very little sedimentation was necessary to cause measurable effects on benthic organisms; whereas, for suspended solids, the concentrations required to cause a deleterious effect were normally quite large. In many respects the physical impact of mine waste disposal would be similar to that of dredge spoil disposal.

All aspects of the biological impact which can be associated with mine waste disposal in Rupert Inlet have not been fully assessed, nor has the Island Copper Mine been in operation long enough for all of the potential deleterious effects to fully develop. However, at the

present time, the major biological impact appears to be the burial of marine biota and their habitat by the deposition of both mine tailings solids and fine material from the waste rock dump. Based on the qualitative assessments of the total area affected, the physical impact from mill tailings deposition presents the more serious problem.

4.9 Biological Impact in Intertidal and Shallow Subtidal Zones

4.9.1 Aquatic Habitat and Marine Life. Much of the shoreline habitat in the study area consists of steep sloping bedrock, with numerous crevices and outcroppings. In many areas, particularly where strong tidal currents occur, the rocky surfaces were relatively free of natural sediment deposits.

The variety of habitats provided by this type of substrate plus the extreme tidal mixing which occurs in Quatsino Narrows, promotes a rich growth of marine life along the shoreline. The intertidal and subtidal zones, particularly throughout the Narrows, are heavily populated by a variety of marine invertebrates and algal species. Typical examples are shown in Plate 18, (A-F) see pages 84 and 85. Among the more common macroinvertebrates are the large red and purple sea urchin (*Strongylocentrotus franciscanus*), sea cucumbers (*Parastichopus sp.* and *Cucumaria sp.*), rock scallop (*Hinnites multirugosus*), starfish (*Pisaster sp.*), and a variety of sabellid and serpulid polychaetes.

Benthic algae, e.g., *Fucus* sp. and *Laminaria sp.*, are prevalent, and the rocky surfaces are covered with the pink encrusting algae, *Lithothamnion sp.* Rockfish (*Sebastodes sp.*), kelp greenling, (*Hexagrammos decagrammus*) and lingcod (*Ophiodon elongatus*) are common throughout the study area, especially in Quatsino Narrows. Details of marine organisms observed during SCUBA diving operations are presented in Appendix V.

4.9.2 Impact on Intertidal and Shallow Subtidal Benthos. Substantial deposits of mine sediments have formed on shorelines around the mouth of

Rupert Inlet and the mine area, with lighter deposits extending into Quatsino Narrows and Quatsino Sound.

In areas of heavy deposition, much of the original substrate and resident biota were blanketed by mill tailings. SCUBA observations at Hankin Point (1974) and northeast of Kenny Point (1975) revealed that many of the sessile invertebrates were partially or totally covered by mine sediment. Barnacles in the intertidal zone at Hankin Point (Plate 19) were almost completely buried, and empty barnacle and serpulid polychaete shells were frequently found beneath the layer of sediment. The black colouration on the underside of rocks in this area (Plate 20) suggests that fine tailings particles are restricting water circulation and oxygen transport through the sediment presumably promoting anaerobic conditions. Those invertebrates (polychaetes, barnacles and gastropods) which commonly live under rocks were noticeably absent from certain areas around Hankin Point.

After removing sediment from the bottom strata, the observers exposed many live but covered invertebrates such as chitons, limpets, and snails. Mucus secreting organisms were often coated by a layer of grey silt. Tailings particles were also accumulating around the sieve plate or madreporite on the upper surface of the large sea urchin, conceivably inhibiting water circulation into the body cavity.

From observations off Hankin Point, it appears that only a minor deposit is required to noticeably affect the encrusting algae, Lithothamnion sp., a food source for many grazing invertebrates. Plate 21 illustrates a "dusted" area where mine sediment 0.5 to 1.0 cm thick had covered part of the inlet bed off Hankin Point. In the blackened areas the algae was completely absent; while the white areas show algae in advanced stages of decay. Similar effects were seen in Kokwina Cove (Quatsino Narrows) under approximately 1.0 cm of new sediment.

Heavy siltation throughout much of the Rupert-Holberg system suggests that the observed biological effects around the mouth of Rupert

Inlet will spread into other areas if present turbidity levels and sediment deposition continue. Gradual accumulation and spreading of sediment deposits along the shoreline will seriously reduce available habitat of a large and important segment of the marine community. McDaniel (1973) found that mine tailings adjacent to Britannia Mine in Howe Sound blanketed the original offshore substrate, making it uninhabitable for benthic invertebrate organisms. Similarly, sediment layers developing on rocky shorelines of Rupert Inlet and Quatsino Narrows could prevent the settlement of invertebrate larvae and algae species which require a rocky and stable substrate.

These alterations to the natural substrate in conjunction with the adverse effects on deep benthos (described in sub-section 4.10.1 and 4.10.2) will likely result in a serious impact on the overall biological productivity of the Rupert-Holberg system. These effects will probably persist long after the cessation of mine production, and may become permanent through alterations to the native habitat.

4.10 Biological Impact in the Deep Benthic Zone

4.10.1 Aquatic Habitat and Marine Life. In Quatsino Sound the bottom consisted of soft mud in the deeper areas to coarse sand and gravel in the shallower regions, with an occasional cluster of large boulder or protruding bedrock.

This range of habitat in Quatsino Sound supported an abundance of marine life. During the Pisces IV observations (Appendix II) off Drake Island in February, 1975, numerous crustaceans; e.g., pandalid shrimp (*Pandalus sp.*); squat lobster (*Munida sp.*); echinoderms, e.g., starfish (*Pseudarcaster sp.*, *Crossaster sp.*); sea cucumber (*Parastichopus sp.*, *Psolus sp.*); and a variety of groundfish, e.g., flounder, eelpout, sole, etc., were observed between depths of 25 and 125 metres. Rockfish were seen wherever large boulders were present. Zooplankton were abundant throughout the waters of the study area. The most dominant organisms were chaetognaths (arrow worms) and euphausids. Poor visibility

in Rupert and Holberg inlets limited biological observations, except at the head of Holberg Inlet where numerous shrimps and bottom fish were observed.

4.10.2 Impact on Deep Benthos. Utah Mines Ltd. in their pre-operational brief (Utah, 1971) recognized that tailings disposal would reduce the amount of deep water benthos in both Rupert and Holberg inlets. To monitor this impact, the company began a Ponar grab sampling program in 1970 as part of their quarterly monitoring surveys.

Ellis (1974, UBC Summary Report), after reviewing data compiled by Island Copper Mine, reported that the benthos in the deeper parts of Rupert Inlet had been obliterated for a distance of about 3.2 km down the inlet from the mine site. To determine the zone of obliteration, Ellis based his findings on the number of benthic organisms per grab sample. Ellis (1976, UBC Summary Report) after further review of the Island Copper grab sample data reported the presence of substantial numbers of plankton. He indicated that 50% or more of the organisms counted in certain stations were copepods, which are almost certainly planktonic; other organisms counted may also have been planktonic. This suggests that the original area of obliteration identified by Ellis in 1974 could have been of greater extent had the plankton counts been removed from the data.

Jones (1974), reported an area of "sub-obliteration" consisting of reduced species diversity and abundance, and a decrease in overall benthic productivity fringing Ellis's area of obliteration. This area of "sub-obliteration" may possibly have extended for a further 1.8 km down inlet. Jones estimated benthic production by studying a single species of polychaete, *Ammotrypane aulogaster*, abundant in the area. Population density, biomass, and body length measurements were inversely related to increased tailings deposition. Results indicated that even under light tailings deposition, there is some loss of benthic production.

Polychaetes are more resistant to burial than many other benthic organisms. Oliver and Slattery (1973), during subtidal community experiments, observed that two species of polychaetes were capable of burrowing upward from beneath 30 cm of sediment; whereas, all small bivalves and crustaceans were killed by burial in 15 cm of sediment.

Kranz (1974) studied 25 species of bivalves and found that certain forms were unable to escape from a sediment thickness greater than 1 cm. He concluded that a radical change from the native sediment could be highly lethal by reducing burrowing ability, and often burial in only 1 cm of an exotic sediment was fatal. During submersible studies of abandoned marine tailings disposal sites (Britannia, Yreka and B.C. Molybdenum mines), the authors of the present report noted a marked decrease in the number of burrows and worm castings in comparison to those observed at control sites. This suggested a reduction of infaunal populations, which was maintained even after a mine had been abandoned for 10 years, as in the case of Yreka.

Ellis (1976, UBC Summary Report), following further review of the Island Copper Mine benthos program (to December, 1975), concluded that light tailings deposits (less than 20 cm) may reduce mollusc populations which include many edible species of shellfish. Molluscs were considered to be a sensitive indicator of the effect of tailings in reducing benthic diversity.

Utah Mines Ltd., based on the results of Ponar grab sampling by Beak (1970), concluded that deep water benthos consisted primarily of polychaete worms, small clams, shrimp-like animals (euphausids?), and a number of relatively minor groups. Consequently, much of the emphasis in the company's benthic program to date has been an enumeration and identification of infaunal organisms, as discussed above.

Experimental trawl studies by Butler and Dubokovic (1955), Smith and Butler (1968), and submersible observations made during this study indicate a much more diverse deep water benthic community resident

in the Quatsino Sound area than that implied by Utah Mines Ltd. For example, the studies showed the presence of significant numbers of important commercial species such as shrimp, crab, and ground fish (sole and rockfish).

Studies in Howe Sound by Fisheries and Environment Canada (Goyette and Levings, unpublished), compared the effectiveness of grab sampling and trawling techniques as a means of defining benthic communities. Grab samples did not provide a true representation of the benthic diversity because they selected only a fraction of the number of species present, as compared to trawling. Those species not represented included commercial species of invertebrates (crab, shrimp, prawn) and ground fish (sole and flounder).

Many of the animals observed during submersible dives in Quatsino Sound (Appendix II), are sufficiently mobile to escape sediment burial. However, alterations in native habitat by tailings deposition will likely have a significant effect on the populations and distribution of these animals. For example, many invertebrates and fish showed a preference for rocky or hard coarse substrates. Schools of rockfish were frequently associated with rock outcropping and boulders projecting from the muddy bottom near center channel in Quatsino Sound. This type of habitat in many regions of the system is being inundated by the large volume of mine waste entering Rupert Inlet. This alteration in native habitat coupled with the physical impact of tailings deposition on both deep water and shallow water benthos will likely have a severe affect on biological productivity (i.e., species diversity and abundance) in Rupert Inlet and contiguous waters.

4.11 Heavy Metal Concentrations in Shellfish and Sediments

In addition to the physical impact of mine waste deposition on marine biota, the bio-accumulation and bio-magnification of heavy metals are major concerns, both in their effect on the organism itself and

potential hazards to human health if contaminated organisms are consumed. Molluscan filter-feeders in particular are capable of concentrating potentially toxic heavy metals to levels many times greater than those found in the environment. Contamination can occur by absorption of heavy metals dissolved in sea water, or by ingestion of particles containing heavy metals which may be either suspended or in the sediments on the bottom.

Nelson and Goyette (1976) found high zinc levels (up to 19,000 µg/g, dry weight) in oysters contaminated by groundwood pulp mill effluent. In the vicinity of the Britannia Mine, Howe Sound, oysters and mussels contained an average copper concentration of 2250 and 390 µg/g, respectively (Goyette, 1975). Copper levels in control samples were 380 and 23 µg/g, respectively, for oysters and mussels. Work by Ayling (1974) on the Pacific oyster showed that the tissue heavy metal concentrations were more closely related to those found in the sediment than the overlying water. This suggests that the ingestion of particles suspended in water or derived from the sediment represent a significant source of heavy metal contamination.

Studies by Elderfield and Hepworth (1975) on heavy metals in estuarine sediments, suggested that a process of diagenesis (defined as a recombination of constituents resulting in a new product) occuring in the sediment column caused an enrichment of metals at the sediment surface or in the overlying waters. Consequently the availability of metal particles for ingestion by benthic organisms resident in surface sediment was increased.

Five species of intertidal bivalves were collected annually between 1971 and 1974 in Rupert Inlet at Red Island and a station located west of the mine site and in Holberg Inlet at Apple Bay (Figure 2). Tissues were analyzed routinely for copper and zinc. Results are tabled in Appendix VI.

Copper concentrations in bivalves from both stations in Rupert Inlet, in general, tend to be slightly higher than those from Holberg

Inlet (Apple Bay). The concentrations however do fluctuate from year to year and further sampling will be required before any definite conclusions can be made. The concentrations found in most species are not considered to be very high.

However, there does appear to be an increase in copper concentrations in certain areas and in certain species of bivalve. Ellis (1974, UBC Summary Report) noted a statistically significant high level of copper in mussels, Mytilus edulis, from the Island Copper Mine bulk loading dock. Surface spillage from the loading dock was a suggested source of contamination.

In the present study Macoma iris collected from Red Island between 1971 and 1973 showed considerably higher concentrations (mean = 305 μg/g) than those from Holberg Inlet (mean = 30 μg/g) and the station west of the mine site (mean = 66 μg/g) (Appendix VI). Macoma feeds by filtering bottom sediment rather than material in suspension.

Mussels (Mytilus edulis) collected from Hankin Point in July, 1975 showed higher copper concentrations than those collected from the station west of the mine site, Apple Bay (Holberg Inlet) and Red Island between 1971 and 1973 (Appendix VI). Hankin Point samples ranged from 82 to 150 μg/g Cu, dry wt compared to 5 to 87 μg/g Cu, dry wt found in mussel samples from the other stations. Intertidal sediments from Hankin Point showed a much higher copper level than those from Holberg Inlet at Thorp Point (Table 5). Thorp Point was not subjected to either surface

TABLE 5 HEAVY METAL CONCENTRATIONS - INTERTIDAL SEDIMENT (December, 1975)

Station	Cu	Zn	Pb	Cd	Mn	Ni	Co	Fe
				(μg/g)				(%)
Hankin Point	689	84	8	0.0	388	18	13	3.3
Thorp Point	62	59	13	0.4	308	13	13	2.7
Tailings Effluent	524	254	29	1.7	442	12	13	5.9

*Analysis by Dr. W.K. Fletcher, University of British Columbia

turbidity or mine sediment deposition, whereas, considerable deposition of tailings occurred at Hankin Point. A tailings sample collected in December, 1975 showed a copper concentration of 524 μg/g.

Analysis of marine sediments by Utah Mines Ltd. (Figure 17) and by Thompson and Paton (1975) revealed a widespread increase in many of the metal species, in particular copper. Near the outfall, copper concentration in marine sediment was nearly five times greater than that in tailings effluent (3480 μg/g versus 700 μg/g) (Utah, 1975). Littlepage (1975), reported a similar situation at Alice Arm, where metal levels in marine sediments adjacent to the discharge point were 2.5 to 4 times greater than those found in a tailings sample.

Based on the evidence of increased heavy metal concentration in marine sediment and their potential bioaccumulation into marine organisms, particularly molluscan bivalves, the authors of the present report anticipate that the concentration of certain metals will increase in marine biota exposed to mine sediment deposition.

The biological and human health consequences of increased copper in tissue of marine organisms are unknown. However, a potential for bioaccumulation of heavy metals known to be toxic to humans such as arsenic, lead, and cadmium may exist as these metals are present in the tailings effluent from the Island Copper Mine.

4.12 Commercial Fisheries

The streams in Quatsino Sound support a variety of salmon species. Marble River, which enters near the mouth of Rupert Inlet, is the largest salmon producer in the Rupert-Holberg area. Waukwaas Creek is also considered an excellent spawning stream. Many of the smaller streams in both Holberg Inlet and Rupert Inlet support significant numbers of salmon. Estimates of salmon spawning escapement for the Marble River between 1935 and 1976 are presented in Table 6. The

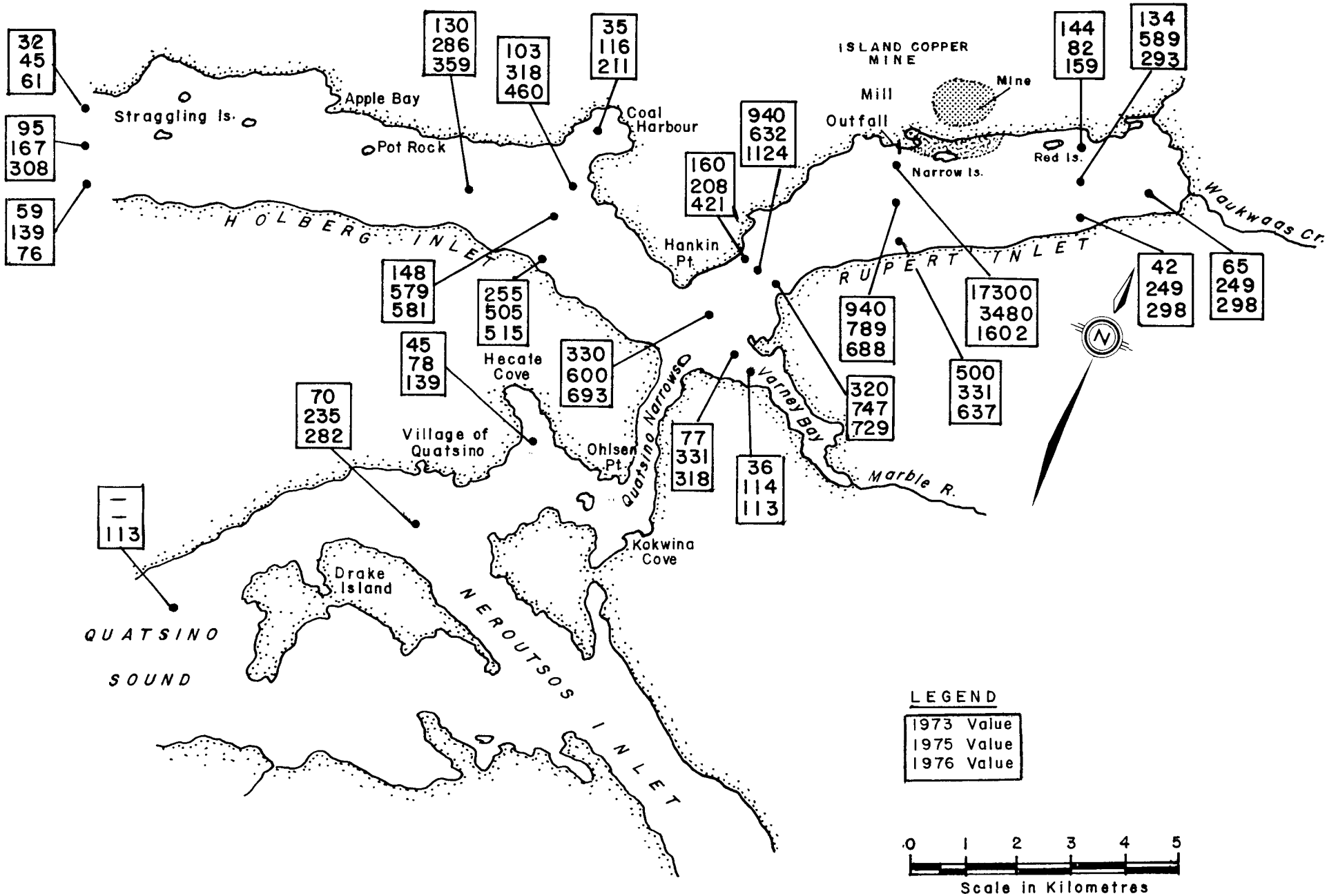


FIGURE 17 COPPER CONCENTRATION IN MARINE SEDIMENTS (µg/g Dry Weight)
(Data extracted from Utah Quarterly Reports 1973, 1975 and 1976)

TABLE 6 ESTIMATES OF SALMON SPAWNING ESCAPEMENT FOR MARBLE RIVER, 1935 to 1976*

Year	Salmon Species				
	Coho	Chum	Pink	Chinook	Sockeye
1976	2000-5000	500-1000	-	300-500	100-300
1975	1000-2000	50-100	50-100	300-500	100-300
1974	2000-5000	500-1000	-	300-500	50-100
1973	5000	4000	-	100-300	
1972	5000	2000		600	
1971	6000	900	0	600	100-300
1970	5000-10000	500-100		300-500	0
1969	5000-10000	100-300	0	100-300	50-100
1968	14000	250	150	200	600
1967	500-1000	1-50		100-300	500-1000
1966	5000-10000			100-300	300-500
1965	10000-20000	1-50	1-50	100-300	1-50
1964	2000	300	1500	3000	2000
1963	1000-2000	300-500		300-500	100-300
1962	1000	100		1500	400
1961	1500			200	25
1960	110	0		40	20
1959	700	200		250	100
1958	3000	400		100	150
1957	5000-10000	400		3500	500-1000
1956	1000	1000	0	5000	1000
1955	750	400		2000	700
1954	1000	1000	500	7500	2000
1952	25000	1000	1000	8000	2000
1951	3300	1000		5500	960
1948	1000	25000	500	7500	600
1947	2000-5000	1000-2000		5000-10000	1000-2000
1946	5000-10000	1000-2000		1000-2000	500-1000
1945	5000-10000	100-300		2000-5000	500-1000
1944	5000-10000	300-500		2000-5000	300-500
1943	5000-10000	2000-5000		2000-5000	500-1000
1942	10000-20000	1000-2000	100-300	2000-5000	500-1000
1941	10000-20000	1000-2000		2000-5000	1000-2000
1940	5000-10000	1000-2000		2000-5000	500-1000
1939	5000-10000	1000-2000		5000-10000	300-500
1938	5000-10000	1000-2000	500-1000	1000-2000	
1937	5000-10000	1000-2000	500-1000	500-1000	300-500
1936	5000-10000	10000-20000	5000-10000	500-1000	
1935	10000-20000	50000-100000	100-300	500-100	1000-2000

*Taken from local Fisheries Officers' records.

majority of the commercial catch of salmon originating from Quatsino Sound takes place off the west coast of Vancouver Island. Salmon are taken in smaller numbers within Quatsino Sound by sport fishermen.

Both adult and juvenile salmon must pass through areas where extremely high turbidity has been observed. Whether or not the concentrations of suspended material are high enough to cause physiological damage or interfere with migration, feeding behavior, or predator prey relationships has not been investigated.

The authors have noted that since turbidity levels in Quatsino Narrows have increased, the frequent observations of what appeared to be feeding frenzies by the resident black rock fish have ceased. This led to the assumption that although these fish were still present in reasonable numbers, as noted by scuba divers, their feeding habits may have changed.

A commercial crab and shrimp fishery operates in the Rupert-Holberg area and in Quatsino Sound. Exploratory trawl fishing by Butler and Dubokovic (1955) in Rupert Inlet yielded a shrimp average fishing rate of 68 lb/hour, consisting of 66% smooth pinks (Pandalus jordani) and the remainder mostly prawns. Stations were located off Red Island and south of Narrow Island in Rupert Inlet. In Quatsino Sound between Brockton and Drake Island, trawl catches yielded an average rate of 42 lb/hour of shrimp.

Smith and Butler (1968) reported shrimp catches between 86 and 270 lb/hour in Quatsino Sound.

The Fisheries Officer at Port Hardy reports (personal communication) shellfish catches in the Quatsino Sound area for the years 1973 to 1976 as follows:

1976 - 7,000 lbs (crab, shrimp)
1975 - 30,000 lbs (crab only)
1974 - 8,000 lbs (crab only)
1973 - 6,000 lbs (crab only)

These figures do not include unrecorded catches taken by local commercial fishermen which the Fisheries Officer estimates could double the magnitude of the catch. The physical impact of mine waste disposal on the native habitat of benthic marine biota which includes certain commercially important species has been discussed in Sections 4.9 and 4.10.

4.13 Relationship to Other Studies

The granting of Utah Mines Ltd's Provincial Pollution Control Branch permit included provision for a comprehensive environmental monitoring program to be carried out by the company. The program is directed by an independent agency which is co-ordinated by J.B. Evans, Head of the Department of Mineral Engineering, University of British Columbia. The monitored program data is reported quarterly by the company and summarized annually by the independent agency. Evans and Poling (1975) and Pelletier (1977) have discussed the Island Copper Mine (I.C.M.) program, which is outlined in Table 7 (extracted from Pelletier, 1977), and includes the routine investigation of a wide variety of physical, chemical and biological parameters in the study area. In this section of the present report the authors discuss possible reasons for differences between their conclusions and those reported in other studies.

With regard to the overall environmental impact in the study area, Evans and Poling (1975) concluded that, "...throughout the initial 3½ years of production, except for benthos obliteration occurring in the Rupert Inlet trough, as yet, the discharge of 35 million tons of tailings solids into Rupert Inlet has resulted in minimal detectable change to the

TABLE 7 OUTLINE OF ENVIRONMENTAL CONTROL MONITORING PROGRAM*

Marine Program 1977

	Description	Frequency	Objective
PHYSICAL			
Bottom Sediment Distribution			
Bottom Coring	Cores at 24 stations - log and measure tailings thickness on bottom	Quarterly	Visually determine tailings distribution less than 2 feet in thickness
Bottom Grab Sampling	Sediment sample for heavy-metal analysis	Annually	Chemically delineate the spread of tailings
Seismic Survey	Bottom profile and sediment distribution	Annually	Record tailings greater than 2 feet in thickness
Suspended Sediment Distribution			
Discrete Water Samplings	Water samples collected in profile at 7 stations for turbidity measurements	Monthly	Delineate suspended sediment distribution
Discrete Water Samplings	Water samples collected at 7 stations for suspended sediment analysis	Quarterly	Quantify suspended sediment load
Transmissometer Survey	Continuous in situ profiling of water column	Bi-weekly in Rupert Inlet	Delineate turbidity
		Annually throughout system	Clouds in water column
Fixed Suspended Sampler Survey	At 4 stations and two depths (30' and 60') sedimentation is monitored	Quarterly	To identify and quantify sedimentation at 30' and 60' (feet)

* Extracted from Pelletier (1977).

TABLE 7 OUTLINE OF ENVIRONMENTAL CONTROL MONITORING PROGRAM* (Cont.)

Marine Program 1977

	Description	Frequency	Objective
CHEMICAL			
Chemical Water Analysis			
Discrete Water Sample	At 7 stations profile temperature, salinity and turbidity. Color and surface transparency are also measured	Monthly	Record water-column physical properties
Discrete Water Sample	At 7 stations profile dissolved oxygen, pH, alkalinity, salinity, spent sulphite, cyanide dissolved and particulate Cu, Mo, Fe, Mn, Ni, Pb, Zn, Cr, Co, Cd and totals As, Hg	Quarterly	Record water-column chemical properties
BIOLOGICAL (PLANTS)			
Primary Prodution Study			
Euphotic Depth Survey	Measure amount of light attenuation and scatter at depth	Monthly	Record depth of photozone in the water-column
Discrete Water Sample for Nutrients	Collect water samples at 6 stations for nutrients	Monthly	Record nutrient levels in water-column
Carbon^{14}	At 6 stations monitor the assimilation rate of primary producers	Monthly	Record assimilation rate of prime producers
Chlorophyll 'a'	At 7 stations collect sample chlorophyll 'a' standing crop	Monthly	Record standing crop of primary producers in water-column
Macrophyte Study	At 3 sites detailed samples of flora & fauna	Annually	Monitor plan communities at depth

* Extracted from Pelletier (1977).

TABLE 7 OUTLINE OF ENVIRONMENTAL CONTROL MONITORING PROGRAM* (Cont.)

Marine Program 1977

	Description	Frequency	Objective
Intertidal Plate Study	At 16 sites artificial samples are set for continuous monitoring	Monthly	Monitor settling organisms and flora in intertidal zone
Metal Analysis of Fixed Algae	At 16 sites *Fucus* is collected and retained for metal analysis (Cu, Mo, Cd, Pb, Zn, As, Hg)	Quarterly	Monitor metal concentration in primary producer
BIOLOGICAL (ANIMALS)			
Zooplankton	At 4 sites collect zooplankton for density, diversity and metal analysis	Quarterly	Monitor population changes and metal concentration
Benthic Organisms	Benthic organisms collected at 24 stations - sort to polychaetes, mollusc and other aboard ship for live counts and biomass	Quarterly	Monitor benthic population and diversity
	At 4 stations collect benthic samples for species-diversity study	Quarterly	Monitor benthic population and diversity
	At each of 24 stations collect 3 samples for detailed identification	Annually	Monitor in detail, change in benthic communities
Crabs	At 6 stations collect crab samples to determine body condition and metal concentration	Quarterly	Monitor crab population and metal content
Shrimps and Prawns	At 3 locations collect shrimps and prawns for metal concentration	Annually	Monitor metal content
Intertidal Invertebrates			
Clams	Collect clams at 9 sites, identify, weigh, measure and analyze for metals	Quarterly	Monitor body condition and metal content

* Extracted from Pelletier (1977).

TABLE 7 OUTLINE OF ENVIRONMENTAL CONTROL MONITORING PROGRAM* (Cont.)

Marine Program 1977

	Description	Frequency	Objective
Mussels	Collect blue mussels at 3 sites. Measure, weigh, and analyze for metals	Quarterly	Monitor body condition and metal content
Fish			
Intertidal Fish	At 7 intertidal sites sculpins are collected by beach seining. Identify, weigh, measure and analyze for metals	Semi-Annually	Monitor metal content
Bottom fish	Longlines set at 4 stations to collect bottom fish. Identify, weigh, measure, sex, and analyze for metals	Semi-Annually	Estimate population and monitor metal content
	At 6 sites jigging is done to collect reef-dwelling and bottom species. Identify, weigh, measure, sex, and analyze for metals	Semi-Annually	Monitor metal content
Pelagic Fish	At 5 sites gill nets are set to collect pelagic species. Identify, weigh, measure, sex, and analyze for metals.	Semi-Annually	Monitor metal content

* Extracted from Pelletier (1977).

natural marine ecosystem." Furthermore, Pelletier (1977), based on I.C.M. marine monitoring data stated:

1) "A sediment distribution system exists which funnels tailings down inlet into the deepest part of Holberg Inlet.
2) Generally turbidity does not exist at levels that affect primary production
3) No detectable increases in dissolved metals have occurred in the water column of Rupert Inlet, Holberg Inlet nor Quatsino Sound.
4) There is evidence that benthic organisms will recolonize areas obliterated by tailings upon completion of the mining activity."

Pelletier further stated that: "Realizing that the tailings have an impact on the environment, data to-date suggests that the disposal system can exist in reasonable harmony with the marine environment."

In addition, annual summaries by the independent agency, although reporting some environmental changes (e.g., tailings upwelling, benthic obliteration) which have occurred, have not indicated any major environmental problems.

In contrast to these previous studies, investigations by the Environmental Protection Service revealed that the existing and continuing environmental degradation represents a serious problem, particularly the impact on the total benthic community (infauna, epifauna and demersal fish). Several explanations which may account for the divergence of opinion concerning the degree of environmental degradation include:

1. Turbidity

Results of the Environmental Protection Service studies indicate that surface and subsurface turbidity and tailings upwelling is much more extensive and frequent than suggested by the company and the independent agency.

Evans and Poling (1975) reported "mist-like" turbidity layers within the water column, and that on occasion turbidity boils reached the surface off Hankin Point, a phenomenon which predominated during the Equinoxes. Pelletier also reported a "mist-like" turbidity field below 50 metres and an upwelling of tailings near Hankin Point on occasional high tides during deep water exchange.

In contrast, the present study reports extensive surface and subsurface turbidity even during a less than average (2.8 metres) tidal exchange (Plates 1 to 8 and Sections 4.1 and 4.2). These plates were taken on a day when the tidal exchange was approximately 2.5 metres.

2. Nearshore Tailings Deposition

The I.C.M. monitoring program has not adequately defined the extent, nor biological impact of nearshore tailings deposition.

Tailings upwelling off Hankin Point and the resultant increase in surface and subsurface turbidity levels indicated that tailings deposition had extended beyond the pre-operational predicted limits. This has led to extensive nearshore tailings deposition in certain regions and gradual deposition encroachment over a larger, highly productive area. A study undertaken by the independent agency (Forman, 1976, UBC Summary Report) was designed to determine the impact of mine activities on the nearshore benthic biota. Sampling station locations, however, did not correspond with the relevant areas, e.g., Hankin Point and around the mouth of Rupert Inlet, where the greatest nearshore deposition was occurring, nor was the outward movement of tailings through Quatsino Narrows investigated. Ellis (1977), reported tailings upwelling at the Rupert - Holberg junction and the re-deposition in localized shallow beds. He also indicated transport through Quatsino Narrows to Quatsino Sound but the magnitude of emigrating tailings and their dispersion pattern and impact were not known in detail, consequently, the requirement for mitigating control measures was not assessed.

3. Island Copper Mine Benthos Program

Many of the statements and conclusions made by the company and the independent agency were based on I.C.M's benthic studies. Problems inherent in the company's benthos program are discussed below and in Section 4.10.2 of this report.

(a) It was previously recognized that the disposal system would result in the reduction or elimination of many marine organisms living in the deeper portions of Rupert and Holberg inlets. A pre-operational study carried out on behalf of the company (Beak, 1970) indicated that the benthic community was dominated by marine worms and the balance of the animal populations on the bottom of Rupert Inlet consisted of small clams, shrimp-like animals and a number of relatively minor groups. As discussed previously the authors consider this inadequate since the definition of bottom life in the area was based on the results of Ponar Grab sampling.

(b) Detailed analysis of the benthos data has been largely confined to the identification and enumeration of organisms which live in the sediments, i.e., infauna. The impact of smothering, and that of physically altering the habitat of other members of the benthic community have not been adequately considered. Other members include groundfish and epifaunal macroinvertebrates such as shrimp, prawns, and crabs. Conclusions drawn from the company's benthos program have been applied to the total benthic community when, in fact, they are only applicable to species of infauna collected in grab samples.

(c) Determination of obliterative effects based on the company's benthic data may be inaccurate and conservative, due to the inclusion of planktonic species. Benthic data for September 1974 (Ellis, 1976, UBC Summary Report) indicated a "general pattern of much benthos" at three stations where heavy tailings deposits had been recorded. Ellis, on reviewing the data states, "...the organisms present at

these stations were 50% or more copepods, which are almost certainly planktonic. The stations are devoid of molluscs, which are benthic, and have few polychaetes which are usually benthic."

The overall benthic data for 1975 indicated that benthic reduction had occurred at only two stations. However, when only mollusc data was analysed, reduced counts appeared at eleven stations. Ellis concludes that "...mollusc counts per sample appear to be the most sensitive, and practical benthic monitoring index derived to date by the program." He further stated that the benthic sampling to 1975 strongly suggests that even light tailings deposits can reduce mollusc populations, including many edible species of shellfish.

Pelletier (1977) by averaging total benthic invertebrate counts from all stations in Rupert and Holberg inlets concluded that, although a general reduction in the number of benthic invertebrates after six months of discharge was evident, the last two years indicated a return to the pre-operational level of 100 organisms per square foot. This implies that the overall benthic community in the Rupert - Holberg system during the operational life of the mine has not been significantly altered and is therefore subject to recolonization. The independent agency (UBC Summary Report, 1976) suggests that data indicating natural recolonization may be "confounded" by including plankton (as discussed previously) or by changes in sampling procedure. Observations at abandoned marine tailings disposal sites by the present report authors have shown a marked reduction in burrowing activity which suggests that infaunal recolonization was limited.

4. Other Data

A considerable volume of data has been compiled in the Island Copper Mine monitoring program on such parameters as dissolved metals in seawater, zooplankton abundance, chlorophyll 'a' levels, and effluent

toxicity. These data have not revealed any deleterious impact attributable to the mine waste disposal system. The present report authors feel that the extensive data on these parameters (excluding benthos) tends to obscure the significance of the impact on benthic biota and their habitat, which is presently the major area of environmental concern in Rupert Inlet and contiguous waters.

PLATES 1 TO 21

PLATE 1 SURFACE TURBIDITY AROUND THE NORTHERN END OF QUATSINO NARROWS AND MOUTH OF RUPERT INLET, August 3, 1973

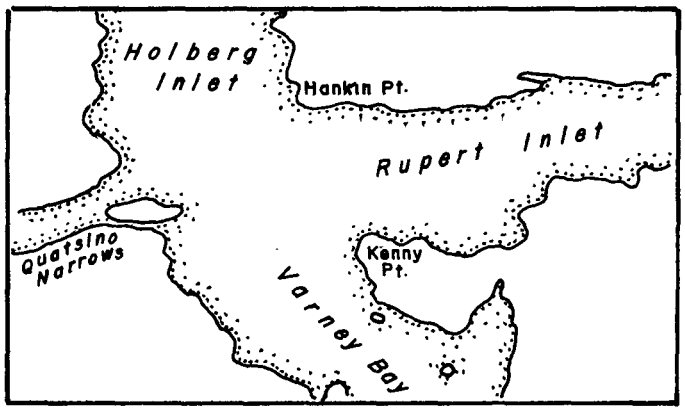


PLATE 2 "TURBIDITY CLOUDS" OFF THE MOUTH OF RUPERT INLET, August 3, 1973

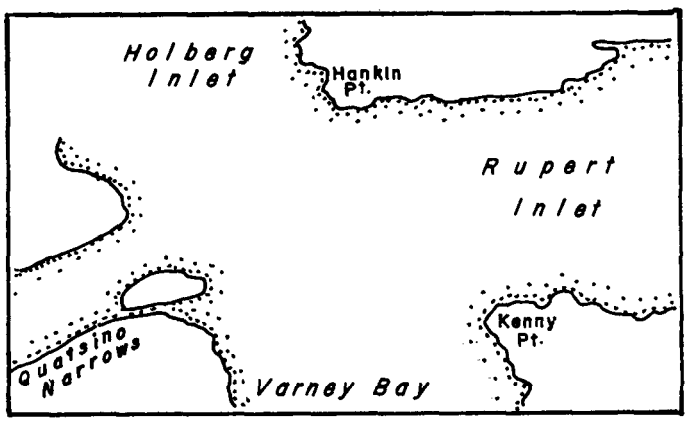


PLATE 3 TURBIDITY FIELD OFF HANKIN POINT, August 3, 1973

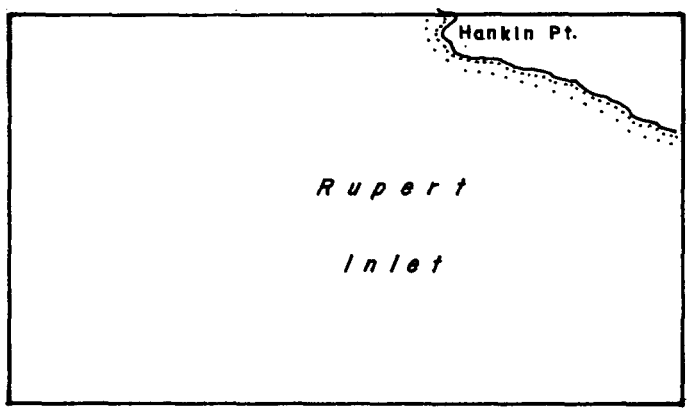


Plate 1

Plate 2

Plate 3

PLATE 4 REDUCTION IN SURFACE TURBIDITY WEST OF MINE SITE, RUPERT INLET, August 3, 1973

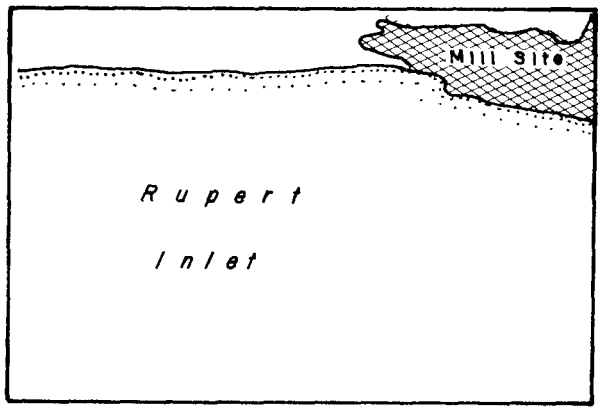


PLATE 5 SURFACE TURBIDITY AROUND THE WASTE DUMP AND EMERGENCY TAILINGS IMPOUNDMENT, August 3, 1973

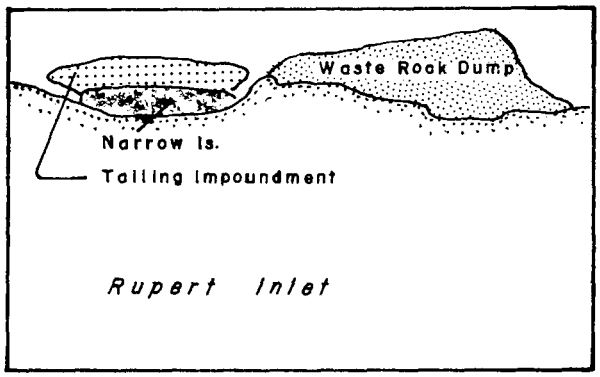


PLATE 6 SHORELINE EAST OF THE WASTE DUMP (UPPER LEFT), August 3, 1973

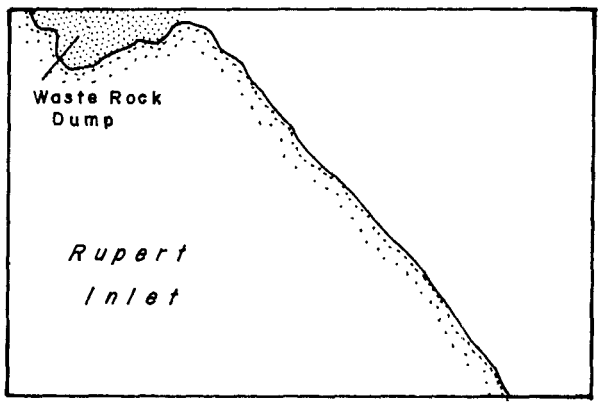


Plate 4

Plate 5

Plate 6

PLATE 7 SURFACE TURBIDITY IN THE WESTERN PORTION OF QUATSINO NARROWS, August 3, 1973

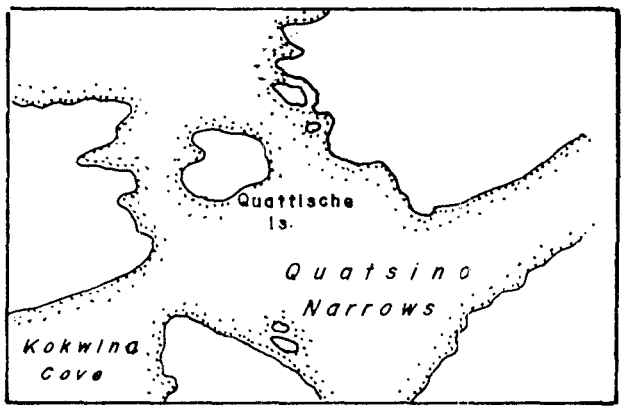


PLATE 8 SURFACE TURBIDITY IN QUATSINO SOUND OFF DRAKE ISLAND, August 3, 1973
(Note the break in surface turbidity as a result of the intrusion of water from Neroutsos Inlet.)

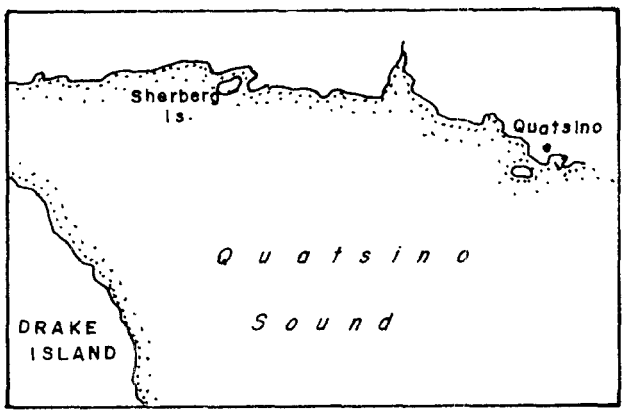


Plate 7

Plate 8

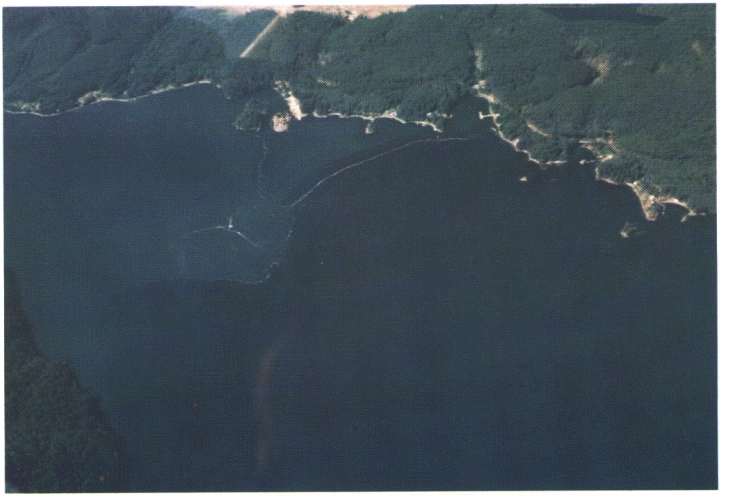


PLATE 9 EXTENSION OF TURBIDITY FROM THE NORTHERN END OF QUATSINO NARROWS DURING EARLY FLOOD TIDE, May 8, 1974

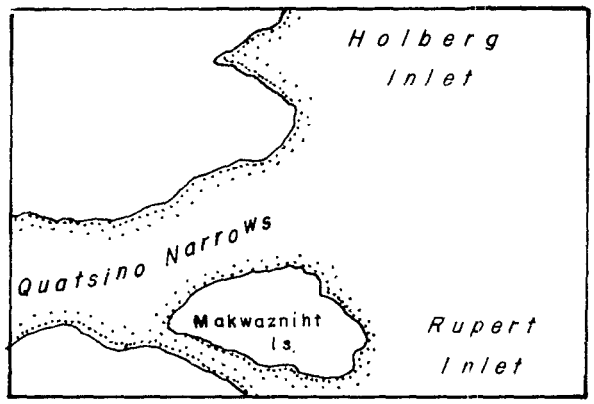


PLATE 10 TURBID "BOILS" OFF HANKIN POINT DURING THE LATE FLOOD TIDE, May 8, 1974

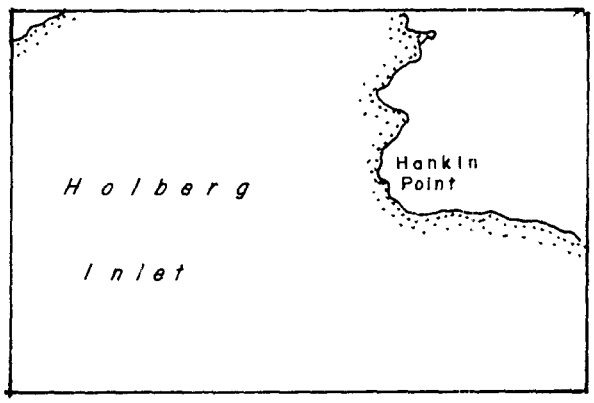


PLATE 11 WASTE DUMP TURBIDITY, May 8, 1974

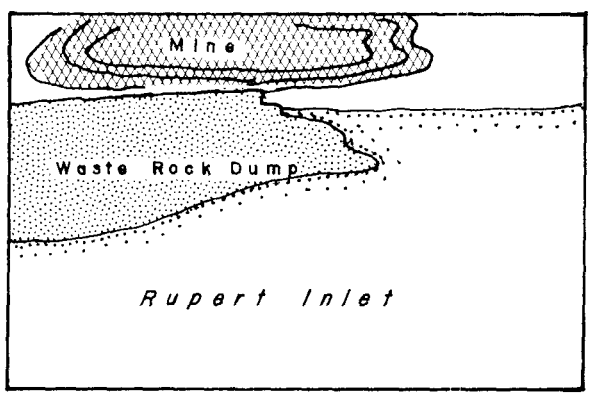


Plate 9

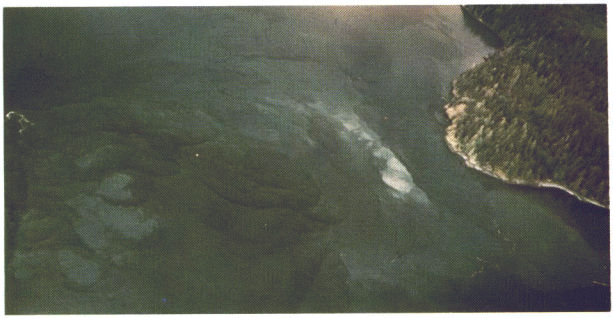


Plate 10

Plate 11

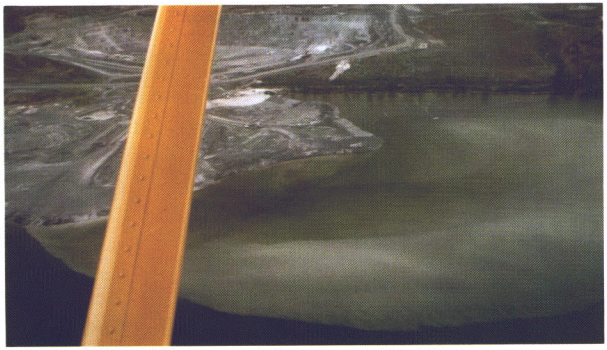


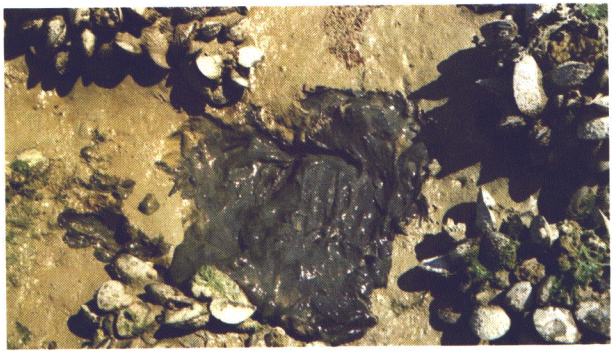
PLATE 12 MUSSEL BED ON RED ISLAND SHOWING WASTE DUMP SEDIMENT DEPOSITS

PLATE 13 MUSSEL BED ON RED ISLAND, SURFACE SEDIMENT REMOVED

PLATE 14 HANKIN POINT SHOWING TAILINGS DEPOSITS IN THE INTERTIDAL ZONE

Plate 12

Plate 13



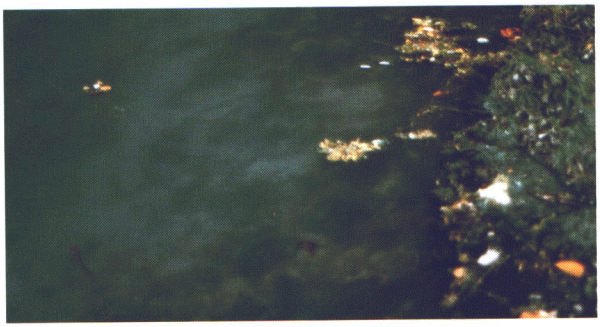


Plate 14

PLATE 15 KELP COATED IN FINE SILT, KOKWINA COVE, QUATSINO NARROWS

PLATE 16 TAILINGS DEPOSITS AT HANKIN POINT

PLATE 17 TAILINGS BUILD-UP, HANKIN POINT

Plate 15

Plate 16

Plate 17

PLATE 18 TYPICAL EXAMPLES OF MARINE LIFE AND BOTTOM CONDITIONS IN QUATSINO SOUND

A. Sea Urchin, *Strongylocentrotus franciscanus*, and star fish *Henricia leviuscula*.

B. Starfish, *dermasterias imbricata*

C. Tubiculous Polychaetes (Serpulids, Sabellids)

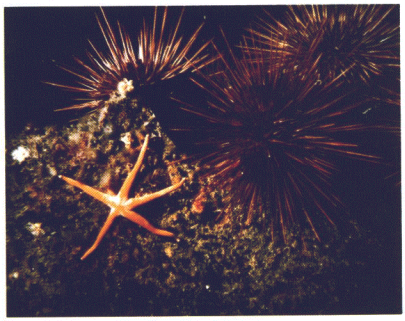
D. Sponge

E. Rock Crab, *Cancer productus*

F. Nudibranch, *Triopha carpenteri*

Plate 18

A



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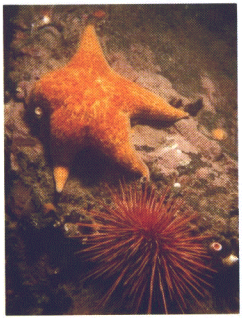

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D

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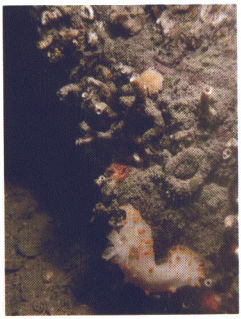


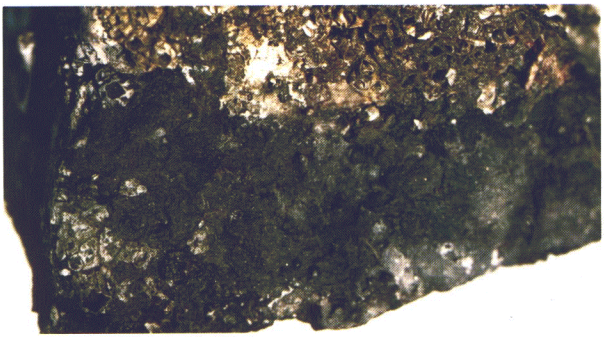
PLATE 19 BARNACLES WITH A COVERING OF MINE SEDIMENT, HANKIN POINT

PLATE 20 ROCK SURFACE BLACKENED UNDER FINE SEDIMENT

PLATE 21 DEGENERATION OF ENCRUSTING ALGAE

Plate 19

Plate 20



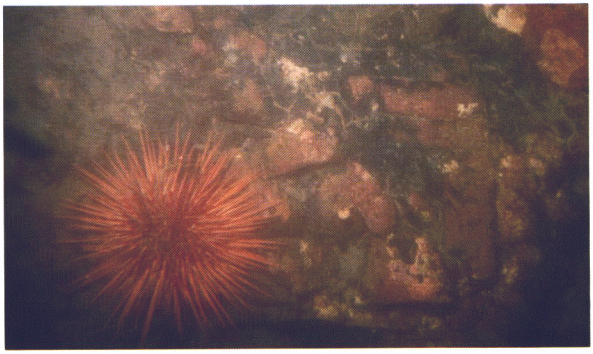


Plate 21

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ACKNOWLEDGEMENTS

The authors of this report wish to express their appreciation to Messrs. D. Brothers and D. DeMill and Ms. D. Sullivan of the Environmental Protection Service, for their assistance during the field studies and data analysis.

The assistance and cooperation of Capt. R. Jones and the crew of M.V. Pandora II, and the pilots of submersible, Pisces IV, are gratefully acknowledged.

Thanks are also due to Drs. I. Birtwell and J. Davis of the Fisheries and Marine Service for their review and comments regarding the technical contents of the report, and to Ms. C. Manness for her help in preparing the manuscript.

The cooperation provided by Utah Mines Ltd. during the study is also gratefully acknowledged.

APPENDIX I

PERCENT TRANSMISSIBILITY* AND TIDAL CURVES FOR TRANSMISSOMETER SURVEYS

(a) Percent Transmissibility - November 8, 1973
(b) Percent Transmissibility - April 23, 1974
(c) Percent Transmissibility - May 22, 1974
(d) Percent Transmissibility - May 28, 1974
(e) Percent Transmissibility - June 3, 1974
(f) Percent Transmissibility - June 10, 1974
(g) Changes in Percent Transmissibility During a Tidal Cycle in Rupert Inlet - July 16, 1976
(h) Tidal Curves for Transmissometer Surveys

*One-metre light path used.

APPENDIX I PERCENT TRANSMISSIBILITY

(a) November 8, 1973

Depth (m)	Station/Time (PST)				
	T-1 0925	T-2 0800	T-3 1140	T-4 1240	T-2A 0845
0	32	38	40	40	33
5					
10	40	34	40	50	38
15					
20	43	49	36	49	50
25					
30	53	53	39	44	49
35					
40	42	47	36	42	46
45					
50	11	37	29	42	37
55					
60	10	30	28	32	26
65					
70	13	20	24	37	24
75					
80	12	0	18	56	21
85					
90	6	0	16	63	18
95					
100		0	12	67	
105					
110			13	45	
115					
120			12		
125					
130			15		
135					
140					
145					
150					

APPENDIX I PERCENT TRANSMISSIBILITY

(b) April 23, 1974

Depth (m)	Station/Time (PST)				
	T-1 1825	T-2 1500	T-3 0900	T-4 1225*	T-5 0830*
0	0	0	0	0	17
5	9	25	3	0	18
10	30	35	15	48	19
15	34	29	12	55	18
20	23	24	14	61	18
25	11	19	17	57	18
30	9	15	17	53	18
35	3	11	19	43	19
40	0	8	20	39	
45	0	6	20	38	
50	0	6	22	35	
55	0	5	22	35	
60	0	4	22	35	
65	0	4	17	34	
70	0	4	18	34	
75	0	5	18	34	
80		0	17	31	
85		0	17	31	
90		0	16	31	
95			16	28	
100			15	25	
105			14	27	
110			13		
115			13		
120			14		
125			15		
130			14		
135			14		
140			13		
145			12		
150			12		

* Sampling date - April 24, 1974

APPENDIX I PERCENT TRANSMISSIBILITY

(c) May 22, 1974

Depth (m)	Station/Time (PST)				
	T-1 1520	T-2 1505	T-3 1450	T-4 1610	T-5 1435
0	46	50	47	53	37
5	51	52	38	65	38
10	53	48	38	66	38
15	53	36	34	66	39
20	47	26	36	68	41
25	47	22	33	66	44
30	42	19	32	57	52
35	37	15	28	48	58
40	33	14	25	41	60
45	30	14	25	38	
50	27	13	23	36	
55	23	12	23	34	
60	21	11	24	33	
65	19	11	25	31	
70	16	11	27	30	
75	15	10	31	29	
80	12	8		27	
85		7		27	
90		4		27	
95		2		27	
100				26	
105				24	
110				17	
115					
120					
125					
130					
135					
140					
145					
150					

APPENDIX I PERCENT TRANSMISSIBILITY

(d) May 28, 1974

Depth (m)	Station/Time (PST)				
	T-1 1600	T-2 1530	T-3 1130	T-4 1020	T-5 1250
0	22	16	8	0	18
5	32	27	2	28	20
10	35	37	20	53	20
15	31	34	25	33	20
20	30	29	24	30	20
25	29	25	23	27	20
30	28	25	22	25	20
35	27	30	21	24	20
40	26	33	18	25	
45	25	25	18	24	
50	26	0	19	25	
55	23	0	18	28	
60	22	0	15	26	
65	18	0	12	26	
70	15	3	12	29	
75	10	8	11	29	
80		5	11	30	
85		0	14	34	
90		0	15	39	
95		0	16	39	
100			14	36	
105			15	31	
110			11	18	
115			12		
120			10		
125					
130					
135					
140					
145					
150					

APPENDIX I PERCENT TRANSMISSIBILITY

(e) June 3, 1974

Depth (m)	Station/Time (PST)		
	T-1 1025	T-2 1040	T-3 1110
0	8	13	20
5	10	31	23
10	48	26	38
15	50	50	34
20	45	38	33
25	48	42	32
30	21	30	23
35	14	21	25
40	7	10	27
45	11	5	28
50	12	5	28
55	10	5	23
60	9	4	25
65	7	3	20
70	6	2	14
75	5	3	10
80		3	8
85		3	10
90		3	15
95			14
100			20
105			22
110			23
115			20
120			7
125			8
130			7
135			9
140			9
145			10
150			8

APPENDIX I PERCENT TRANSMISSIBILITY

(f) June 10, 1974

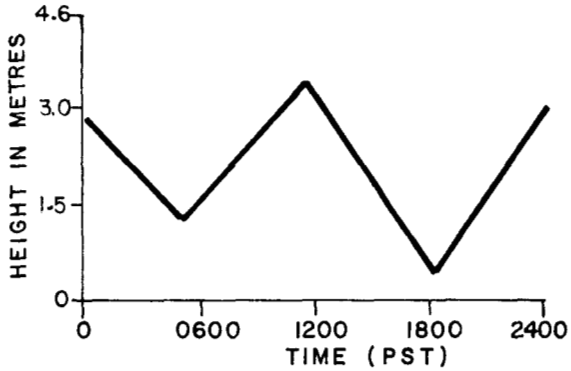
Depth (m)	Station/Time (PST)			
	T-1 2145	T-2 2100	T-3 1945	T-4 1545*
0	9	0	5	45
5	6	45	20	60
10	33	40	35	70
15	29	33	40	70
20	52	43	33	67
25	58	41	34	63
30	58	22	28	59
35	55	10	27	57
40	52	3	25	60
45	30	5	24	61
50	10	5	23	61
55	7	7	23	62
60	40	5	21	64
65	41	2	18	64
70	32	0	18	58
75	10	0	20	50
80		0	19	45
85		0	18	41
90		0	18	34
95			16	26
100			14	24
105				20
110				14
115				4
120				2
125				
130				
135				
140				
145				
150				

* Sampling date - June 11, 1974

APPENDIX 1 (g) CHANGES IN PERCENT TRANSMISSIBILITY DURING A TIDAL CYCLE IN RUPERT INLET - July 16, 1976

DEPTH (m)	SAMPLING TIME (PDT) 1000 ↓	1000 ↑	1100 ↓	1100 ↑	1200 ↓	1200 ↑	1300 ↓	1300 ↑	1530 ↓	1530 ↑	1745 ↓	1745 ↑	1815 ↓	1815 ↑
0	15	11	9	8	6	5	5	3	9	9	6	9	8	10
5	22	29	17	18	18	26	13	20	12	19	12	20	20	25
10	35	37	30	34	33	31	29	31	24	31	33	35	35	36
15	39	35	38	36	35	34	33	30	35	36	36	35	36	37
20	37	36	37	35	35	21	33	32	38	37	36	35	38	38
25	36	38	34	34	35	32	33	32	39	32	38	38	38	36
30	41	39	37	36	34	32	33	32	35	35	37	36	36	33
35	37	35	38	34	33	31	33	31	36	34	34	35	34	34
40	36	35	36	34	33	31	29	26	34	26	36	35	35	35
45	35	34	34	31	30	25	23	19	26	18	31	29	34	29
50	33	27	25	21	23	21	18	15	19	14	25	24	25	24
55	26	23	21	19	22	17	16	17	11	0	24	22	22	20
60	23	23	18	17	14	15	18	16	0		19	13	19	22
65	20	21	16	14	15	14	14	11			6	0	21	15
70	23	13	13	12	15	15	9	8			0		5	0
75	10	3	9	9	16	10	6	3					0	
80	0	0	4	3	9	6	0							
85	0	0	0	0	0	05								
90	0	0												

Lowering transmissometer ↓ Raising transmissometer ↑



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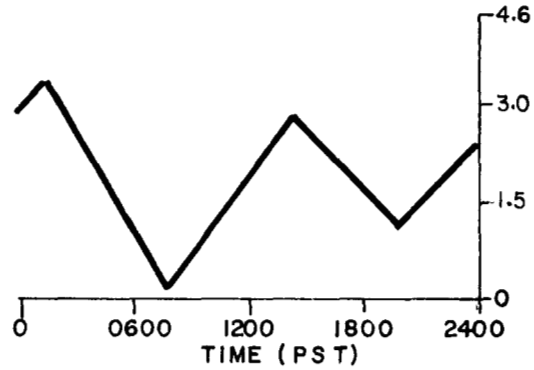

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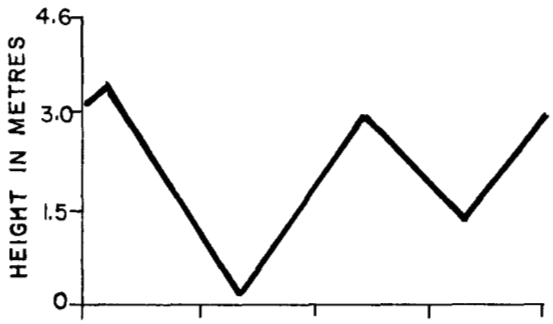

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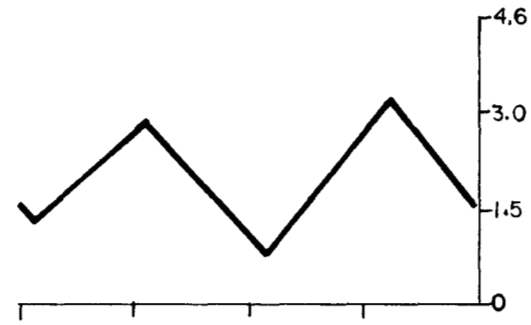

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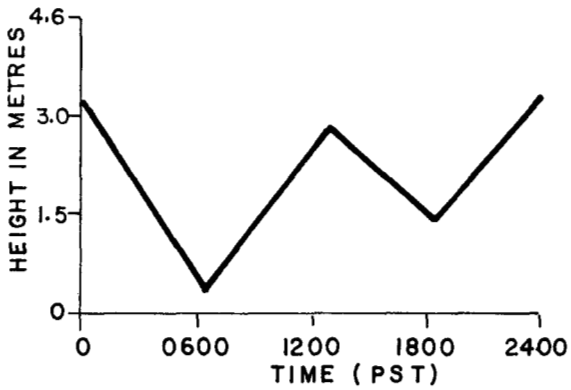
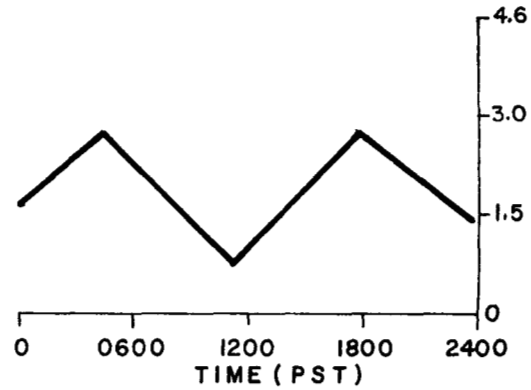


JUNE 3, 1974



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APPENDIX I(h) TIDAL CURVES FOR TRANSMISSOMETER SURVEYS

APPENDIX II

SUBMERSIBLE DIVING OBSERVATIONS - PISCES IV

(a) Holberg Inlet - February 11, 1975
(b) Rupert Inlet - February 11, 1975
(c) Rupert Inlet - February 12, 1975
(d) Holberg Inlet - February 13, 1975
(e) Holberg Inlet - February 13, 1975
(f) Quatsino Sound - February 14, 1975

APPENDIX II SUBMERSIBLE DIVING OBSERVATIONS - PISCES IV

(a) Holberg Inlet - February 11, 1975

DIVE NO.:	294	
LOCATION:	Holberg Inlet (off Pot Rock)	
POSITION:	Submerge	Surface
	50°35.0'N	50°35.0'N
	127°39.4'W	127°39.1'W
TIME:	1010 hours	
DEPTH:	115 metres	
DURATION:	3 hours	
PILOT:	P. LeGallais	
OBSERVER:	D. Goyette	

OBSERVATIONS:

30 m	Water murky, visibility approximately 1.8 metres (end of orange claw). Individual suspended particles distinguishable.
50 m	Few chaetognaths appearing.
65 m	Visibility approximately 1.8 metres.
75 m	Increase in particulate matter, zooplankton not in significant numbers.
100 m	Visibility reduced due to large particles in suspension.
115 m	On bottom, visibility 0.6 metres, bottom covered in tailings, numerous craters, few shrimp (Pandalid) observed. Fish observed were hake, eelpout, sole, ratfish.
80 m	Moved to new position, tailings present, visibility improved but insufficient for adequate observations, a few shrimp observed.
50 m	Visibility moderate, rocky bottom, light brown sediment, no tailings observed, few rockfish, starfish (*Pseudarcaster* sp), and shrimp observed.

40 m	Substrate small rocks, visibility approximately 3 metres.
20 m	Returned to surface.

REMARKS:

Visibility was very poor at 115 metres and improved slightly above 50 metres. Observations were limited and Pisces operations difficult. The reduced visibility was due to a high concentration of brown coloured particles suspended in the water. No definite layering of either turbidity or zooplankton was observed. Tailings (from the distinct grey colour) were evident up to a depth of 80 metres and not seen at 50 metres.

APPENDIX II SUBMERSIBLE DIVING OBSERVATIONS - PISCES IV
(b) Rupert Inlet - February 11, 1975

DIVE NO.:	295	
LOCATION:	Rupert Inlet center channel, abeam of Red Island	
POSITION:	Submerge	Surface
	50°35.25'N	50°35.25'N
	127°27.4' W	127°27.4' W
TIME:	1355 hours	
DEPTH:	90 metres	
DURATION:	65 minutes	
PILOT:	I. Sanderson	
OBSERVER:	D. Goyette	

OBSERVATIONS:

10 m	Fine particles suspended in the water producing a milky grey appearance.
25 m	Halocline observed.
60 m	No zooplankton observed to this depth.
85 m	A few euphausids and hyperid amphipods appearing. Size of suspended particles increasing.
90 m	On bottom. Bottom not visible due to high turbidity, appearance of water similar to a very dense fog. Distance - viewport to bottom approximately 0.7 metre. Returned to the surface.

REMARKS:

Entire water column extremely turbid with visibility ranging between 1.8 metres at the surface to less than 0.3 metre below a depth of 60 metres. Appearance of the water column, surface to the bottom, similar to a dense fog. Visibility decreased gradually with no distinct layering. Fine suspended particles throughout the water column giving it a definite grey

colour. Lack of visibility prevented observations and photography. Unable to see the bottom, approximately 0.7 metre from viewport. Particles extremely fine, unable to distinguish individual particles until near the bottom. Increase in particle size possibly due to flocculation.

APPENDIX II SUBMERSIBLE DIVING OBSERVATIONS - PISCES IV
(c) Rupert Inlet - February 12, 1975

DIVE NO.:	297	
LOCATION:	Rupert Inlet center channel, abeam of Red Island	
POSITION:	Submerge	Surface
	50°35.35'N	50°35.35'N
	127°26.7' W	127°26.7' W
TIME:	1345 hours	
DEPTH:	75 metres	
DURATION:	92 minutes	
PILOT:	J. Power	
OBSERVER:	D. Goyette and C. Pelletier	

OBSERVATIONS:

Transmissometer readings were recorded during the descent:

Surface	-	18%	
15 m	-	26%	
30 m	-	12%	
35 m	-	9%	
50 m	-	5%	
70 m	-	4%	
75 m	-	3%	(bottom)

Little change in visibility over Dive No. 295 in the same area. Dense grey fog throughout water column. Size of many of the suspended particles appeared to increase near the bottom. Contact with the bottom at 75 metres.

REMARKS:

Unable to observe the bottom. Dive was terminated soon after colliding with an underwater object.

APPENDIX II SUBMERSIBLE DIVING OBSERVATIONS - PISCES IV

(d) Holbert Inlet - February 13, 1975

DIVE NO.:	298	
LOCATION:	West of Straggling Islands	
POSITION:	Submerge	Surface
	50°36.0'N	50°35.1'N
	127°43.9'W	127°44.0'W
TIME:	0950 hours	
DEPTH:	90 metres	
DURATION:	1 hour, 54 minutes	
PILOT:	P. LeGallais	
OBSERVER:	H. Nelson	

OBSERVATIONS:

Transmissometer readings on descent:

Surface - 51% transmissibility
25 m - 36%
50 m - 26%
90 m - 7% on bottom

Visibility poor, worse than Dive No. 294 (Pot Rock). Particle size larger than that observed in Rupert Inlet. Ascended to 50 metre depth for better visibility and headed to north shore. Contacted bottom again at 65 m. Transmissibility at 65 m was 22%, substrate soft mud, no evidence of tailings on the bottom. Numerous craters, few shrimp. Plankton (chaetognaths, amphipods, small euphausids) fairly abundant during descent.

APPENDIX II SUBMERSIBLE DIVING OBSERVATIONS - PISCES IV

(e) Holbert Inlet - February 13, 1975

DIVE NO.:	299	
LOCATION:	Near the head of Holberg Inlet	
POSITION:	Submerge	Surface
	50°37.9'N	50°38.15'N
	127°54.9'W	127°54. 7'W
TIME:	1345 hours	
DEPTH:	55 metres	
DURATION:	96 minutes	
PILOT:	I. Sanderson	
OBSERVER:	H. Nelson	

OBSERVATIONS:

Transmissometer readings on descent and ascent:

Surface	-	60 - 70% transmissibility
50 m	-	40%
55 m	-	50% on bottom
45 m	-	30% "
40 m	-	26% "

Many plankters observed during descent. Contacted bottom at 55 m, visibility 2.4 to 3.0 m and murky. Substrate soft, brown mud; numerous craters up to 10 cm in diameter. Amphipods and euphausids abundant during descent. Several flat fish observed. Size of suspended particles smaller than those seen on Dive No. 298. At 45 m moving towards shore, little change in substrate, few shrimp, occasional eelpout. Visibility decreased towards shore, increase in marine life, eg., pandalid shrimp, eelpouts, flatfish (15 to 20 cm long) frequently observed. At 40 m water murky; a few anemones, number of large empty clam shells, many zooplankters (mostly euphausids) observed. At 20 m, ascended to surface.

APPENDIX II SUBMERSIBLE DIVING OBSERVATIONS - PISCES IV

(f) Quatsino Sound, February 14, 1975

DIVE NO.:	300	
LOCATION:	West of Drake Island	
POSITION:	Submerge	Surface
	50°29. 9'N	50°30.23'N
	127°44.65'W	127°45.35'W
TIME:	1320 hours	
DEPTH:	125 metres	
DURATION:	2 hours, 34 minutes	
PILOT:	F. Chambers	
OBSERVER:	D. Goyette	

OBSERVATIONS:

Surface	Visibility very good, clear.
25 m	Water colour dark blue, increase in suspended particles compared with the surface but water clarity remained extremely clear.
35 m	Increase in size and concentration of suspended particles, no sign of zooplankton, suspended particles appear as brown to whitish coloured matter, short (20.3 mm) strings to small spheres (presumably diatom).
50 m	Few chaetognaths appearing; odd, small euphausid
65 m	Number of small euphausid increasing.
75 m	Concentration of suspended particles remaining relatively uniform, chaetognaths and euphausids the dominant plankton.
100 m	Holding at 100 m to attach more line to surface buoy, number of white flecks observed, similar in size and shape to herring scales.

120 m	On the bottom, visibility very good, approximately 4.5 m; light brown to slightly grey colour to sediment, no sign of tailings; mud very soft, vibrates ahead of sub when skids touch; number of shrimp present; substantial numbers of chaetognaths (most dominant plankton); number of large (5.0 to 7.6 cm) shrimp observed; increase in the number of Hyperid amphipods; 40 to 50 chaetognaths observed at any given time; several small (2.5 cm) orange coloured pelagic polychaetes; one pteropod (pelagic mollusc); bottom smooth with numerous large craters; large numbers of Pandalid shrimp (Pandalopsis dispar); a number of flatfish, eelpouts, ratfish, hake, small orange-banded rockfish; several clumps of cloud sponge 0.3 to 0.6 m in diameter.
105 m	Steep mud incline.
100 m	Bottom changed to coarser sediment, rock cod, sea urchin; large number of shrimp observed.
75 m	Crossaster sp, Pseudarcaster sp.
70 m	Clump of cloud sponge.
65 m	Large numbers of Psolus (creeping cucumber) on small rocks; large numbers of squat lobsters and Munida sp. Substrate type has a definite relationship to the species observed.
60 m	Sea anemone; number of boot sponge (Hexactinellida) similar to those commonly seen in Saanich Inlet; bottom consisted of rock and coarse sediment; several large schools of rockfish; noticeable increase in variety of marine life over that observed at 120 m.
50 m	Area of large boulders; further increase in amount of marine life; large schools of rockfish, Parastichopus sp; bottom changing to coarse gravel and sand; decrease in the number of shrimp; large skate; pink and white banded rockfish; water slightly murky.

30 m	Gravel bottom, occasional boulder; wood debris (natural).
25 m	Left bottom; steep cliff; visibility 5.5 to 6.0 m.

REMARKS:

Visibility excellent, making Pisces operation easier than previous dives. No evidence of the grey coloured suspension which was noted in Rupert Inlet. Although the concentration of suspended particles was relatively high, the water between the particles was clear, giving excellent visibility (to the maximum penetration of the submersible's lights). Plankton abundant below 65 m with very large concentrations of chaetognaths. Area extremely rich in marine life with a variety of fish and invertebrates. Pandalid shrimp very abundant up to 50 metres. Numbers and presence of shrimp appear to be associated with mud bottom. Increase in numbers of rockfish associated with boulders or rocky areas. Numerous craters observed in the mud bottom. Craters have been seen frequently in Alberni Inlet, Indian Arm, and Howe Sound. Craters appear to be formed by an unidentified organism. Craters end in a well-defined and maintained hole approximately 3.0 to 7.6 cm in diameter which frequently leads off at right angles to the base of the crater. No tailings observed at any depth.

APPENDIX III

COULTER COUNTER ANALYSIS

APRIL, 1974

AT STATIONS T-1, T-2, T-3, T-4, T-5

APPENDIX III COULTER COUNTER ANALYSIS - APRIL, 1974

Station	Depth (m)	Transmis-sibility (%)	Volume Range (μm^3)	Diameter Range (μm)	Particle Count/mℓ	Distri-bution (%)
T-1	0	0	4 - 11	1.9 - 2.8	17,644	18.5
			11 - 25	2.8 - 3.6	21,318	22.3
			25 - 39	3.6 - 4.2	11,760	12.3
			39 - 60	4.2 - 4.8	11,822	12.4
			58 - 116	4.8 - 6.0	15,230	15.9
			116 - 174	6.0 - 7.0	7,538	7.9
			174 - 290	7.0 - 8.2	7,750	8.1
			290 - 520	8.2 - 10.0	1,892	2.0
			520 - 752	10.0 - 11.2	462	0.5
			752 - 984	11.2 - 12.4	144	0.2
				Total Count	95,560	
	30	9	4 - 11	1.9 - 2.8	10,490	46.8
			11 - 25	2.8 - 3.6	7,016	31.3
			25 - 39	3.6 - 4.2	2,070	9.2
			39 - 60	4.2 - 4.8	1,280	5.7
			58 - 116	4.8 - 6.0	716	3.2
			116 - 174	6.0 - 7.0	346	1.5
			174 - 290	7.0 - 8.2	302	1.3
			290 - 520	8.2 - 10.0	200	0.9
			520 - 752	10.0 - 11.2	0	0.0
			752 - 984	11.2 - 12.4	0	0.0
				Total Count	22,420	
	70	0	4 - 11	1.9 - 2.8	14,042	44.0
			11 - 25	2.8 - 3.6	7,974	25.0
			25 - 39	3.6 - 4.2	2,986	9.4
			39 - 60	4.2 - 4.8	2,228	7.0
			58 - 116	4.8 - 6.0	2,384	7.5
			116 - 174	6.0 - 7.0	908	2.8
			174 - 290	7.0 - 8.2	832	2.6
			290 - 520	8.2 - 10.0	404	1.3
			520 - 752	10.0 - 11.2	120	0.4
			752 - 984	11.2 - 12.4	0	0.0
				Total Count	31,878	

APPENDIX III COULTER COUNTER ANALYSIS - APRIL, 1974

Station	Depth (m)	Transmis-sibility (%)	Volume Range (μm^3)	Diameter Range (μm)	Particle Count/mℓ	Distri-bution (%)
T-2	0	0	4 - 11	1.9 - 2.8	6,590	9.9
			11 - 25	2.8 - 3.6	16,348	22.3
			25 - 39	3.6 - 4.2	13,436	18.3
			39 - 60	4.2 - 4.8	9,838	13.4
			58 - 116	4.8 - 6.0	13,812	18.9
			116 - 174	6.0 - 7.0	5,978	8.2
			174 - 290	7.0 - 8.2	4,734	6.5
			290 - 520	8.2 - 10.0	2,082	2.8
			520 - 752	10.0 - 11.2	380	0.5
			752 - 984	11.2 - 12.4	54	0.1
				Total Count	73,252	
	50	6	4 - 11	1.9 - 2.8	7,098	29.7
			11 - 25	2.8 - 3.6	10,804	45.2
			25 - 39	3.6 - 4.2	1,882	7.9
			39 - 60	4.2 - 4.8	1,122	4.7
			58 - 116	4.8 - 6.0	1,762	7.4
			116 - 174	6.0 - 7.0	582	2.4
			174 - 290	7.0 - 8.2	374	1.6
			290 - 520	8.2 - 10.0	228	1.0
			520 - 752	10.0 - 11.2	56	0.2
			752 - 984	11.2 - 12.4	0	0.0
				Total Count	23,908	
	90	0	4 - 11	1.9 - 2.8	16,944	33.9
			11 - 25	2.8 - 3.6	12,700	25.4
			25 - 39	3.6 - 4.2	5,862	11.7
			39 - 60	4.2 - 4.8	4,760	9.5
			58 - 116	4.8 - 6.0	5,618	11.2
			116 - 174	6.0 - 7.0	2,026	4.2
			174 - 290	7.0 - 8.2	1,230	2.5
			290 - 520	8.2 - 10.0	642	1.3
			520 - 752	10.0 - 11.2	156	0.3
			752 - 984	11.2 - 12.4	0	0.0
				Total Count	49,938	

APPENDIX III COULTER COUNTER ANALYSIS - APRIL, 1974

Station	Depth (m)	Transmis-sibility (%)	Volume Range (μm^3)	Diameter Range (μm)	Particle Count/mℓ	Distri-bution (%)
T-3	0	0	4 - 11	1.9 - 2.8	31,032	
			11 - 25	2.8 - 3.6	19,260	
			25 - 39	3.6 - 4.2	14,050	
			39 - 60	4.2 - 4.8	11,650	
			58 - 116	4.8 - 6.0	N/R*	
			116 - 174	6.0 - 7.0	"	
			174 - 290	7.0 - 8.2	"	
			290 - 520	8.2 - 10.0	"	
			520 - 752	10.0 - 11.2	"	
			752 - 984	11.2 - 12.4	"	
				Total Count		
	20	14	4 - 11	1.9 - 2.8	7,778	
			11 - 25	2.8 - 3.6	2,316	
			25 - 39	3.6 - 4.2	2,222	
			39 - 60	4.2 - 4.8	2,586	
			58 - 116	4.8 - 6.0	N/R	
			116 - 174	6.0 - 7.0	"	
			174 - 290	7.0 - 8.2	"	
			290 - 520	8.2 - 10.0	"	
			520 - 752	10.0 - 11.2	"	
			752 - 984	11.2 - 12.4	"	
				Total Count		
	150	12	4 - 11	1.9 - 2.8	20,546	27.1
			11 - 25	2.8 - 3.6	19,844	26.2
			25 - 39	3.6 - 4.2	11,644	15.4
			39 - 60	4.2 - 4.8	8,388	11.1
			58 - 116	4.8 - 6.0	8,180	10.8
			116 - 174	6.0 - 7.0	3,384	4.5
			174 - 290	7.0 - 8.2	1,520	2.0
			290 - 520	8.2 - 10.0	1,686	2.2
			520 - 752	10.0 - 11.2	456	0.6
			752 - 984	11.2 - 12.4	60	0.1
				Total Count	75,708	

*N/R - No Record

APPENDIX III COULTER COUNTER ANALYSIS - APRIL, 1974

Station	Depth (m)	Transmis-sibility (%)	Volume Range (μm^3)	Diameter Range (μm)	Particle Count/mℓ	Distri-bution (%)
T-4	0	0	4 - 11	1.9 - 2.8	3,294	42.7
			11 - 25	2.8 - 3.6	2,044	26.5
			25 - 39	3.6 - 4.2	884	11.5
			39 - 60	4.2 - 4.8	572	7.4
			58 - 116	4.8 - 6.0	686	8.9
			116 - 174	6.0 - 7.0	226	2.9
			174 - 290	7.0 - 8.2	-	-
			290 - 520	8.2 - 10.0	N/R*	
			520 - 752	10.0 - 11.2	"	
			752 - 984	11.2 - 12.4	"	
				Total Count	7,706	
	40	39	4 - 11	1.9 - 2.8	4,786	46.3
			11 - 25	2.8 - 3.6	3,068	29.7
			25 - 39	3.6 - 4.2	1,440	13.9
			39 - 60	4.2 - 4.8	642	6.2
			58 - 116	4.8 - 6.0	342	3.3
			116 - 174	6.0 - 7.0	56	0.5
			174 - 290	7.0 - 8.2	N/R	
			290 - 520	8.2 - 10.0	"	
			520 - 752	10.0 - 11.2	"	
			752 - 984	11.2 - 12.4	"	
				Total Count	10,334	
	100	25	4 - 11	1.9 - 2.8	16,220	38.6
			11 - 25	2.8 - 3.6	9,638	22.9
			25 - 39	3.6 - 4.2	5,740	13.6
			39 - 60	4.2 - 4.8	5,250	12.5
			58 - 116	4.8 - 6.0	2,474	5.9
			116 - 174	6.0 - 7.0	1,470	3.5
			174 - 290	7.0 - 8.2	1,266	3.0
			290 - 520	8.2 - 10.0	N/R	
			520 - 752	10.0 - 11.2	"	
			752 - 984	11.2 - 12.4	"	
				Total Count	42,058	

*N/R - No Record

APPENDIX III COULTER COUNTER ANALYSIS - APRIL, 1974

Station	Depth (m)	Transmis-sibility (%)	Volume Range (μm^3)	Diameter Range (μm)	Particle Count/mℓ	Distri-bution (%)
T-5	0	0	4 - 11	1.9 - 2.8	6,282	31.9
			11 - 25	2.8 - 3.6	3,756	19.1
			25 - 39	3.6 - 4.2	2,172	11.0
			39 - 60	4.2 - 4.8	2,174	11.0
			58 - 116	4.8 - 6.0	1,932	9.8
			116 - 174	6.0 - 7.0	1,096	5.6
			174 - 290	7.0 - 8.2	1,080	5.5
			290 - 520	8.2 - 10.0	828	4.2
			520 - 752	10.0 - 11.2	264	1.3
			752 - 984	11.2 - 12.4	108	0.5
				Total Count	19,692	
	30	18	4 - 11	1.9 - 2.8	6,516	32.5
			11 - 25	2.8 - 3.6	3,256	16.2
			25 - 39	3.6 - 4.2	2,062	10.3
			39 - 60	4.2 - 4.8	2,198	11.0
			58 - 116	4.8 - 6.0	2,358	11.8
			116 - 174	6.0 - 7.0	1,304	6.5
			174 - 290	7.0 - 8.2	1,324	6.6
			290 - 520	8.2 - 10.0	806	4.0
			520 - 752	10.0 - 11.2	194	1.0
			752 - 984	11.2 - 12.4	22	0.1
				Total Count	20,040	

APPENDIX IV

MINE SEDIMENT DEPOSITION - GRAB SAMPLES

(a) November, 1971
(b) October, 1973
(c) May and June, 1974

Legend

T - tailings
O - overburden
m - mud
sh - shell fragments
g - gravel
s - sand
rk - rock

APPENDIX IV MINE SEDIMENT DEPOSITION - GRAB SAMPLES

(a) November, 1971

Station	Depth (m)	Original Substrate	Sediment Description	Thickness (cm)
1	67	m	T	trace
2	100	m	T	1.3
3	110	m	T	trace
4	100	m	T	5.0
5	98	m	T	1.3
6	82	-	T	>30.0
7	89	m	T	0.6
8	85	m	T	-
9	93	m	T	trace
10	33	rk	T	1.3
11	24	rk	T	1.3
12	19	rk	T	trace
13	130	m	T	trace
14	105	m	T	trace

(b) October, 1973 (continued)

Station	Depth (m)	Original Substrate	Sediment Description	Thickness (cm)
27	138	g, sh	T	light
28	159	rk	T	trace
29	155	rk	T	trace
30	149	rk	T	trace
31	44	g, sh	T	light
32	150	0	T	>30.0
33	60	m	T	0.6
34	120	m	T	1.3
35	45	g, sh	-	-
36	48	g	-	-
37	24	rk	-	-

APPENDIX IV MINE SEDIMENT DEPOSITION - GRAB SAMPLES

(b) October, 1973

Station	Depth (m)	Original Substrate	Sediment Description	Thickness (cm)
1	30	m, sh	-	-
2	68	m	T	>2.5
3	16	m	0	-
4	10	g	0	-
5	10	m	0	-
6	-	m	T	20.0
7	97	-	T	>30.0
8	45	-	T	1.3
9	72	-	T	>2.5
10	43	-	T	trace
11	52	-	T	0.6
12	74	m	T	>30.0
13	44	m	0	1.3
14	35	m, coarse s	0	0.6
15	24	m, coarse s	-	-
16	76	m	T	20.0
17	37	m	T	2.5
18	19	m	T	1.3
19	20	m	T	light
20	47	m	T	1.3
21	70	g	T	20.0
22	104	m	T	20.0
23	101	-	T	>30.0
24	101	-	T	>30.0
25	35	m, s	T	trace
26	87	rk	-	-

(continued)

APPENDIX IV MINE SEDIMENT DEPOSITION - GRAB SAMPLES

(c) May and June, 1974

Station	Depth (m)	Original Substrate	Sediment Description	Thickness (cm)
1	20	rk, m	-	-
2	32	brown sediment, fine g	T	2.5
3	50	?	T	5.0
4	137	-	T	>30.0
5	105	rk	-	-
6	116	s, possibly on rk	-	-
7	166	-	T	>30.0
8	165	-	T	>30.0
9	164	-	T	>30.0
10	157	-	T	>30.0
11	165	s, possibly on rk	T	trace
12	168	-	T	>30.0
13	151	coarse s	T	light
14	129	coarse s	T	light
15	158	rk	-	-
16	168	rk	-	-
17	159	rk	-	-
18	166	rk	-	-
19	153	-	T	30.0

APPENDIX V

QUALITATIVE SCUBA DIVING OBSERVATIONS, 1970 - 1975

(a) July, 1970
(b) July, 1971
(c) August, 1972
(d) October, 1973
(e) April, 1974
(f) May, 1974
(g) June, 1974
(h) September, 1974
(i) July, 1975

APPENDIX V QUALITATIVE SCUBA DIVING OBSERVATIONS, 1970 - 1975

(a) July, 1970

LOCATION: Narrow Island, Rupert Inlet
STATION NO.: 4
OBSERVATIONS: Substrate; rock ledges and sand in the more level areas. Visibility good. Unusually large sea pens, numerous starfish, and an abundance of other invertebrates and algae.

(b) July, 1971

LOCATION: West of Ohlsen Point, Quatsino Narrows
STATION NO.: 16
OBSERVATIONS: Substrate, rock face and boulders. Surface relatively free of natural sediment deposits. Visibility good. Dense growth of *Nereocystis* sp, large purple sea urchins, sponges, tunicates, hydroids present. Numerous rockfish. Rocky surfaces heavily encrusted with marine life - *Lithothanmion* sp., scallop, sponge, tubiculous polychaetes, anemones, gastropods, chitons common. Few abalone, kelp greenling and black sea bass common.

(c) August, 1972

LOCATION: Varney Bay, Rupert Inlet
STATION NO.: 8
OBSERVATIONS: Substrate sand. Visibility good. *Cancer magister* common, numerous burrowing anemones and clams. Vertebrates included herring, anchovy, and perch also observed.

(c) August, 1972 (continued)

LOCATION: South of Quattische Island, Quatsino Narrows
STATION NO.: 14
OBSERVATIONS: Substrate rock ledges and boulders. Visibility very good. Many tubiculous polychaetes, sponges, tunicates and sea urchins (*Strongylocentrotus franciscanus*) very abundant.

(d) October, 1973

LOCATION: Near Apple Bay, Holberg Inlet
STATION NO.: 11
OBSERVATIONS: Substrate sand and cobble with very little fine sediment. Visibility good. Numerous burrowing anemones and starfish.

(e) April, 1974

LOCATION: Kokwina Cove, Quatsino Narrows
STATION NO.: 15
OBSERVATIONS: Substrate sand and small rocks with a light covering of fine sediment up to 1 cm in thickness. Visibility fair. Several burrowing anemones. Rocks covered with encrusting algae, *Lithothamnion* sp., bryozoans, and sponges. *Laminaria* sp. common. Some marine life being smothered by covering of fresh fine sediment.

LOCATION: Bay northeast of Kenny Point, Rupert Inlet
STATION NO.: 7
OBSERVATIONS: Substrate sand and cobble with a light covering of fine, fresh sediment over all vegetation. Visibility poor. Rich algal growth and a variety of invertebrates.

(e) April, 1974 (continued)

LOCATION: Bay northeast of Hankin Point
STATION NO.: 6
OBSERVATIONS: Substrate sand and some cobble with a light covering of fine sediment over vegetation. Visibility moderate. Numerous *Cancer* crabs, few clams, generally less marine life than other stations.

LOCATION: Adjacent to Mine Tailings Impoundment
STATION NO.: 5
OBSERVATIONS: Substrate originally rock, now covered by mine tailings up to a depth of 1 metre. Visibility extremely poor. No benthic organisms observed.

LOCATION: West of Red Island, Rupert Inlet
STATION NO.: 3
OBSERVATIONS: Substrate cobble stones and brown mud. Visibility very poor. Bottom covered with a thick layer of mud 10 - 20 cm in depth. No marine life observed.

LOCATION: North shore Holberg Inlet near Pot Rock
STATION NO.: 10
OBSERVATIONS: Substrate mud. Visibility good. No evidence of fresh sediment deposits on vegetation. Very little suspended material in the water.

(f) May, 1974

LOCATION: Bay at north end of Quatsino Narrows
STATION NO.: 12
OBSERVATIONS: Substrate rock ledges and boulders with a fresh covering of fine sediment. Visibility moderate to poor.

Invertebrates such as sea urchins, scallops, sponges, tunicates, cup-corals, anemones, and polychaetes, very common. Numerous rock fish, and a few abalone. Fine sediment covering vegetation and the mucus on some organisms. Sedimentation less obvious below a depth of 12.2 metres. Tailings noted in areas of the intertidal zone.

(g) June, 1974

LOCATION: Ohlsen Point, Quatsino Narrows
STATION NO.: 13
OBSERVATIONS: Substrate rock ledges, boulders and coarse sand. Fresh, fine sediment in crevices and on vegetation in areas removed from strong current activity. Visibility good. Marine life adundant. Fine sediment covering encrusting algae. Some darkening of the underside of small rocks imbedded in fresh sediment deposits. Areas towards the center of the Narrows where strong tidal currents exist were relatively free of fine sediment deposits.

(h) September, 1974

LOCATION: Hankin Point
STATION NO.: 9
OBSERVATIONS: Substrate rock ledges, sand, and boulders. Heavy deposits of fresh sediment in rock crevices with a light film covering the rock ledges. Visibility moderate. Fine grey sediment covering much of the substrate, smothering encrusting algae and covering invertebrates in some areas. Exposed areas of rock had a normal abundance of marine life. Sea urchins actively feeding on exposed encrusting algae. Substantial build-up of mine tailings around Hankin Point, infilling many of the depressions along the rock ledges. Upper surface of most rocky areas also covered by tailings, only the verticle faces remained free of sediment. Most benthic invertebrates normally found on clean, rocky surfaces were absent in areas affected by tailings deposition.

(i) July, 1975

LOCATION: Hankin Point

STATION NO.: 9

OBSERVATIONS: Substrate rock ledges, sand and boulders. Visibility moderate. Dove 0 to 9.1 metres from small bay east of Hankin Point to center of the point. Tailings evident throughout the area, intertidal as well as subtidal. Algae covered with a thin layer of tailings. Crevices and flat surfaces of rock covered with varying thicknesses of tailings, up to 25 cm. Underside of rocks blackened. *Lithothamnion* sp. (encrusting algae) covered by tailings was either decaying or absent. Removing sediment from rocks, "dusting" often revealed chitons still feeding on remaining algae. Empty barnacle shells commonly seen beneath the tailings deposits.

In deeper areas where the bottom flattened out, numerous tube worms and burrowing anemones were observed. Other marine life included *Cancer* crabs, rockfish, sea cucumber (*Parastichopus* sp.), and large purple sea urchins (*S. franciscanus*).

Pyrite flecks were very evident in the sediment deposits. In some areas a brown gelatinous scum was noted on the surface of tailings.

Considerable increase in the thickness and area of the tailings deposits over the previous year. Large portion of the substrate around Hankin Point now blanketed by tailings.

LOCATION: South shore of Rupert Island

STATION NO.: 1

OBSERVATIONS: Substrate mud and sand with some cobbles covered with a thin layer of fine, brown (natural) sediment. Visibility good. Many large *Parastichopus* sp. and laminarians. A trace of fine, grey sediment was noted at 7.6 to 9.1 metre depth. This was not seen at a

(i) July, 1975 (continued)

depth of 15.2 to 18.2 metres. South shore, across from mine site does not show the heavy siltation observed around the mouth of Rupert Inlet and Quatsino Narrows.

LOCATION: East of Red Island, Rupert Inlet
STATION NO.: 2
OBSERVATIONS: Substrate rock ledges, sand, mud and a few cobbles. Visibility good. Rock ledges covered with encrusting coralline algae, pink and dark red. No tailings evident in crevices and pockets. A thin covering of fine brown sediment, presumably from the waste rock dump, on vegetation and rocks. No significant effects of sediment deposition on marine life were noted.

LOCATION: Ohlsen Point, Quatsino Narrows
STATION NO.: 13
OBSERVATIONS: Substrate, rock ledges, boulders and coarse sand. Visibility fair. Fine grey sediment (tailings) accumulating in rock crevices, in pockets in the sand and gravel and at the base of rocks. This is most noticeable in the sheltered notch to the north of Ohlsen Point. Sediment deposits appear to have increased since previous dives.

LOCATION: Kokwina Cove, Quatsino Narrows
STATION NO.: 15
OBSERVATIONS: Substrate and vegetation covered with heavy accumulation of fresh, grey coloured sediment up to 2 cm in thickness. Visibility very poor. Large laminarians and corallina covered by film of sediment finer than that observed off Hankin Point. Strings of particulate matter observed suspended in the water column (top 6.1 metres).

(i) July, 1975 (continued)

LOCATION: Bay northeast of Kenny Point, Rupert Inlet

STATION NO.: 7

OBSERVATIONS: Substrate, rock ledges, cobble. Fine, light grey coloured sediment covered most of the substrate beneath the intertidal zone, in some areas up to 2 cm in thickness. Sediment much finer than that seen off Hankin Point. Noticeable increase in thickness of the deposits over previous observations. Area appears to be affected by the deposition of fine material originating from turbidity "clouds" generated off Hankin Point. The accumulation of sediment deposits appears to be occurring at a greater rate than other locations studied, with the exception of the area around Hankin Point. Deeper areas (15.2 to 21.3 metres) entirely covered by tailings. Dark brown scum observed on the surface of the sediment in many areas. This was not observed on natural sediment deposits in other areas of Quatsino Sound.

LOCATION: Drake Island, Quatsino Sound

STATION NO.: 17

OBSERVATIONS: Substrate; rock ledges, cobble, coarse sand. Abundance of marine life observed, in particular tubiculous polychaetes. Rocky surfaces heavily encrusted with a variety of macro-invertebrates - sponge, tunicates, molluscs, nudibranch, etc. Goby and kelp greenling fish commonly observed. Light grey sediment, presumed to be tailings, observed amongst the gravel at a depth of 12.2 metres, in certain areas. No definite indication of tailings deposition at other depths, although an abnormal amount of sediment was noted on the vegetation and rocky surfaces in most areas. No visual impact on the resident biota was noted.

APPENDIX VI

TISSUE HEAVY METAL ANALYSIS

APPENDIX VI TISSUE HEAVY METAL ANALYSIS IN μg/g

Species	Station	Date	# of Specimens	Zn Dry Wt.	Zn Wet Wt.	Cu Dry Wt.	Cu Wet Wt.
Macoma irus	Red Is. (Rupert Inlet)	Aug. '71	6	260	44	460	79
		June '72	6	140	18	100	14
		June '73	4	380	53	350	50
			4	300	46	310	48
	Scuba Station 6 (West of Mill Site)	June-Aug. 1971	3	320	43	59	8.0
			3	370	54	42	6.3
			11	110	24	71	15
		Sept. '71	1	170	32	70	14
		June '73	3	230	28	130	16
			3	300	44	38	5.6
			3	280	39	53	8.2
	Apple Bay (Holberg Inlet)	June '73	6	180	27	9	1.4
		May '74	2	150	18	61	7.3
			2	180	21	17	2.0
			2	140	18	16	2.1
			2	160	23	19	2.8
			2	150	18	59	7.4
Mya arenaria	Red Is.	Aug. '71	6	105	16	77	12
		June '72	4	68	9	34	4.4
		June '73	2	140	19	31	4.1
			3	130	17	33	4.1
			3	120	16	29	3.8

APPENDIX VI TISSUE ANALYSIS IN ug/g

Species	Station	# of Specimens	Zn Dry Wt.	Zn Wet Wt.	Cu Dry Wt.	Cu Wet Wt.
Mya arenaria (cont'd)	Red Is.	2	83	12	27	3.8
		2	78	13	25	4.1
		2	74	10	33	4.6
		2	110	12	30	3.3
		3	61	11	24	4.1
	Scuba Ste	4	160	26	13	3.0
		2	110	18	24	4.0
		2	80	12	31	4.5
		1	160	22	31	4.4
		1	180	19	30	3.2
		2	170	17	27	2.8
		1	150	16	37	3.8
		1	110	13	18	2.3
		1	42	7	25	4.4
		1	50	10	12	2.5
		1	65	12	31	5.5
		1	48	9	25	4.0
	Apple B	2	140	13	17	1.6
		6	140	11	16	1.4
		2	130	17	55	7.2
		3	160	17	13	1.4
		3	110	13	15	1.9
		1	69	9	16	2.1
		1	48	7	22	3.3
		1	62	9	29	4.3
		1	68	10	19	2.7

APPENDIX VI TISSUE HEAVY METAL ANALYSIS IN μg/g

Species	Station	Date	# of Specimens	Zn Dry Wt.	Zn Wet Wt.	Cu Dry Wt.	Cu Wet Wt.
Saxidomus giganteus	Red Is.	June-Aug 1971	1	115	15	55	7.1
			1	250	39	40	6.3
			1	270	35	30	3.9
			1	160	23	7	1.1
			1	86	15	13	0.4
			1	90	16	40	7.2
		June '72	1	120	16	16	2.1
			1	81	8	25	2.3
		June '73	2	97	14	32	4.6
			2	110	16	29	3.9
			2	120	15	52	6.2
		May '74	1	69	13	14	2.6
			1	88	18	13	2.6
			1	54	12	11	2.2
			1	60	11	10	1.8
			1	56	8	16	2.2
	Scuba Station 6	June-Aug 1971	1	110	17	27	4.2
			1	110	16	24	3.5
			1	120	15	34	4.3
			1	90	34	26	9.7
			2	82	17	17	3.7
		Sept. '71	1	73	14	12	2.2
			1	56	10	17	2.9
		June '73	1	100	18	23	3.9
			1	120	22	19	3.6
			1	98	16	17	2.7
		May '74	1	100	21	23	4.7
			1	100	25	19	4.6
			1	69	17	13	3.2
			1	49	11	18	4.0
			1	85	19	20	4.5

APPENDIX VI TISSUE HEAVY METAL ANALYSIS IN μg/g

Species	Station	Date	# of Specimens	Zn Dry Wt.	Zn Wet Wt.	Cu Dry Wt.	Cu Wet Wt.
Saxidomus giganteus (cont'd)	Apple Bay	June '73	1	120	20	17	2.8
			1	96	13	7	1.3
			1	100	16	11	1.7
		May '74	1	55	12	9	2.0
			1	86	18	10	2.1
			1	56	11	14	2.8
			1	53	11	11	2.2
			1	54	10	10	1.8
Protothaca staminea	Red Is.	Aug. '71	6	92	15	10	1.7
			12	110	17	13	2.0
		June '72	2	110	12	20	2.1
		June '73	5	150	19	37	4.7
			5	120	15	37	4.6
			5	140	17	45	5.5
		May '74	1	57	11	18	3.3
			1	70	13	19	3.5
			1	110	20	15	2.7
			1	92	15	22	3.6
	Scuba Station 6	Aug. '71	7	110	18	15	2.4
			7	87	17	14	2.7
		Sept. '71	7	78	12	26	3.8
		June '73	2	12	2	30	3.8
			2	150	15	31	3.1
			3	120	17	40	5.4
		May '74	1	67	14	12	2.6
			1	86	16	15	2.9
			1	120	22	16	3.1
			1	69	12	13	2.4
			1	62	11	15	2.6

APPENDIX VI TISSUE HEAVY METAL ANALYSIS IN μg/g

Species	Station	Date	# of Specimens	Zn Dry Wt.	Zn Wet Wt.	Cu Dry Wt.	Cu Wet Wt.
Protothaca staminea (cont'd)	Apple Bay	June '73	5	110	13	19	2.2
			5	140	17	14	1.8
			5	130	16	13	1.6
		May '74	1	97	7	24	4.4
			1	110	20	13	2.4
			1	99	16	11	1.8
			1	83	13	14	2.2
			1	88	12	15	2.2
Mytilus edulis	Red Is.	July-Aug. 1971	18	340	14	44	7.8
			25	89	16	16	6.2
		June '73	7	220	25	87	10
		May '74	3	33	13	20	2.8
			3	120	16	13	1.8
			3	120	15	14	17
			3	120	-	14	-
	Scuba Station 6	July-Aug. 1971	12	190	30	52	8.4
			26	100	19	17	3.3
		June '73	9	190	17	43	4.0
		May '74	2	63	84	16	2.1
			2	110	16	17	2.4
			2	87	12	12	1.6
			2	130	19	10	1.4
			2	75	13	13	2.2
	Apple Bay	June '72	2	51	12	5	1.2
		June '73	6	120	18	9	1.4
		May '74	2	51	12	5	1.2
			2	62	11	12	2.3
			2	64	11	7	1.1
			2	95	12	10	1.3
			2	83	13	13	2.0