FISHERIES AND OCEANS CANADA
BRITISH COLUMBIA MINISTRY OF ENVIRONMENT

SIGNIFICANCE OF ENVIRONMENTAL CHANGES DUE TO MINE WASTE DISPOSAL INTO RUPERT INLET

by

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Federal/Provincial (British Columbia) Review of the
Mine Waste Disposal Problem in Rupert Inlet, B.C.

15 November 1980

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Island Copper Mine has been operating an open-pit mine, mainly for copper and molybdenum-bearing minerals, on the north-central shore of Rupert Inlet since October 1971. The ore body is estimated to contain 250 million tons of open-pit ore, giving the mining operation a life of 20 years. Starting production in 1971 with 33,000 tons of ore per day, the mine now (1980) processes daily 41,000 tons of ore, containing on the average 0.52% copper and 0.015% molybdenum. The tailings from this operation, consisting mainly of finely pulverized rock, 65-75% of which is less than 74 μm in diameter, are discharged through a high density polyethylene pipeline of 0.85 m diameter and approximately 1 km in length to a seawater mix-tank chamber. An underwater polyurethane-lined steel pipe of 1.05 m diameter discharges the tailings, premixed with seawater in a ratio of 1:1, through an outfall 250 m off the north shore of Rupert Inlet at a depth of 50 m. Waste rock from the mine, at 120,000 tons per day, generally containing less than 0.30% copper, is dumped in the northern foreshore area of Rupert Inlet from 0.5 km east of the Island Copper Mine wharf and planned to extend eventually to a point about 1.5 km from the head of the inlet.

On leaving the outfall, the tailings with a specific gravity of 1.2 to 1.4 compared to 1.03 for seawater, flow down the north slope of Rupert Inlet to the bottom at about 100 m depth, or the momentum of the flow may carry them for a distance up the opposite slope. They then slide down the inlet trench and flow westward in a sinuous path along the axis of the inlet to the deepest part of the Holberg-Rupert system, past the entrance of Quatsino Narrows. The particulate material may settle from the tailings into sediment banks near the outfall and along the route of the flow. Levees are formed on either side of the tailings channel. As these banks grow, they become unstable, slough off and form submarine "mud slides" with associated swift turbidity currents carrying tailings in suspension to the deepest part of the inlet system. The levees appear to be highly transient features, sometimes changing location and height during successive traverses by a vessel taking soundings for profiles of the bottom. The suspended materials may be carried to the surface by the strong upwelling that occurs near Quatsino Narrows during large tides under certain conditions. Resuspension of some of the deposited material occurs under the turbulent conditions associated with large tides. It is believed that a certain proportion of the suspended material in the water between Hankin Point and the entrance to Quatsino Narrows may be due also to the uplift by upwelling and vertical stirring by tidal turbulence of the tailings carried in suspension by the turbidity currents.

The suspended tailings can be clearly seen as a cloud at the surface, and deposits of this material have been noted to a depth of 10-25 cm in the intertidal zone at Hankin Point. Observations in Quatsino Narrows over several tidal cycles indicate that a net seaward flow of about 50 tonnes (1 tonne = 1000 kg) of tailings occurs during a 25-hour period. Deposition of these tailing in layers of a few millimeters thickness has been recorded in the intertidal and subtidal areas of Quatsino Sound proper.

The tailings contain on the average 700 ppm (0.07%) copper, 650 ppm manganese, 140 ppm chromium, 80 ppm zinc, 40 ppm molybdenum, 20 ppm cobalt, 20 ppm nickel, 20 ppm lead, 5 ppm arsenic, 3 ppm cadmium and 0.03 ppm mercury. The concentrations of the same metals in natural sediments of Rupert Inlet are 44 ppm Cu, 640 Mn, 125 Cr, 88 Zn, 2 Mo, 20 Co, 40 Ni, 25 Pb, 5 As, 2 Cd, and 0.06 ppm Hg. Only concentrations of copper and molybdenum in the tailings significantly exceed concentrations in the natural sediments. Laboratory leaching experiments, with the tailings held in seawater at a solids concentration of 17%, under constant agitation for 37 days, indicated that none of the metals tested entered the seawater from the tailings. Another exposure test in seawater, conducted over a period of 6 months, gave similar results with respect to leaching of copper and molybdenum, but the manganese content of exposed seawater increased from 4 to 60 ppb in 66 days.

Sampling of the bottom with a grab and corer in the deepest part of the Rupert-Holberg system in July 1978 showed the presence of benthic organisms, indicating that colonization of the deposited tailings by worms and other invertebrates is taking place. Moreover, colonization of deposited tailings by eelgrass, Zostera sp., had occurred in the intertidal zone at Hankin Point. This indicates that the tailings are relatively non-toxic to at least some species of benthic animals and rooted aquatic plants. Moreover, these observations suggest that colonization of the tailings-covered bottom is quite rapid and that populations of certain benthic organisms would be expected in or on the tailings within the first year after the mine ceases discharging.

Analysis of invertebrates and fish sampled in Rupert Inlet and in other parts of Quatsino Sound showed the levels of metals in these organisms to be generally near levels found in organisms taken from uncontaminated areas. Exceptions may be found in local pockets, such as the end of the original outfall and the concentrate-loading wharf, where copper concentrations in the sediments may be substantially higher than in the discharged tailings, owing to enrichment by an inadvertent flotation process (air bubbles) at the original outfall and spillage of copper concentrate at the loading wharf. It was concluded, therefore, that there is little short-term release of metals into the water or bioaccumulation of metals by the biota from tailings deposited in the inlet system under normal circumstances. Nothing can be said, however, about the long-term changes in availability of metals in the sediments through the process of diagenesis, with the addition and decomposition of organic material, creation of anoxic conditions, possible solubilization of metals in the sediments and release into the overlying water.

The main short-term impacts of the mine waste disposal are: (1) smothering of benthic organisms and destruction of bottom habitats by the tailings discharge; and (2) destruction of intertidal organisms and habitats by deposition of waste rock on the northeast shore of Rupert Inlet. Bottom fish and invertebrates in the Rupert-Holberg system could be adversely affected by the tailings. No bottom fish have been harvested commercially in the area, and it is not known what the impact of tailings has been on populations of such species. However, there has been a modest harvesting of Dungeness crabs and prawns trapped commercially and recreationally in Rupert Inlet. During our visit to Rupert Inlet in July

1978, two crab traps set on the bottom about 0.5 km west of the Island Copper Mine wharf yielded about 45 adult crabs in 24 hours. No commercial crab catch records are available for Rupert Inlet alone, but records for Fisheries Statistical Area 27, which includes Quatsino Sound, show no clear trends for the crab catch during the last 10 years. The harvest of prawns, on the other hand, may have declined in Rupert Inlet during the last 5 years, at least according to the reports of one prawn fisherman working the area. Unfortunately, there has been no study to assess carefully the stocks of either crabs or prawns in Rupert Inlet and to document the year-to-year changes in populations since the mine went into operation.

A comparison was made of the mining/concentrating operation, waste disposal practices and environmental conditions in Rupert Inlet with those in Agfardlikavsâ fjord on the central west coast of Greenland, where relatively high concentrations of metals have been found in both the seawater and marine organisms as a result of sea disposal of mine tailings. It was concluded that the difference in metal availability from tailings in the two inlets is probably mainly due to differences in characteristics of the ores and of the concentrating processes used in the mill. The effects of environmental conditions, which are somewhat different in the two locations, are probably secondary factors in the differences of metal-leaching rates.

The discharge of waste rock into the foreshore area of the northeastern part of Rupert Inlet is removing from biological production, at least temporarily, the intertidal and shallow subtidal zones of this part of the inlet. Although there have been no ecological studies on salmon in Rupert Inlet, these shallow estuarine waters may be important as nursery areas for juvenile salmonids originating from Washlawlis and Waukwaas creeks, draining into the head of Rupert Inlet, and possibly for salmonids from other streams tributary to the inlet system. The waste rock also contributes turbidity to the waters of Rupert Inlet, but the proportion of the total turbidity caused by this source is unknown. Metals may be leached from the waste rock into Rupert Inlet waters, although there has been no evidence of this occurring from analysis of the seawater and organisms in the area.

The various options examined as alternative methods for disposal of the mine tailings, including ponding on land, do not offer any obvious risk-free solutions environmentally. It is believed that leaching into freshwater would be higher than into seawater, particularly if the pH were low as a result of oxidation of the sulfide minerals. The possibility of seepage of metal-rich effluent from a tailings pond on land (the area lies in a seismic zone and has high precipitation) would pose a serious threat to at least two salmonid streams. An improvement in retention of tailings on the bottom of the Rupert-Holberg inlet system and prevention of turbidity at Quatsino Narrows might be achieved with a deeper and redesigned outfall. Some preliminary studies are recommended to determine if the resuspension of tailings in the area between Hankin Point and the entrance to Quatsino Narrows is primarily due to sloughing of banks of accumulated sediments and associated turbidity currents, or from erosion of deposited material.

It is recommended that disposal of waste rock on the foreshore of Rupert Inlet be reviewed. To avoid possible further adverse effects on utilization of this area by juvenile salmonids, ideally such waste rock should be dumped on suitable land. If land disposal is entirely unfeasible, action should be taken to render the fronts of the waste rock dumps more readily colonizable by benthic marine organisms, at least by grading them to slopes no greater than 10°.

The environmental and ecological monitoring program should be reoriented to provide data suitable for assessment of the effects of mine tailings on the commercial fisheries supported by these waters, i.e., salmon, crabs and prawns. The program should provide statistically-reliable data on populations and distributions of crabs and prawns, showing year-to-year trends. The impact of mine tailings and waste rock on salmonids utilizing these waters should be studied in a suitable research program. Such research should provide information elucidating: (1) the impact of waste rock on the habitats of Rupert Inlet for rearing juvenile salmonids; (2) the effect of tailings on the food supply for juvenile salmonids, crabs and prawns through destruction by tailings of benthic populations and/or their habitats; (3) the effect of tailings-generated turbidity on migration behaviour of adult salmon; and (4) the effects of turbidity on primary productivity.

Experiments and monitoring should be conducted to determine the long-term behaviour of metals in tailings, so that appropriate action can be taken to prevent adverse long-term effects. Laboratory experiments could include the addition of organic material to tailings held in suitable lysimeters, so that anoxic conditions could be created such as might occur in Rupert Inlet sediments, and the behaviour of metals in the tailings and interstitial water could be monitored under different redox conditions. Bottom cores taken in areas where tailings have been deposited should be analysed for metal concentrations in the tailings solids and interstitial water at various depths in the core, to note if there has been any vertical migration of metal ions. If there is a long-term possibility that metals will be released from the tailings to the overlying water through the process of diagenesis in the sediments, it will be necessary to consider preventative measures to be taken after the release of tailings ceases when the mine closes, e.g., covering the tailings with a layer of clean sand. It may also be found that the physical character of the substrate for certain commercially-important bottom species has been unfavourably altered by the tailings (for example, prawns are known to prefer a rocky bottom), and suitable restorative action might be needed, such as emplacement of rocks on the bottom of parts of Rupert Inlet.

A series of recommendations is listed covering: (a) improvement of the waste disposal system and monitoring; and (b) short and long-term research.

1. INTRODUCTION

This review was initiated at the request of the federal and provincial (B.C.) Ministers of Environment in March 1978, following concerns about the sea disposal of mine tailings raised at the British Columbia Pollution Control Board Inquiry into the Mining, Mine Milling and Smelting Industries of British Columbia, held in Victoria during January 1978. The terms of reference for this review were: "that the British Columbia Ministry of the Environment and Fisheries and Environment Canada will review and report the facts with respect to: (a) the disposal pattern of tailings from Utah Mines in Rupert Inlet; and (b) the envirnomental change which is taking place, and its significance".

In undertaking this review, we were asked to seek the collaboration of those scientists who have been working directly on the project. We have done this through a series of interviews with individual scientists and groups of scientists during the course of 1978-80 (see APPENDIX I). We also took the opportunity of visiting the Island Copper Mine at Port Hardy and accompanying the company's environmental staff on a field trip in Rupert Inlet, Holberg Inlet, Quatsino Narrows and other parts of Quatsino Sound during the week of 17-22 July 1978. In the process of reviewing the effects of mine wastes in Quatsino Sound, we made an effort to study and compare the effects of sea disposal of wastes from other mining operations in the province, e.g. Alice Arm of Observatory Inlet, and in other parts of the world, e.g. Mârmorilik on the central west coast of Greenland. This provided an opportunity to check analyses on a few samples of water, organisms and sediments from Rupert Inlet, in order to authenticate values of metal concentrations obtained in the monitoring program, which are relevant for the review. We had at our disposal all the published and unpublished reports on the environmental aspects of Rupert Inlet, Holberg Inlet and Quatsino Narrows (see APPENDIX II). Reports on observations in other areas, where sea disposal of mine wastes is practised, were examined. Literature on pertinent research concerning effects of suspended solids and metals on marine organisms has also been studied for this review (APPENDIX III). A list of other existing, past and planned mining operations with sea disposal of wastes is given in APPENDIX IV.

The present report summarizes the processes involved in the mining and milling operation and methods of waste disposal, as they affect the marine environment. Some of the environmental problems arising from this activity are identified and these are ranked according to their ecological impact, especially in their effect on the commercial and recreational fisheries. Notwithstanding the fact that the monitoring program conducted by Island Copper Mine in Rupert and Holberg inlets is one of the best of this type conducted anywhere, there are certain shortcomings in the environmental data available for this review. These will be noted in our report. In our recommendations, we are proposing some reorientation of the monitoring program to provide the kind of data that we believe are needed for a proper assessment of the ecological impact of the mine waste disposal, especially as it affects the commercial and recreational fisheries.

2. MINING AND MILLING OPERATIONS

Island Copper Mine, of Port Hardy, a wholly-owned subsidiary of Utah Mines Ltd., which is a company controlled by General Electric Co. Ltd., commenced production in October 1971 with extraction of 33,000 tons per day of copper ore (averaging about 0.52% copper) from an ore body of 250 million tons having a life expectancy of 20 years. There is also present in the ore 0.015% molybdenum, regarded as a valuable supplementary product of the mining operation, owing to the current high demand for molybdenum as an additive for high-grade steel production.

The mining consists of an open-pit operation on the north shore of Rupert Inlet (50°35.8'N; 127°29.5'W), one of the reaches of Quatsino Sound, on the northwest coast of Vancouver Island (Fig. 1). An aerial photograph (Fig. 2) shows the open pit mine and adjacent facilities. Sulphide minerals provide the main source of metals from the ore body. They are also responsible on oxidation for acidification of leach waters. The sulphide minerals that have been identified are: pyrite (FeS_2), 3%; chalcopyrite ($Cu\ Fe\ S_2$), 1.5%; sphalerite (ZnS), 0.02%; molybdenite (MoS_2), 0.02%; bornite ($FeS.2Cu_2S.CuS$) and galena (PbS), 0.01%. The chalcopyrite contains approximately 90% of the copper, and the molybdenite contains about 60% of the molybdenum present in the feed. The main objective of the mine is to win copper from the ore; the secondary objective is to obtain molybdenum. The rarer and noble metals are also extracted in the final refining process, but these are relatively inconsequential in terms of total amount of metals removed. The production of the mine was increased from 38,000 tons of ore in 1978 to 41,000 tons in 1980. About 3 times this amount, or 120,000 tons, of waste rock are also removed daily. The ore is trucked into the mill for processing; the waste rock is trucked to the foreshore of Rupert Inlet where it is dumped.

The following is a highly simplified description of the extraction processes in the mill. For more detailed accounts, the reader is referred to technical reports from the mine and/or those of the faculty of the Department of Mineral Engineering, UBC. The objective in the concentrator mill operation is to extract as much copper and molybdenum concentrate from the ore as technically and economically feasible. This is done by:
(1) grinding the ore to as fine a powder as possible, within technical and economic limits, since metals extraction depends largely on the amount of surface area exposed to flotation and collection chemicals; and
(2) extracting the available metals as completely as technology will allow. To achieve its objective the company has installed the latest in automated testing and controlling devices, which are capable in making continuous adjustments in the grinding and flotation processes to achieve the highest efficiency technically attainable, within economic limitations, in metals extraction.

In the mill, the large blocks of quarried ore initially pass into a chute and primary crusher, where they are reduced by a concentric rolling-pin-type crusher into chunks about 20 cm (8 in) in diameter. Then the crushed ore is screened and the finer and coarser fractions proceed on conveyor belts to separate stock piles from which the different-sized materials are blended as feed into autogenous grinding mills, where the chunks of ore are further broken down by impact with each other and the sides of the rotating cylindrical-shaped drums. Ultimately, the small pieces of ore enter a ball mill, where water is added and they are rendered into a fine powder by the grinding action of steel balls in the rotating drum impacting on the ore fragments. Grinding to a fineness of 75% of the ore passing 74 μm mesh screen is required for efficient liberation of metals. The pulverized ore slurry is then conveyed into the flotation mill. Here, a conditioning agent (xanthate collector) and frothing agent (Shell Froth D frother) are added, along with sodium cyanide and sodium hydrosulphide depressants. These allow the copper ore slurry to foam on aeration and to induce preferential adherance of the fine copper particles to the froth. The copper-rich froth is skimmed off from the vats and is conveyed to a filter and drying operation, where most of the moisture is removed. The copper concentrate in this form contains 23-25% copper. The mine produces about 700 tons of such concentrate daily. It is shipped in bulk on freighters to overseas points or to smelters on this continent for final processing, where the copper is refined and the noble metals are extracted. The ships are loaded at a wharf adjacent to the millsite, directly from the copper-concentrate storage building.

The pulverized rock from the copper concentrator is conveyed to another section of the mill, where another flotation agent and depressant are added to induce preferential adhesion of molybdenum. In the same way as in the copper-concentrating section of the mill, the molybdenum-rich froth is skimmed off and dried for shipment. About 10 tons of molybdenum concentrate (40% Mo) are packed in drums daily for shipment to a molybdenum smelter. Rhenium is extracted as a by-product from the molybdenum concentrate for use mainly in catalytic converters of automobile air pollution control devices to oxidize nitrogen-containing products in the exhaust.

3. WASTE DISPOSAL FROM THE MINE AND MILL

The waste rock from the mine, consisting of overburden and very low-grade ore, is dumped into the foreshore area of Rupert Inlet in front of the mine and millsite. The intertidal and shallow subtidal areas of the north shore of Rupert Inlet are being systematically filled in by this waste rock. The foreshore lease used for the waste rock extends approximately from the midline of the inlet to an elevation of about 5 m above high tide, and from a point about 0.5 km east of the Island Copper Mine wharf to 1.5 km from the east end of Rupert Inlet.

The tailings from the mill, containing 30-34% solids, flow by gravity through a feeder-line to a splitter box, which splits the stream into two Type S, Dorr-Oliver-Long thickeners of 114 m diameter. Here, lime and polyacrylamide reagents are added to thicken or coagulate the tailings, with typical dosages being 0.3 kg/t of lime and 5 g/t of polyacrylamide. The supernatant water overflows to a sump at a rate of 300-375 L/s and is pumped as reclaimed water to a 22 × 10^6 litre head-tank, where it normally exhibits a pH of about 11.3 and contains less than 50 ppm suspended solids. The combined thickener underflow slurry, containing 40% solids by weight, flows by gravity through an 85-cm diameter high density polyethylene discharge-line to a tailings-seawater mix-tank chamber.

The mine tailings are then premixed with seawater in a ratio of 1:1 and are discharged through a 105-cm (42-in) diameter polyurethane-lined steel pipeline, projecting at right angles from the shoreline to a depth of 50 m below lower low water at about 250 m from shore. Being heavier than seawater (specific gravity 1.2 to 1.4), the tailings flow down the slope of Rupert Inlet to the deepest part of the Rupert Inlet-Holberg Inlet system, near Quatsino Narrows. The tailings may form banks and levees from settling of the solids on the sides of the channels at the bottom of the inlet. These banks and levees may occasionally collapse and slough off, causing turbidity currents (mudflows) along the bottom of the inlet. In the highly turbulent area, at the junction of Rupert and Holberg inlets and Quatsino Narrows, some of the tailings are resuspended with the upwelling waters, forming clouds of silty water at the surface between Hankin Point and the north entrance of Quatsino Narrows. This appears to occur particularly during periods of large tidal range when the currents and turbulence are especially strong, and when the density difference between inflowing seawater and resident water is greatest.

Samples of the tailings slurry from the thickeners are shipped bi-weekly to B.C. Research, Vancouver, for 96-hour bioassays. Coho salmon, *Oncorhynchus kisutch*, were originally used as the test organism. Recent bioassays have used rainbow trout, *Salmo gairdneri*, because they are more convenient to maintain and are equally as sensitive as coho. Bioassay results must meet provincial requirements of 50 percent survival of the test fish over a 96-hour period of exposure to slurry diluted in a ratio of 1:1 with clean seawater, but tests almost always yield 100% survival. Corrective action is taken if bioassay tests show that the slurry sample does not meet this requirement, e.g., as occurred when a new frother was used in the mill. The only liquid from the mill operation discharged into Rupert Inlet through the tailings line is that present in the underflow from the thickeners.

In the event that it is found necessary to withhold tailings from sea disposal for some reason, there is an emergency tailings pond on the waterfront adjacent to the mill to which the tailings can be diverted.

4. LIVING RESOURCES

Unlike many inlets along the British Columbia coast, the Rupert Inlet-Holberg Inlet-Quatsino Narrows area is comparatively rich in marine flora and fauna. No doubt, this is due in part at least to the strong tidal currents and turbulence in Quatsino Narrows. The lush beds of kelp and other macrophytes in Quatsino Narrows have associated communities of invertebrates and fishes. On reefs and rocky islets at the south end of Quatsino Narrows, for example, there are beds of the large mussel, Mytilus californianus, associated with luxuriant growths of Laminaria and Fucus. In the quieter coves of Quatsino Narrows, various species of rockfish are present in substantial numbers. Beds of abalone and scallops have been exploited in these waters. Divers have found that the rich benthic flora and fauna of Quatsino Narrows extend for a considerable distance into Rupert and Holberg inlets, but the greater part of these two inlets is more sparsely populated by marine biota than Quatsino Narrows.

Commercial fisheries harvests within the Rupert Inlet-Holberg Inlet system, besides some salmon taken by trolling, consist mainly of Dungeness crabs, Cancer magister, and prawns, Pandalus platyceros, both of which can be trapped in Rupert Inlet. The fishery for these crustaceans is small, supporting only one or two fishermen in season. One fisherman, Mr. Rupert Kevis of Quatsino, has trapped prawns in Rupert and Holberg inlets since 1974, but reported that 1979 was a poor year and that he was planning to move out of the area for prawn fishing. He noted that trap hauls that once yielded 60 lb produced only 30 lb of prawns in 1979. Moreover, there was an alleged discoloration in the prawns after capture that made it difficult to market them. Crabs are not fished regularly in Rupert or Holberg Inlet, but during certain years (e.g., 1975) crab fishermen move in and fish intensively for a period. Part-time crab fishermen harvest crabs in Rupert and Holberg inlets every winter between salmon fishing. The records for crab catches in Fisheries Statistical Area 27, of which Rupert and Holberg inlets are a part, show no significant changes during the years 1963-1978.

The principal fishery resource supported by Rupert and Holberg inlets is Pacific salmon. Several of the streams are good producers of salmonids. A notable salmon producer is the Marble River, which drains into Varney Bay at the southwestern corner of Rupert Inlet near Quatsino Narrows, and supports a major escapement of coho, Oncorhynchus kisutch, averaging 30,000 spawners annually. It also has a significant escapement (7,500) of chinooks, O. tshawytscha, and smaller escapements of sockeye, O. nerka, pinks, O. gorbuscha, and chums, O. keta. The two streams draining into the head of Rupert Inlet, Washlawlis and Waukwaas creeks, support runs of coho, pinks, and chums. Waukwaas Creek has major escapements of pinks (40,000) and coho (7,500). Stephens Creek, which drains into Coal Harbour at the eastern end of Holberg Inlet, is a significant coho producer (1,000 spawners) and has small escapements of pinks (60) and chums (500). These are the major streams which either have their drainage basins adjacent to the mining area or drain into Rupert Inlet. Three small creeks on the site of the Island Copper Mine and the millsite were either destroyed in the excavation of the mine or were reduced to drainage streams through the millsite during construction. The original salmon production, if any, of these streams is unknown.

There is no regular commercial fishery for salmon with seines and gillnets in Quatsino Sound inside Cliffe Point. The Fisheries Officer occasionally opens Rupert Inlet to gill netters for brief periods when the escapement of pinks and coho is large. The salmon troll fishery is restricted principally to the main part of Quatsino Sound, although some troll fishing is permitted in Rupert Inlet near Quatsino Narrows. Varney Bay, at the entrance to the Marble River, is opened occasionally to troll fishing. It has been closed in the past even to sportsfishermen to protect coho and chinooks that congregated there. Both Rupert and Holberg inlets support a substantial salmon sport fishery. There are no official records available of effort or catches in the sport fishery for this area.

No detailed studies have been made on the fishery resources of the Rupert and Holberg inlet area. An exploratory survey was made on shrimp and prawn resources of the inlets, as part of a shrimp and prawn prospecting survey of the whole British Columbia coast in 1954, by Messrs. T. H. Butler and G. V. Dubokovic. Records are maintained of monthly and annual fish catches of all commercial species taken in Statistical Fisheries Area 27. Annual spawning escapement records are maintained by the local Fisheries Officer for significant salmon streams. Although the monitoring program conducted by the environmental staff of the Island Copper Mine includes occasional sampling of crabs with traps, bottom fish taken by long-line, and juvenile salmonids captured by beach seines for metals analysis, there is no systematic study of the various commercially important species in terms of their ecology, life history or population dynamics. The biological data collected could have application to a study of the fisheries resources, but the monitoring program is not specifically designed to gain an understanding of the effects of the mine wastes on individual fish and invertebrate species.

The fisheries officers' records for salmon escapement to the four streams noted above have shown no significant changes since the mine went into operation in 1971. It is noteworthy that the pink salmon run to Waukwaas Creek was remarkably large both in 1978 and 1980, prompting an opening of Rupert Inlet to commercial fishing for two 12-hour periods during the summer of 1980. There were reported to be over 50,000 pinks at the head of Rupert Inlet in August 1980. The one change in spawning migration behaviour noted by Mr. B. A. Richman, Fishery Officer at Port Hardy, was that coho, which normally school inside a small island in Varney Bay during their spawning migration, changed their pattern in 1978 and 1979 and schooled south of Quatsino Narrows. They now appear to move rapidly through Rupert Inlet to their spawning streams. There are no records for commercial catches of salmon heading for individual streams.

Annual records of herring spawning along the British Columbia coast, since 1942, have shown no spawn in Rupert Inlet, but deposition has occurred at a number of points in Holberg Inlet, especially in Coal Harbour, Apple Bay and the mouth of Hathaway Creek. Herring are found almost year-round, however, in Rupert Inlet, and have been fished for bait. A productive fishery for herring existed at the outer entrance to Quatsino Sound at one time (prior to 1967), but the spawning for these stocks apparently occurred outside of Rupert and Holberg inlets.

Various species of bottom fish, including black bass, lingcod and even halibut, have been caught in Quatsino Narrows by sports fishermen. Dogfish are apparently quite plentiful as a nuisance species in most of Quatsino Sound, including Rupert Inlet. However, according to the local fisheries officer, most of the sports fishermen have moved away from Quatsino Narrows and are concentrating on the area between Cliffe Point and Kains Island in outer Quatsino Sound. There is some feeling that rockfish have moved out of parts of Holberg and Rupert inlets because their habitat has changed from preferred rocky bottom to tailings deposits. Clam beds are exploited recreationally at the mouth of Washlawlis Creek in Rupert Inlet and in Apple Bay of Holberg Inlet. During the summer of 1980, the whole area was closed for the taking of molluscan shellfish because of red tides.

The local Indian community has traditionally relied on fish and shellfish from Quatsino Narrows for their fresh fish supply. They harvested mainly lingcod and some abalone for this purpose. According to Mr. Frank Wallas, chief of the Quatsino Band, the Indians have ceased to make use of this resource because waters are "muddy" in Quatsino Narrows and there is concern among the native people that seafood contaminated by the mine tailings may be unsafe to eat. In the 6 years (1974-1980) that Mr. B. A. Richman was a fisheries officer at Port Hardy, only three food fish permits were issued to local Indians and only two of these were used. One of the permits was used for taking sockeye outside the study area. A number of the local Indians are commercial fishermen and do not apply for fish food permits.

Quatsino Sound has varied wildlife. There is a colony of seals at the Straggling Islands in Holberg Inlet. Individual seals can be seen at the head of Rupert Inlet, as observed by one of us (M.W.) during a visit there on 30 August 1980. Sea lions frequent Quatsino Narrows. Assorted water fowl can be found in virtually all the estuaries. A unique feature among the avian fauna is the large number of eagles in the Quatsino Narrows area presumably feeding on the abundant sea life present in these waters.

5. MONITORING PROGRAM

When the permit was issued by the B.C. Pollution Control Branch to Island Copper Mine, allowing it to discharge mine tailings into Rupert Inlet, a condition of the permit was that a monitoring program will be conducted by the company and that the results will be evaluated annually by an independent agency. A monitoring program was developed, in consultation primarily with interested staff in the Departments of Mineral Engineering, Geological Sciences, Zoology and Botany and in the Institute of Oceanography (now the Department of Oceanography) at the University of British Columbia. Later, a member of the Department of Biology in the University of Victoria also provided consultation. These university faculty members formed a consortium, which acted as the independent agency to review the design, methods and results of the monitoring program and to report to the B.C. Pollution Control Branch (now the Waste Management Branch).

In general, the program consists of quarterly observations at a number of selected stations in Rupert Inlet, Holberg Inlet, Quatsino Narrows and the eastern end of Quatsino Sound proper. Bottom samples are taken with a Phleger corer and a Ponar grab for both physical characterization of the sediments, and counts, biomass and identification of benthic organisms. Water samples are taken at about four depths for salinity, dissolved oxygen, nutrients, turbidity and selected metals determinations. A Secchi disc reading is taken on each station for depth of visibility, and a continuous vertical profile of turbidity is made with a transmissometer. Vertical and horizontal plankton tows are made for zooplankton biomass, counts and identification of organisms and metals determinations. Productivity measurements are made with light and dark bottles, using carbon-14 for carbon uptake measurements.

Crabs, fish, prawns, clams, and mussels are taken at several stations for metals analysis. Traps are used for crabs and prawns. Beach seines are used to capture juvenile salmonids in the shallow areas during the spring. Hand-lines are used to capture rock fish near the bottom. Clams are dug in some of the rich intertidal areas, e.g., the south side of Rupert Inlet opposite the mine. Mussels are removed from intertidal rocks and pilings. There does not seem to be a systematic sampling and analysis of the larger organisms in Rupert and Holberg inlets, except for crabs sampled at 6 stations quarterly.

In the intertidal and shallow sub-tidal zones, fibreglass settling plates are set at a number of selected points. These are removed monthly, photographed and the amount of organic matter determined by scraping off the settled material, drying and weighing it, and then burning it in a furnace and weighing it again. In intertidal areas of tailings deposition, the amount of material deposited during different periods of the year is measured at gauging pegs driven into the ground. The general scope of the monitoring program on the effects of tailings in the Quatsino Sound system, for which the Island Copper Mine and the independent agency were responsible to the B.C. Pollution Control Branch, is given in Table 1.

The rock waste dump is monitored at a number of points with seismic observations to determine its stability. This is mainly for safety purposes to ensure that an accumulation of waste rock does not slough off without warning into deep waters of Rupert Inlet. The waste dump did not come under the purview of the Pollution Control Branch of the British Columbia Ministry of Environment. Hence, no biological monitoring program was developed to enable an assessment to be made of the ecological effects of dumping the waste rock. Rather, it is within the responsibility of the British Columbia Ministry of Energy, Mines and Petroleum Resources and is controlled under the B.C. Mines Regulations Act (1967).

While the waste rock aspect of the mine operation does not come strictly within our terms of reference, we would like to note that it may have a significant ecological impact in 3 different ways, given as follows in the expected order of decreasing effect: (1) reduction and possible total elimination of intertidal rearing ground for juvenile salmonids in that section of the foreshore where the waste is dumped; (2) release of metals from the exposed ore (even though this is very low grade, it may contain as much as 2500 μg/g (0.25% or 2500 ppm) of copper, and gravitational sorting of fine material can further concentrate the metal-bearing minerals locally in the intertidal and subtidal zone); and (3) release of pulverized rock, which adds to the turbidity of Rupert Inlet waters, especially during slumping of portions of the waste rock dump into deep water. We were informed by the fisheries officer that some of the waste rock had slumped into Rupert Inlet on several occasions during 1980, according to mine sources.

We noted during examination of the site in July 1978 that the comparatively steep front of the waste rock dump did not permit biological colonization during the period of its exposure since its creation, possibly because of its steepness and instability. An experiment being conducted at that time in a small sector of the waste dump, where the slope of the rock dump front had been bulldozed to a much smaller angle with the horizontal (ca. 5°), appeared to be producing encouraging results. Colonization by algae and associated fauna, e.g., amphipods, had commenced within the 2-month period since the waste rock front had been modified.

The environmental staff of the Island Copper Mine occasionally undertake experiments outside the regular monitoring program. In May 1978, for example, they conducted measurements of turbidity and tailings transport through Quatsino Narrows during two tidal days. This provided an estimate of the amount of suspended matter of mine tailings origin, which escaped from Rupert Inlet into Quatsino Sound proper during a given tide.

Aerial flights are taken regularly to observe and photograph any turbidity from the mine tailings that may be present in the Quatsino Narrows-Hankin Point area or elsewhere in the system. Dye tracer techniques have been used to follow tailings in the turbulent area near Quatsino Narrows.

6. GENERAL OBSERVATIONS OF THE EFFECTS OF MINE TAILINGS IN THE INLET SYSTEM

Mine tailings are making a significant change in the bathymetry of the Rupert Inlet-Holberg Inlet system. They are rapidly filling in the deepest part of the system, with a depth of about 20 m of tailings in some sections of the axial trench by mid 1980. It is anticipated that 10 percent of the volume of Rupert Inlet will have been filled in by tailings during the lifetime of the mine.

6.1. Physical Dispersion of the Tailings

A slurry of pulverized rock in water, which is basically the make-up of the tailings, is heavier than seawater and settles to the bottom. The finer particles of tailings may remain suspended for a long time in freshwater, but they coagulate and flocculate in seawater because of the neutralization of the mutually repulsive electric charges on the particles. For this reason, deposition of mine tailings without visible surface turbidity has been generally more successful in marine environments than in freshwater. Lime and polyacrylamide are added to the tailings in the thickeners to coagulate and flocculate much of the fine fraction in the tailings solids. To provide additional flocculation of the fines, along with increased density of the water in which the tailings are suspended, seawater is pre-mixed with the tailings prior to discharge through the outfall pipe at the Island Copper Mine.

As the tailings leave the open end of the outfall pipe, they flow southward down the slope of the side of the inlet and then veer westward along its longitudinal axis toward the lowest point in the Rupert-Holberg system. Soundings suggest that the momentum of the tailings flow across the inlet as it flows downhill from the outfall pipe actually causes it to flow partway up the slope on the south side before veering westward. Particulate material is deposited by gravity along the way, with the coarser, heavier particles settling out first. There are indications that a trench has been formed by the meandering tailings flow, with levees on either side as much as 10 m high. Soundings taken in rapid succession across Rupert Inlet show that these levees are highly unstable and are constantly changing location and form. Banks of sediments probably accumulate at certain points where settling conditions are suitable. As these banks grow, they become unstable and slough off. If they are high above the deepest part of the inlet, they may form powerful intermittent turbidity flows, which travel considerable distances downhill along the bottom of the inlet axial trench. Tailings have been progressively filling in the deepest parts of Rupert and Holberg inlets. By 1980, tailings had reached the east end of Holberg Narrows off Hathaway Creek, nearly half-way up Holberg Inlet.

In a normally stratified coastal marine system, where fresh and brackish waters overlie denser seawater and there is little vertical interchange between the bottom waters and the surface, mine tailings remain on the bottom with little surface manifestation of the suspended solids. This occurred with the disposal of mine tailings into Howe Sound from the Britannia Mine. However, Rupert Inlet, particularly the waters in the vicinity of Quatsino Narrows, is not the typical vertically-stratified inlet system. It is rather well mixed by tidal currents and turbulence, especially during periods of large tidal range and high density of inflowing seawater relative to water in the inlet. Hence, fine particulate material deposited on the bottom of the inlet does not remain there as it would in a typical stratified inlet, but is subject to resuspension in the turbulent area near Quatsino Narrows. During periods of large tides, especially when seawater entering Quatsino Sound from the Pacific Ocean is dense (high salinity and low temperature) because of coastal upwelling, and seawater in Rupert Inlet has been diluted by precipitation and runoff, the inflowing jet of seawater will plunge downward, displacing the deep water present in the Rupert Inlet-Holberg Inlet system. This leads to a stirring upward of bottom water and tailings in an upwelling action, creating the clouds of silty water at the surface. A crude estimate by UBC geologists of the amount of suspended sediment throughout Quatsino Sound, including Rupert and Holberg inlets, at a given time, is roughly equivalent to one day's tailings discharge from the mine. The surface turbidity, resulting from prolonged suspension or resuspension of tailings and/or mine waste, is clearly visible from the vicinity of Drake Island in Quatsino Sound through Quatsino Narrows into most of Rupert Inlet and at least as far west as Coal Harbour in Holberg Inlet.

The intensity of surface turbidity in the Hankin Point-Quatsino Narrows area undergoes seasonal cycles, related in part to tidal range and in part to density of resident water relative to inflowing sea water. The local fisheries officer stated, however, that it is difficult to relate the intensity of turbidity with tide, from visual observations. There appear to have been year-to-year fluctuations as well. During the early phase of mine operation from 1971 to 1973, there was apparently a rather minimal amount of surface turbidity. Then the turbidity increased for a period of a year or two during 1973-75.

It has been suggested that the greatest amount of tailings came to the surface between Hankin Point and Quatsino Narrows in 1973-1974, when the tailings delta front was moving past the north entrance to Quatsino Narrows. In subsequent years, the turbidity was apparently not nearly as acute. However, both Mr. Brian Richman, the Fisheries Officer at Port Hardy, and Mr. Rupert Kevis, the Quatsino prawn fisherman, reported from their visual observations that turbidity was very high in the Hankin Point-Quatsino Narrows area during the spring of 1979, approaching that observed during 1973-1974. Aerial photographs taken during periods of intensive turbidity show a band of highly turbid water around Hankin Point. This has led to deposition of mine tailings in the intertidal zone at Hankin Point, deposits being as much as 25 cm (10 in) deep in July 1978 on a rather coarse natural substrate.

While the deposition of tailings in the intertidal and subtidal area of Quatsino Sound has been heaviest at Hankin Point, there has been some deposition in other parts of the Sound as well. Most of the shallow-water deposition is concentrated around the confluence of Holberg and Rupert inlets and Quatsino Narrows. There is deposition in virtually all of Rupert Inlet and about half way up Holberg Inlet, as well as a light deposition in the north-eastern sector of Quatsino Sound proper. Mr. B. A. Richman reported that there was turbidity as far west as Brockton Island in Quatsino Sound during 1980. Mine monitoring staff have attempted to determine the maximum possible net transport of suspended solids through Quatsino Narrows into Quatsino Sound, and have estimated it to be less than 50 tonnes per day. Air photos indicate that some of the tailings lost through Quatsino Narrows on the ebb tide may return with the rising tide. There is always a marked delineation between Rupert Inlet and Holberg Inlet waters at changing tides.

6.2. Biological Effects of Mine Tailings

6.2.1. Particulate Matter

Suspended particulate matter has a variety of biological effects in seawater, ranging from inhibition of light penetration in the water column and reduction of photosynthesis to burial of organisms on the bottom when deposition is heavy enough. In Rupert and Holberg inlets, with an introduction of 41,000 tons per day of inorganic particulate matter, there is little question about the most significant ecological impact being the burial of bottom organisms and the obliteration of benthic habitats.

Bottom fishes and invertebrates, which can swim or crawl, probably avoid the deepest parts of Rupert and Holberg inlets, where there is undoubtedly a continuous flow of tailings. Even mobile animals occupying areas subject to intermittent episodic events, such as slumps and turbidity currents, are probably killed outright when these events occur. Sedentary organisms, indigenous to the deepest parts of the inlet system, were probably buried by the tailings and do not have an opportunity to become reestablished with the continuing tailings input. The effects of tailings particulate matter deposited on benthic organisms and habitats in shallower water is unknown, but it is felt that most species can cope with the lighter deposition, i.e., less than that occurring at Hankin Point. Crabs are probably affected to some extent by mine tailings, but their normal habitat occupies a depth range of 10-30 m, which is outside the heaviest deposits of tailings. Prawns are likely affected more because they prefer depths of 70-100 m and a rocky substrate. Mine tailings could be reducing the habitable zone of Rupert Inlet and eastern Holberg Inlet for both crabs and prawns to the shallow waters, where deposition is less.

Research on the effects of suspended matter on fish shows that, except for very high concentrations of suspended material, there appears to be little acute effect on fish from this type of pollution. Weak fish and those suffering from any kind of disease are the first to succumb from stress brought on by particulate materials in the water. Particulate matter affects the gills and the ability of the fish to exchange carbon dioxide for oxygen across the gill membranes. Except for the zone of concentrated tailings near the bottom, it is unlikely that the particulate matter from tailings in most of the water of Quatsino Sound would have any noticeable effect on fish performance. It is conceivable, however, that the presence of tailings could affect the migration behaviour of salmonids, since the fish seem to be delicately tuned to certain physical and chemical characteristics of the water when they seek their home stream.

The effect of particulate matter on zooplankton is virtually unknown. If there is any influence of mine tailings particles on zooplankton, the impact is probably greatest on the egg and larval stages. At this time, however, there is no reason to suspect that there is a marked effect of the mine tailings particles on the zooplankton, except in the deepest water, in any part of Quatsino Sound.

Phytoplankton require light for photosynthesis, and anything present in the water which inhibits the penetration of light will affect the productivity of phytoplankton. Suspensions of tailings particles could cause such light attenuation and reduction in productivity. However, observations made so far on primary productivity in Rupert Inlet have not shown a significant decline since the mine went into operation. It is possible that at the concentrations of tailings particles present in most parts of Quatsino Sound, the effect on light is to scatter it rather than to attenuate it effectively in the euphotic zone.

The deep, intense, turbulent mixing prevalent in eastern Quatsino Sound proper, Quatsino Narrows, Rupert Inlet and eastern Holberg Inlet can be expected to reduce photosynthesis by phytoplankton significantly below their potential, based on the nutrients and surface illumination available. Consequently, the rich benthic and pelagic fauna present in these areas will depend more upon production by benthic plants and upon imported particulate organic matter than on phytoplankton production for their food supply. Thus, reduction in phytoplankton production would have less serious effect, and reduction in benthic algae production would have more serious effect, upon overall productivity of this tidally-mixed system than in more quiescent waters. Suspended sediments within the affected area do not alter the amount of suspended organic matter originating outside and carried into the affected area by tidal exchange. It is theoretically possible, moreover, for suspended particles to adsorb dissolved organic matter, thereby rendering it accessible to filter-feeding organisms, and to promote its sedimentation to the bottom, where it can nourish deposit feeders living in the sediments. Such an adsorption process would tend to increase the biological productivity of the system to the extent that the adsorbed carbon is incorporated not into microorganisms (which would tend to mineralize it to carbon dioxide), but into higher animals.

The effect of deposition of tailings on macrophytes and rooted aquatic vegetation is unknown. Underwater photographs of bottom vegetation near Quatsino Narrows show fronds of Laminaria sp. and other macrophytes covered by tailings, giving the appearance of greyish and rather unhealthy plants. We were not aware of any detailed investigation of the actual impact of tailings on these submerged marine plants. It was apparent during our July 1978 visit to Rupert Inlet, Holberg Inlet, Quatsino Narrows and eastern Quatsino Sound proper that the intertidal and shallow subtidal seaweed populations were quite dense and diverse compared to other inlets, even in areas having visible tailings turbidity in the water.

At Hankin Point, it was clearly noted during the above visit that eelgrass Zostera sp., had colonized the tailings deposits. The roots were obviously in the tailings and not in the natural substrate. This indicated that the tailings were not acutely toxic at least to the eelgrass.

In areas experiencing heavy and permanent deposition of mine-related sediments, there will be a long-term change in the fauna colonizing the sites. The degree and duration of change will depend on the difference of tailings-produced sediment from the original sediment, and the nature and rapidity of subsequent alterations in the sediment. The change will be most marked in sites where the original substrate was bare rock or an encrustation of coralline algae. It is not possible at present, however, to assign relative values to productivity under the original conditions and under the changes that might occur.

6.2.2. Metals

There are several important effects of metals on marine organisms, which could arise from mine tailings: (i) acute toxicity; (ii) bioaccumulation; and (iii) other sublethal effects (e.g., metabolic dysfunction, behaviour alteration, chemoreception impairment). The metals must be present, however, in a biologically available form to have any impact on marine organisms. If the metal is in particulate, insoluble form, it is unlikely to become available to marine organisms, unless it is ingested, and under acidic conditions in the gut, it becomes at least partically solubilized.

There are various metals in tailings discharged into Rupert Inlet, and the concentrations of copper and molybdenum are considerably higher than those originally present in the natural sediments (Table 2). Although there are virtually no data on metal concentrations in the interstitial water of the tailings deposits or in the water immediately overlying the sediments of

Rupert Inlet, there is no field evidence that any appreciable quantities of copper or molybdenum are leaching into the water. Laboratory experiments confirm this, and showed in fact, that over a period of 37 days exposure to sea water of finely-ground Island Copper Mine tailings at a solids concentration of 17%, copper and iron concentrations in the supernatant water both decreased. In another leaching test of up to 6 months' duration, similar effects were found with respect to copper and molybdenum, but manganese increased in the supernatant seawater from 4 to 60 ppb (μg/kg) in 66 days. Metal concentrations in water samples taken at 50 m depth in Rupert Inlet prior to operation of the Island Copper Mine in May 1971, and in June 1978, are shown in Table 3. The increase in copper concentration is not considered significant, in view of the precision of the analytical method, and the fact that the two sets of analyses were done by different laboratories using different analytical techniques.

The reader should bear in mind, when reading the following paragraphs, that copper plays a special role in the respiration of certain crustaceans. The Malacostracan crustraceans (crustacea with compound eyes on stalks among other distinguishing features), which includes the mysids, cumaceans, isopods, amphipods, euphausiids, and decapods (crabs, lobsters, prawns, shrimps and others) have copper-containing haemocyanin as an oxygen carrier in place of iron-containing haemoglobin in their blood. This has obvious implications for the copper content of such animals and for the copper intake of those organisms which feed upon them.

There have been no indications of acute toxicity from metals to aquatic plant and animal life in the Quatsino Sound system. Sampling of marine organisms has been conducted for metal analyses by both environmental staff of the Island Copper Mine and by government laboratories. A typical set of analytical data for zinc and copper in samples of organisms taken at certain points in the Quatsino Sound area is given in Table 4. There is no clear-cut indication of higher-than- background copper concentration in organisms of Rupert Inlet, except in areas of acute exposure, such as near the concentrate-loading wharf. It is obvious that the metals in the tailings are largely not biologically available to organisms in Rupert and Holberg inlets.

Bottom organisms taken in the Ponar dredge and corer are washed out of the sediments, weighed for biomass and sent to BEAK Consultants for identification. Eventually metal analyses are conducted on the specimens. No unusually high metals concentrations have been reported.

Zooplankton samples are divided into two equal portions with a Folsom plankton splitter. Half of the sample is used for biomass determination and zooplankton identification. The other half is used for metal analyses. Zooplankton exhibit a seasonal fluctuation in copper concentration, which is obviously related to their seasonal feeding habits and metabolism. No year-to-year trends in copper concentration have been identified. There were occasionally large peaks in copper concentration. This was believed to be associated with the presence of larger crustaceans in the plankton, such as euphausiids, which normally contain higher copper concentrations than other planktonic organisms. At the recommendation of Dr. A. G. Lewis of the Institute of Oceanography, UBC, the various groups of zooplankton, e.g. euphausiids, copepods, chaetognaths, and ctenophores, are segregated for separate analysis. Any changes in metal concentrations can now be followed according to groups of zooplankton. So far, there are insufficient data on these analyses to allow any assessment of trends in metal concentrations in groups of zooplankton.

Metal data for water and organisms in the Rupert-Holberg inlet system indicate that most metal concentrations exhibit little change from background levels so far. If any of the elements have shown an increase, these are manganese and arsenic. An increase in manganese has been found in the Rupert-Holberg system, but its source is unclear, since there is a gradient in the system, with increasing levels into Quatsino Sound and toward Neroutsos Inlet. Dr. E. V. Grill of the Insitute of Oceanography, UBC, confirmed this gradient in one of his sampling programs. There is some suggestion that it may have originated from the Rayonier (B.C.) Ltd. pulpmill in Port Alice on Neroutsos Inlet. However, mine tailings exposed to sea-water have led to an increase of manganese concentration in the water with time. This is the one metal that exhibits a greater solubility in the sulphide form than the others in both fresh and salt-water environments. It does not appear to bioaccumulate appreciably in organisms of the Rupert-Holberg inlet system, judging by the data available so far.

Arsenic is one of the more toxic elements, and concern is expressed whenever it exhibits levels that are higher than background. Some crab specimens from Rupert Inlet have been found to show higher-than-background levels of arsenic in their tissues. Dungeness crab trapped in Rupert Inlet on 20 July 1978 were analysed by the Department of Fisheries and Oceans Fish Inspection Laboratory, Vancouver, for arsenic and other elements (Table 5). There was no significant difference between the arsenic concentration in the meat of Rupert Inlet crabs and that of crabs from an unpolluted area of the British Columbia coast. The arsenic level is close to the maximum permissible (5 ppm) specified for aquatic food products by the Food and Drug Directorate, but it is evident that this prescribed maximum can be reached or even exceeded in crabs taken from natural, unpolluted areas of the coast. Some further studies are needed to establish clearly the effects of mine tailings on arsenic levels in crabs, possibly by conducting uptake experiments with crabs exposed to tailings in the laboratory and in the field using caged crabs at different locations in the inlet system. A similar study may be warranted also for prawns in view of some recent data on arsenic in prawns from Holberg Inlet.

Analyses of fish-eating bird tissues taken from the Rupert-Holberg inlet system by the Canadian Wildlife Service indicate higher levels of arsenic than normally found in such birds. However, this aspect of the contamination problem has not been sufficiently investigated to provide conclusive evidence that the arsenic originates from mine tailings and passes through the food chain in the marine system to fish-eating birds.

6.3. Aesthetic Effects of Mine Tailings

There is an undeniable effect of tailings on the aesthetic quality of the Rupert-Holberg inlet system. A cloud of mine tailings in the turbulent area between Quatsino Narrows and Hankin Point is not as acceptable to the public as a plume of natural silty river water, e.g., at the Fraser River estuary during freshet. The net effects may not be too different, but the public views the man-made silt cloud as an unnatural phenomenon that is altering the natural ecosystem and interfering with the aesthetic quality of the environment. The effects of this silt on the number of visitors to the area may be insignificant, because there may be as many visitors coming to see the tailings boiling up in the Quatsino Narrows area from a curiosity point of view, as avoiding it from an aesthetics point of view. Real estate for permanent residences, however, may not be in as great demand as it might otherwise be. Sports fishermen probably sense an undesirable effect on the quality of their fishing experience and may go further afield to partake of their recreation rather than fish in Rupert Inlet, even though fish may be plentiful in the latter.

For recreational divers, mine tailings are definitely a serious interference with their sport. Suspended material from tailings reduces visibility and often covers those organisms which most divers seek to observe underwater at their best and to photograph. Although Rupert Inlet is known to have had large populations of certain marine organisms attractive for divers, e.g., sea pens, it is not likely that the area is frequented by recreational divers at present. There is still a diving site at the head of Holberg Inlet, but it is not utilized extensively.

There is a matter of adjustment to man-made changes, which over a period of time may lead to lessening of abhorance of residents to industrial activity in an area. It does not take long for recreational fishermen to exploit an area for crabs and fish, even if it is industrialized, once they find their efforts reasonably rewarded and the quality of the product not visibly impaired. After all, there is no unpleasant odor or other offensive condition in Rupert Inlet that interferes with amenities, other than the visual appearance of the mine and mill on the shore and the turbidity in the water from the tailings. For those who are sensitive to these aspects of industrial development and urbanization, however, there will always be a lingering feeling that things aren't the way they used to be. The local residents who once regularly fished the clear waters of Quatsino Narrows for lingcod and black bass have moved further afield away from the turbid waters, partly because of a concern that fish taken in the presence of mine tailings are unsafe to eat.

7. COMPARISON OF THE EFFECTS OF ISLAND COPPER MINE TAILINGS DISPOSAL INTO RUPERT INLET WITH OTHER SIMILAR SEA DISPOSAL OPERATIONS

A number of sea disposal operations similar to the one in Rupert Inlet have been reviewed through the literature or by discussions with individuals involved in such operations, in order to obtain a comparison of effects with those of the Island Copper Mine (APPENDIX IV). Some of the mining activities contributing to such sea disposal involve copper and molybdenum extraction, as at the Island Copper Mine; others are zinc and lead mines. Most of the mines reviewed have a substantially lower daily production in terms of ore processed than the Island Copper Mine. However, nearly all of them have higher concentrations of metals in the ore than that available at the Island Copper Mine.

The operation that was chosen for detailed comparison with the Island Copper Mine is the Greenex A/S (Black Angel) mine in Mârmorilik on the central west coast of Greenland. This mine extracts lead and zinc from a rather high-grade ore found in a mountain on the side of Agfardlikavsâ fjord. Tailings are released into the deep water of this fjord by an outfall discharging at 25 m. Agfardlikavsâ fjord is tributary to a larger fjord Qaumarujuk, from which its deep water is separated by a shallow sill (21 m). The tailings are confined behind the sill in Agfardlikavsâ. There is little evidence of turbidity from tailings in the surface waters, resulting from the discharge or from later resuspension of settled particulate materials. However, metals leach from the tailings into the overlying sea water, increasing the concentrations of zinc and lead a thousandfold in the bottom seawater.

There is a seasonal overturn of the bottom water in Agfardlikavsâ, partly due to increased density of surface water in winter caused by freezing, and partly due to a winter inflow of dense seawater over the sill. Thus the metal-rich bottom water is not only stirred to the surface in Agfardlikavsâ, but it eventually reaches also the outer fjord Qaumarujuk. Uptake of metals occurs in subtidal and intertidal organisms of the fjord system, including the seaweeds, invertebrates and fishes (mainly in the liver). This has created a great deal of concern, because seafood products from these waters are used extensively by the natives of the region.

Various options have been examined for reducing the amounts of metals that leach from the tailings into the water leading to the uptake by marine organisms. A dam across Agfardlikavsâ at its entrance sill would be not only costly, but would cause a great deal of inconvenience in navigation into the fjord, in addition to producing undesirable environmental effects, some of which are unknown. At the present time (since January 1979), alum, a flocculating agent, is being added to the tailings prior to discharge, in order to minimize the leaching of metals. Its effectiveness will not be known for at least two years.

We examined reports on the Greenex A/S mine waste disposal operation, and the effects of the tailings on seawater and marine organisms, with considerable interest, because of some similarity of environmental conditions there with those in Rupert Inlet. Were we failing to observe an effect of mine tailings on metal concentrations in the seawater and biota of Rupert Inlet because analytical measurements were inadequate? For this reason, we obtained the cooperation of Mr. Gert Asmund of the Geological Survey of Greenland, Copenhagen, Denmark, who had been much involved with chemical analyses of samples from the Qaumarujuk-Agfardlikavsâ system. He agreed to run analyses of check samples for us on water, sediments and tissues of marine organisms taken from Rupert Inlet. These are shown for seawater in Table 3 and for crab tissues in Table 5. The data confirmed the earlier analyses conducted at the Island Copper Mine and at other laboratories in the Pacific Region, which showed that little of the metals in the tailings from the Island Copper Mine was being leached into the seawater of Rupert Inlet and bioaccumulated in marine organisms. A laboratory study was conducted recently on uptake by a filter-feeding mussel, *Mytilus edulis*, and a deposit-feeding clam, *Macoma balthica*, of metals from three types of mine tailings, incluing those from Island Copper Mine and Greenex A/S. It gave results comparable to those observed in the field with high uptake of metals from tailings of the latter mine.

On finding the foregoing difference in the behaviour of mine tailings in two different areas, one immediately seeks the cause of this difference. There is no obvious reason for this anomaly, and no one was able to explain it to us clearly and convincingly. It is true that the ore mined by Greenex A/S is much higher grade in metals than that at Island Copper Mine, but the concentrations of metals in tailings from the two mines are not too different. Because the Island Copper Mine extracts mainly copper and molybdenum, whereas Greenex A/S is a lead/zinc operation, there is a basic difference not only in the characteristics of the mined ore, but also in the process applied in extracting metals from the ore. It would seem that both of these factors may play an important role in the eventual solubility of the metals from the tailings in the seawater. There is little difference between environmental conditions at Agfardlikavsâ and those at Rupert Inlet to lead to different rates of metal leaching. In laboratory tests, tailings taken from the various process streams at the Greenex A/S mine have shown an increasing release of the metals in seawater with advancing stages of processing in the mill. This suggests that the mill process itself, as well as the final treatment of tailings before discharge, are important factors in the availability of the metals from the tailings for solution in seawater. At the Island Copper Mine, the metals remaining in the tailings appear to be quite firmly fixed in a highly refractory matrix of silica or other comparatively insoluble mineral. The tailings from Greenex A/S contain metals in a more soluble carbonate form. There appears to be little question that all factors at the Island Copper Mine are favourable for reduced mobility of metals from tailings into seawater. This comparative study showed that there is no substitute for a site-specific investigation of mine tailings disposal into the sea for a reliable assessment of the environmental effects of such an operation.

8. CONCLUSIONS

1. Mine tailings from the Island Copper Mine at Port Hardy are altering the Rupert Inlet-Holberg Inlet ecosystem, primarily by the heavy deposition of the pulverized rock material on the bottom in the deepest part of this inlet system. Bottom organisms are being smothered and benthic habitats are obliterated in the inlet trench by 41,000 tons of mine tailings discharged daily into Rupert Inlet. This was anticipated in planning the mine and tailings disposal operation. About 10 percent of the volume of the Rupert-Holberg inlet system in its deepest part will be filled in by the tailings discharge during the life of the mine.

2. Judging by the presence of worms and other invertebrates in tailings deposits of Rupert and Holberg inlets, recolonization of the

tailings-covered bottom by many species should be quite rapid (within five years) following cessation of tailings discharge. It may be decades, however, before the system stabilizes itself ecologically, as natural material from the drainage basin covers the tailings deposits. There is little information on recovery of similar marine systems elsewhere containing mine tailings.

3. Tailings are resuspended by tidal turbulence and upwelling at the junction of Rupert and Holberg inlets, in the vicinity of Quatsino Narrows. This phenomenon was apparently not anticipated when the tailings disposal system was planned. The resuspension appears to be most intensive on the flood stage of the tide during periods of large tidal range. Some of the resuspended material is deposited in the intertidal and shallow subtidal areas of Rupert and Holberg inlets. The heaviest deposit of up to 25 cm has been noted at Hankin Point. Suspended tailings have also been transported seaward on the ebb tide through Quatsino Narrows and reached the eastern end of Quatsino Sound proper. This material has been deposited thinly (up to a few millimeters) in the northeastern sector of Quatsino Sound south of Quatsino Narrows. The ecological impact of the deposit of resuspended tailings is unknown, although some physical damage to intertidal plant and animal organisms could be expected. The tailings appear to be relatively non-toxic to marine plants and animals, judging by the colonization of the intertidal tailings deposit at Hankin Point by eelgrass, colonization of the tailings on the bottom by worms, and the generally low concentrations of metals found in the various species of invertebrates analysed.

4. The foreshore area on the north shore of Rupert Inlet from a point just east of the Island Copper Mine wharf to a point 1 km east of Red Island (1.5 km west of the east end of Rupert Inlet) is being filled in by 120,000 tons daily of waste rock from the Island Copper Mine. This material is degrading the intertidal area that is at least potentially valuable as rearing ground for juvenile salmonids. The extent of use, if any, of this intertidal and shallow subtidal area by salmonids, either before or since the mining started, is unknown at present. However, the large salmon production by the Marble River and Waukwaas Creek suggests a need by the juveniles of the various salmon species for a substantial amount of rearing ground, such as might be provided by the intertidal zone of Rupert Inlet. This waste rock apears not to colonize too rapidly along its front, presumably because of the steepness and unstable conditions of dumped rock. The waste rock also contributes some suspended material to the inlet waters from abraded rock and overburden. Attempts to distinguish between turbidity from the waste rock and that from tailings, and to determine the contribution by each, have been unsuccessful, because there is no basic physical or chemical difference of the particulate matter from these two sources. The waste rock may contain as much as 0.25% (2500 ppm) copper, and could conceivably add metals to the water by leaching. The extent of this is really not known, although the contribution to the whole Rupert Inlet-Holberg Inlet system must be small, judging by the comparatively low concentrations of copper in the water and in marine organisms.

Gravity separation of relatively heavy metal-bearing mineral particles from particles of host rock could result in localized metal concentrations in the intertidal and subtidal zone. This phenomenon may be more extensive and protracted where slopes are unstable for extended periods, but not overlain with fresh deposits of waste continuously. For this reason, and because recolonization by intertidal and shallow subtidal organisms should be promoted, it would be desirable for the front of the waste rock dump to be flattened to a stable slope as early as possible. The turbidity in Rupert Inlet caused by suspended sediment from this source would be reduced coincidentally.

5. There has been no documented evidence of a decline in stocks of commercially-important species during the period of the mine operation. However, there are no precise data on the crab, prawn, salmon and other fisheries in Rupert and Holberg inlets with which a critical assessment of the stocks can be made. The commercial fisheries catch statistics covering this area are reported for Fisheries Statistical Area No. 27 as a whole, which covers the northwest coast of Vancouver Island, from Cape Cook to Cape Scott, including all of Quatsino Sound. The spawning escapement of adult salmon to the various streams in Rupert Inlet is estimated annually by the Fisheries Officer located in Port Hardy. The escapement records, which are rather grossly estimated by visual observations, show no significant trends, although there are year-to-year fluctuations of considerable magnitude.

6. Tailings exhibit, on the average, concentrations of 700 ppm copper and 40 ppm molybdenum, which compare with 44 and 2 ppm, respectively, in the natural sediments of Rupert Inlet. There is no evidence that copper is leaching into the seawater in appreciable amounts from the tailings deposits in Rupert and Holberg inlets. The copper concentration is generally low in the water column. There are virtually no data on copper concentrations in the interstitial water of the sediments or in seawater immediately over-lying the sediments, but little of such copper in solution, if it exists there, appears to be reaching the water column. A similar situation prevails for other metals measured, such as molybdenum, cadmium, lead and zinc. However, manganese appears to leach from tailings into the water, judging by both laboratory leaching experiments and analysis of water samples taken in Rupert Inlet.

7. Metals are not being bioaccumulated in appreciable amounts by organisms anywhere in Quatsino Sound, except in some local areas of high exposure, such as the Island Copper Mine's copper concentrate-loading wharf and the early tailings outfall. Dungeness crabs, *Cancer magister*, trapped in Rupert Inlet about 500 m west of the mine wharf on 20 July 1978, did not exhibit metal concentrations significantly above background levels. However, a detailed statistically-reliable study of bioaccumulation of metals at a number of selected points in the Rupert-Holberg inlet system by various organisms, particularly in their different tissues and organs, has not been made.

8. The existing monitoring program, although one of the most comprehensive of this type known to us, does not provide information to enable one to assess definitively the effects of tailings and of the waste rock disposal on the commercial and recreational fisheries. There is no information, for example, to show if and how the benthic ecosystem is coupled to the ecosystem in the upper layer, e.g., via the meroplankton (planktonic stages of organisms which are not planktonic throughout their life cycle). No studies have been made on the food chain leading to

juvenile salmonids rearing in the inshore waters and on how this might be affected by the tailings and waste rock. Some reorientation of the monitoring program is required in order to provide essential data on direct and indirect effects of the mine tailings on crabs, prawns, bottom fish and salmonids and their habitats in Quatsino Sound.

9. The long-term effect of the mine tailings on the Rupert-Holberg inlet system cannot be predicted. The inlet system will be shallower, and the final bottom topography can be estimated from the annual input of tailings and their dispersal, and the life expectancy of the mine. Similarly, the ultimate change in lateral dimensions can be approximated from the amount of waste rock expected to be dumped along the foreshore. However, the alteration of the character of the surface layer of mine tailings due to diagenetic changes with addition of organic matter from settling land-derived and plankton-produced detritus cannot be predicted. Decomposition of the organic matter will probably lead to some anoxic, reducing conditions in the sediments, which may affect the leachability and mobility of some metals in the tailings. Release of interstitial dissolved metals into the overlying water would depend on permeability of sediments, progressive compaction, activity of sediment-burrowing organisms and physical disturbances, such as slumping, earthquakes or dredging. The incidence of these factors in the future cannot be predicted with any degree of confidence.

10. Of the various options examined as alternatives to the present method of mine tailings disposal in Rupert Inlet [(a) tailings pond on high ground behind the mine; (b) tailings pond within the foreshore zone in the northeast corner of Rupert Inlet; (c) sub-surface dam in Rupert Inlet across the present path of tailings flow; (d) tailings pipeline extension along the bottom of Rupert Inlet into Holberg Inlet, past the most turbulent area near the entrance to Quatsino Narrows; (e) barging for deep-sea disposal; and (f) trucking for land disposal in a remote part of Vancouver Island], none appeared to be environmentally without risks. Some would present serious technical difficulties. One of the more attractve alternatives, (a), poses a risk to the freshwater phase of the salmonids in the area. Heavy precipitation and comparatively frequent seismic activity in the area could lead to leakage from a tailings pond into the drainage basin. Leaching of copper from tailings can be expected to be higher in freshwater than in seawater, particularly because of a lower pH that would probably be found in the former. The risk of leaching from an uplands tailings pond into salmonid streams would continue after the mining operation ceased. With the present evidence available on the ecological impact of the existing mine tailings disposal system, a change to one of the alternative techniques for tailings disposal does not appear to be warranted.

11. The resuspension of tailings particles in the region between Quatsino Narrows and Hankin Point could conceivably be eliminated, or at least minimized, by a redesign of the existing tailings outfall to reduce the incidence of slumps and the consequent turbidity currents. This might be a combination of a deeper discharge and an outfall configuration that provides better initial spreading of the tailings. At least one of the scientists interviewed, who had worked on the sedimentary aspects of the tailings disposal, suggested that a modification in outfall design could

eliminate much of the tailings resuspension problem. He suggested that a deeper outfall, which would bring the tailings closer to their final resting place, could be a partial solution.

12. It is uncertain from existing data what impact the turbidity from suspended mine tailings has on light penetration and primary productivity.

13. It is unknown also if turbidity has an effect on migratory behaviour of salmonids and other species.

9. RECOMMENDATIONS

Based on our findings in reviewing the mine waste disposal problem in Rupert Inlet, the following recommendations, classified in terms of modification of waste disposal systems and monitoring on the one hand and research on the other, are made:

9.1. Improvement of Waste Disposal Systems and Monitoring

1. It is conceivable that a deeper outfall with a different discharge configuration could eliminate or reduce some of the intermittent turbidity current that appears to flow through the turbulent region between the northern entrance to Quatsino Narrows and Hankin Point. In this connection, investigations should be undertaken to determine whether there is a stronger relationship between visible surface turbidity and slumps, which result in violent turbidity currents, than with the more or less continuous near-bottom density flow of tailings slurry along the leveed bottom channel. If the intermittent turbidity currents are found to be the major contributor to surface turbidity, a study should be conducted on the outfall design, possibly with recourse to a hydraulic model, toward elimination or at least minimization of the resuspension of suspended solids from tailings between Hankin Point and the northern entrance of Quatsino Narrows.

2. Water samples should be carefully taken for metals analysis at the Water Column Control Stations of the Monitoring Program, at least at the surface, 50 m, 100 m (if the water depth will allow), and at the bottom as close as possible to the sediments. At the same stations, interstitial water samples should be taken from the surficial sediments by the best available technique, either in situ, or by coring and squeezing the water from the cores in the laboratory. Analysis should be conducted by the most sensitive available techniques at least for dissolved copper, lead, zinc, cadmium, molybdenum, arsenic and manganese. This will provide analytical data on metals in the water of the sediments and water column, which would be expected to be biologically available to marine organisms.

3. A program should be designed to investigate the effect of mine tailings on benthic organisms along transverse transects from the deepest part of the Rupert-Holberg inlet trench to the intertidal zone. This should include species diversity, communities, biomass, and any suitable indices of pollution effects, e.g., departure from a log-normal distribution of individuals among species.

4. An alternative disposal site on land for the waste rock would be desirable to minimize encroachment on productive marine habitat, provided toxic leachates would not result. If it is totally impractical to dispose of this waste on land, the length of foreshore used for such waste rock disposal should be kept to a minimum, and in any case, graded to a colonizable slope in the intertidal and subtidal area. A gentle slope of no more than about 10° would enhance its colonization by algae and the smaller invertebrates. Under present operational procedures, the entire length of the waste dump is kept unstable by new additions of waste. Changing the procedure, so that the active waste dump face could be as narrow as possible and the rest could be graded and stabilized, would be preferable on several grounds. Figure 3 depicts a suggested alternative. It is recommended that this suggested alternative be investigated as to its feasibility on engineering grounds, and if feasible, implemented. The importance of maintaining stability in the waste dump is acknowledged as a preeminent consideration that should not be jeopardized.

5. Bioaccumulation by a standard organism, e.g., blue mussel, *Mytilus edulis*, should be monitored at a number of representative locations of high, intermediate and low exposure to tailings, in the Rupert-Holberg inlet system. Special precautions should be taken to avoid contamination in analysis, especially by particles of tailings in the gut of the test animals.

6. Analytical chemical techniques used in the on-site monitoring program should be upgraded from time to time to take into account the latest developments in analysis, in order to achieve good reproducibility and detection limits as low as possible for metals, particularly in seawater.

7. Methods should be improved for examination of sediment cores and marine organism settling plates in the intertidal and shallow subtidal zones, and the scope of these monitoring activities should be extended. Sediment cores should be segmented for metal analysis along the length of the core, and/or interstitial water should be analyzed for metals, to shed some light on diagenetic processes (*cf.* Recommendation 9.2.2). Settling plates could be analyzed with respect to diversity of species and community structure, in order to determine if ecological changes are occurring as a result of deposition of suspended tailings in the intertidal and shallow subtidal areas.

9.2. Short and Long-term Research

1. Research should be initiated on the direct and indirect effects of mine tailings on living resources of commercial and recreational

importance in the Rupert-Holberg inlet system. These resources include Pacific salmon, crabs and prawns. The research should examine the direct effects of the tailings on the animals, e.g., toxicity, bioaccumulation of metals, behaviour and migration patterns, growth rates and population trends. The indirect effects to be examined would include impact on habitats, food supply and food chains (including coupling of the benthic ecosystem with the pelagic ecosystem through eggs and larvae), diseases and parasites, and predator-prey relationships.

2. The long-term effects of mine tailings in sedimentary environments, particularly after tailings discharge ceases, should be investigated. The changes in metal concentrations in the tailings particles and interstitial water with depth of core may provide some clues of diagenetic alterations in the tailings deposits with time. These investigations may also include simulation of long-term diagenetic changes by addition of detritus-type organic material and maintenance of the tailings in an anoxic condition in the laboratory. In the event that there is a strong indication that metals will be released in the long term through diagenetic changes, it may be necessary, when the mine operation ceases, to cover up the tailings in the Rupert-Holberg inlet system with clean sand, non-metal-containing dredge spoils or milled waste rock having very low metal content, in order to seal off the sediments from direct exposure to the over-lying water.

3. Research should be conducted on the release of metals from the tailings into seawater, varying the different parameters, e.g., salinity, temperature, pH of the water and chemical treatment of the tailings, in order to determine what factors are most significant in mobilizing the metals. This is important for a better understanding of the processes, which bring metals from tailings into solution, and for improved control in the event that there is evidence of increased metals in the water column and in marine organisms, as noted in sea disposal of mine tailings elsewhere.

4. Ambient light intensity measurements should be made at various depths in areas affected most heavily by mine tailings and in areas of comparable environmental conditions unaffected by tailings. Primary productivity should be measured at selected depths on the same stations. This information should shed some light on the impact of suspended tailings on primary productivity in the water column.

5. The effect of suspended tailings-generated turbidity on migration behaviour of adult salmon should be investigated and compared with the effects of natural turbidity in salmon-rearing rivers.

Table 1. Outline of the environmental control monitoring program of the Island Copper Mine during the third production year, October 1973 to October 1974 (from Evans et al., 1979).

Program	Description	Frequency	Objective
Marine Observations			
Seismic Survey	Bottom profile and sediment distribution	Annually, Oct. 1974	Record Tailings Distribution
Bottom Coring	Cores at 24 stations - log and measure tailing thickness on bottom	Quarterly	Visually determine tailings distribution
Bottom Grabs	Sediment sample for heavy-metal analysis	Annually, March 1974	Chemically delineate the spread of tailings
	Collect benthic samples at 24 stations - log, sort to polychaetes and others, count and weigh, prepare samples for long-term storage	Quarterly	Monitor benthic population changes
	At four stations collect benthic samples for species-diversity study	Quarterly	Monitor benthic population-diversity
	Collect benthic samples at 24 stations - log, and forward to consultant for detailed identification	Annually, Oct. 1974	Monitor in detail, change in benthic communities
Water Column	At 7 stations profile temperature, turbidity, colour, transparency and suspended solids	Monthly	Record water-column physical properties
	At 7 stations profile salinity, alkalinity, pH, dissolved oxygen, spent sulphite, "total" As, CN and Hg; and dissolved and particulate Cd, Co, Cr, Cu, Fe, Mo, Mn, Ni, Pb, and Zn	Quarterly	Record water-column chemical properties
	At 120 stations determine clarity of water by use of transmissometer	Annually, April 1974	Record clarity of water-column

Table 1 (cont'd)

Program	Description	Frequency	Objective
Marine Observations (cont'd)			
Water Column (cont'd)	At 7 stations sample for chlorophyll 'a' standing crop	Monthly	Record standing crop of primary-producers in water-column
	At 4 stations zooplankton samples collected by quantitative horizontal tows and vertical hauls. Samples are sorted, counted and identified, and analyzed for heavy metals	Quarterly	Record abundance, diversity, and metal concentration of primary-consumer in water-column
Intertidal	From 16 plates estimate growth-rate and sediment-deposition	Monthly	Record primary-production in intertidal area and estimate sediment-deposition
	From 7 stations collect various species of intertidal invertebrates and intertidal fish. Weigh, measure and determine metal concentration	Quarterly	Record metal concentration in intertidal organisms
Fishing	At specific sites collect fish by various methods; identify, measure, weigh, sex, and determine metal concentration	Quarterly	Record metal concentration in fish and estimate population
Crabbing	At 6 stations collect crabs; identify, weigh, measure, sex and determine metal concentration. Male-female frequency-distribution and population estimate	Quarterly	Record metal concentration in edible crabs
Fresh-water Observations			
Water Sampling	At 9 mid-stream locations collect samples for temperature, pH, alkalinity, dissolved solids, suspended solids, turbidity, colour, hardness, dissolved oxygen, sulphates, nitrates, total extractable Hg and As, dissolved and particulate Fe, Cd, Cu, Co, Cr, Mo, Pb, Zn, Ni, Mn	Quarterly	Record chemical characteristics of water flowing into inlet

Table 1 (cont'd)

Program	Description	Frequency	Objective
Meteorological Observations			
	At the mine-site record temperature, wind, precipitation, cloud-cover, and sea-state	Hourly	Record of meteorological conditions
Effluent Discharge Measurements			
	From weekly composites of daily samples taken from the thickener U/F determne pH, % solids, temperature, total cyanide, total mercury, dissolved Cu, Mo, Cd, Cr, Co, Fe, Pb, Mn, Ni, Zn, As	Daily samples analyzed weekly	Monitor physical and chemical characteristics of effluent
	Samples of final-effluent sent out for 96-hour TLM bioassay tests	Bi-weekly	Record tailings-toxicity
	Determine effluent volume	Continuous	Record volume of effluent discharged to sea
	Study composition of tailings, settling-rates and leaching potential	Ongoing research	Research activity

Table 2. Typical chemical and mineralogical compositions of tailing solids and natural sediments in Rupert Inlet (from Evans *et al.*, 1979).

Element or Oxide	Content of Sediments A Tailings	Content of Sediments B Natural	Ratio A:B	Mineral species	Tailings content
	Percent	Percent			Percent
SiO_2	62			Quartz	50-70
Al_2O_3	14			Feldspar	2-20
Ca,K,Na, Mg Oxides	10			Biotite and Chlorite	5-10
Fe Oxides	8			Magnetite	2-4
Fe Sulphide	2-3	2-3	1:1	Pyrite	2-4
CO_2	2	-		Calcite	2.5
Total	98-99	~95	1:1		
Element	ppm	ppm			
Cu	700	44	16:1	Chalcopyrite	0.2
Mn	650	640	1:1	Mn Oxides	n.d.
Cr	140	125	1:1	In silicates	n.d.
Zn	80	88	1:1	Sphalerite	0.02
Mo	40	2	20:1	Molybdenite	0.01
Co	20	20	1:1	In silicates	n.d.
Ni	20	40	1:2	In silicates	n.d.
Pb	20	25	1:1	Galena	0.002
As	5	5	1:1	Arsenopyrite	n.d.
Cd	3	2	3:2	In sphalerite	n.d.
Hg	0.03	0.06	1:2	Cinnabar	$>4\times10^{-6}$

n.d. - not determined

Table 3. Dissolved metal concentrations in Rupert Inlet water at 50 m, 13 May 1971 and 15 June 1978.

	Concentration, μg/kg (ppb)	
Element	31 May 1971[a]	15 June 1978[b]
Copper	0.37	0.60
Cadmium		0.07
Lead		0.67
Zinc	2.34	2.17
Manganese	1.20	
Nickel	0.31	

[a]Data from Dr. E. V. Grill, Institute of Oceanography, University of British Columbia, Vancouver, B. C.

[b]Analyses by Mr. G. Asmund, The Geological Survey of Greenland, Copenhagen, Denmark.

Table 4. Metal concentrations, μg/g (ppm) dry weight, in invertebrates (all bivalve molluscs) of Rupert and Holberg inlets, 1971-1974. See Figure 1 for station locations. (From Goyette and Nelson, 1977).

			Zn		Cu	
Station	Species	Sampling Date	Average	Range	Average	Range
Red Island	Macoma iris	Aug. 1971	260		460	
(Rupert	"	June 1972	140		100	
Inlet)	"	June 1973	340	300-380	330	310-350
SCUBA Stn. 6	"	June-Aug. 1971	233	110-370	57	42-71
(West of	"	Sept 1971	170		70	
mill site)	"	June 1973	270	230-300	74	38-130
Apple Bay	"	June 1973	180		9	
(Holberg Inlet)	"	June 1974	156	140-180	34	9-61
Red Island	Mya arenaria	Aug. 1971	105		77	
"	"	June 1972	68		34	
"	"	June 1973	130	16-19	31	29-33
"	"	May 1974	81	61-110	28	24-33
SCUBA Stn. 6	"	Aug. 1971	135	110-160	19	13-24
"	"	Sept 1971	120	80-160	31	(31)[a]
"	"	June 1973	167	150-180	31	27-37
"	"	May 1974	63	42-110	22	12-31
Apple Bay	"	June 1972	140	(140)[a]	16	16-17
"	"	June 1973	133	110-160	28	13-55
"	"	May 1974	62	48-69	22	16-29
Red Island	Saxidomus giganteus	June-Aug. 1971	162	86-270	31	7-55
"	"	June 1972	101	81-120	21	16-25
"	"	June 1973	109	97-120	38	29-52
"	"	May 1974	65	54-88	13	10-16
SCUBA Stn. 6	"	June-Aug. 1971	102	82-120	26	17-34
"	"	Sept 1971	65	56-73	15	12-17
"	"	June 1973	106	98-120	20	17-23
"	"	May 1974	81	49-100	19	13-23
Apple Bay	"	June 1973	105	96-120	12	7-17
"	"	May 1974	61	53-86	11	9-14

Table 4 (cont'd)

Station	Species	Sampling Date	Zn Average	Zn Range	Cu Average	Cu Range
Red Island	Protothaca staminea	Aug. 1971	101	92-110	12	10-13
"	"	June 1972	110		20	
"	"	June 1973	137	120-150	40	37-45
"	"	May 1974	82	57-110	19	15-22
SCUBA Stn. 6	"	Aug. 1971	99	87-110	15	14-15
"	"	Sept 1971	78		26	
"	"	June 1973	94	12-150	34	30-40
"	"	May 1974	81	62-120	14	12-16
Apple Bay	"	June 1973	127	110-140	15	13-19
"	"	May 1974	95	83-110	15	11-24
Red Island	Mytilus edulis	July-Aug. 1971	215	89-340	30	16-44
"	"	June 1973	220		87	
"	"	June 1974	98	33-120	15	13-20
SCUBA Stn. 6	"	July-Aug. 1971	145	100-190	35	17-52
"	"	June 1973	190		43	
"	"	May 1974	93	75-130	14	10-17
Apple Bay	"	June 1972	51		5	
"	"	June 1973	120		9	
"	"	May 1974	71	51-95	9	5-13

[a]All samples gave the same value.

Table 5. Metal concentrations in Dungeness crabs, *Cancer magister*, taken from Rupert Inlet 20 July 1978, in comparison to metal concentrations in crabs from a typical unpolluted area on the B.C. coast.

	Concentration, µg/g (ppm) wet weight*				
	Rupert Inlet				Unpolluted Area of B.C. Coast
	Meat only		All soft tissues		
Element	a	b	a	b	Meat only
Copper	14.2	5.9	38.4	13	12.7
Cadmium	0.03	0.48	0.04	<0.05	0.24
Lead	0.04	0.27	0.15	0.2	<0.2
Zinc	46.0		34.3		46.0
Mercury	0.09		0.06		
Arsenic	4.3		2.6		5.6

[a]Analyses by the Fish Inspection Laboratory, Department of Fisheries and Oceans, Vancouver, B.C.

[b]Analyses by Mr. G. Asmund, The Geological Survey of Greenland, Copenhagen, Denmark.

*For approximate conversion to dry weight concentrations, multiply by 5.

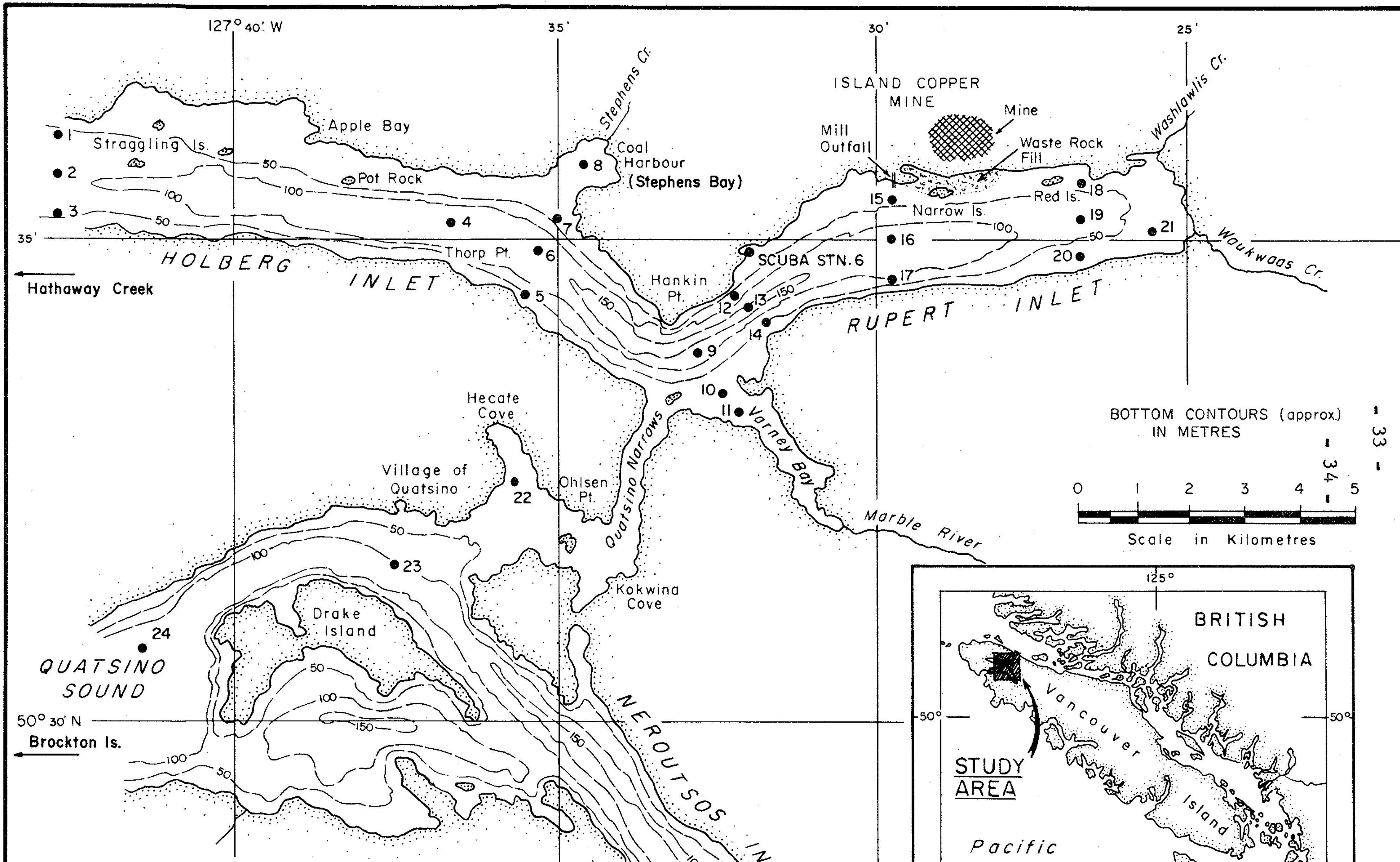

Figure I. Chart of the northwest coast of Vancouver Island, showing the location of the Island Copper Mine, and the stations regularly occupied in surveys.

Figure 2

Aerial view of Island Copper Mine site

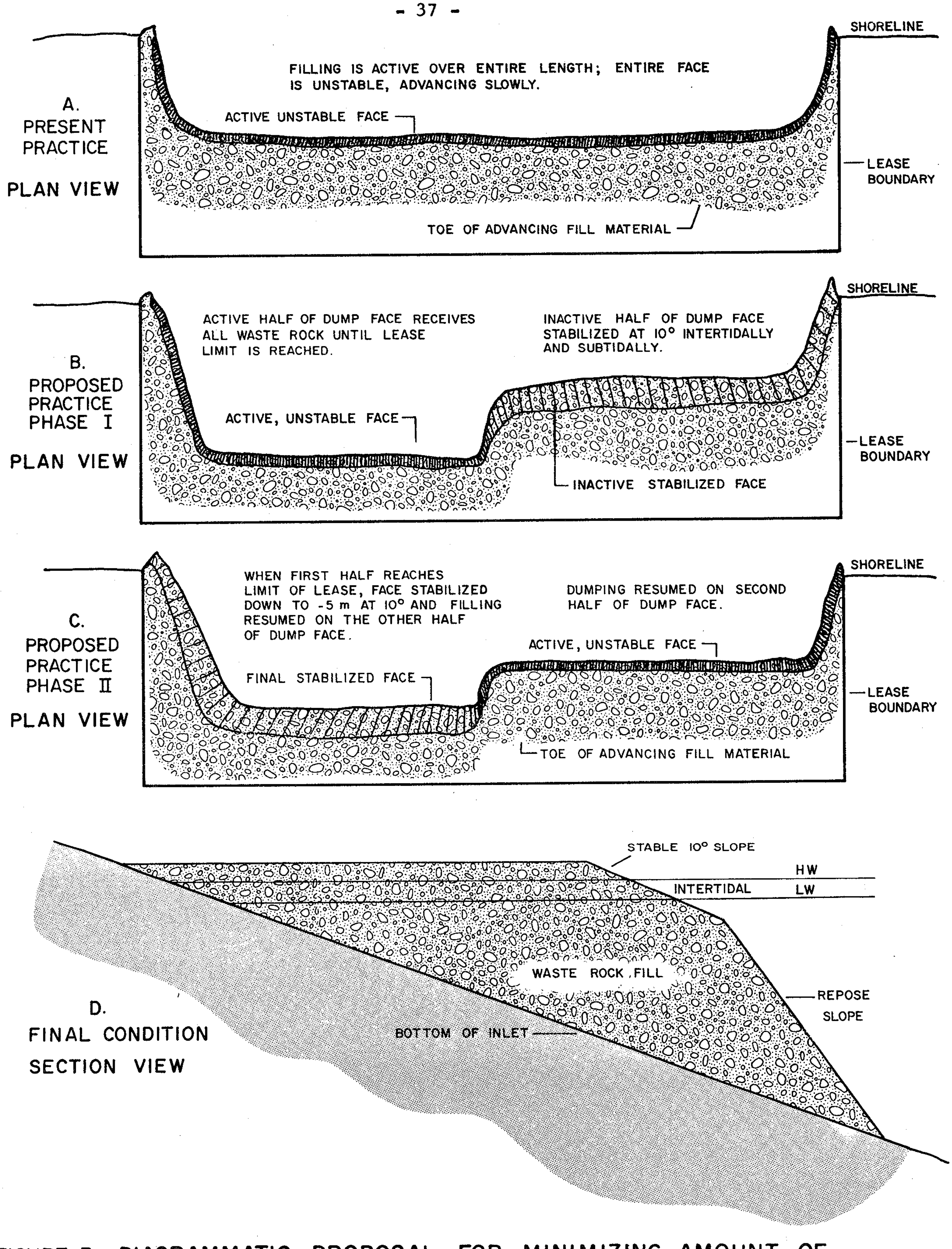

FIGURE 3 DIAGRAMMATIC PROPOSAL FOR MINIMIZING AMOUNT OF UNSTABLE FACE ON THE WASTE ROCK DUMP AT RUPERT INLET. NOT DRAWN TO SCALE.

APPENDIX I

INTERVIEWS WITH INDIVIDUALS IN CONNECTION WITH THE RUPERT INLET MINE WASTE DISPOSAL REVIEW.

Individuals	Affiliation[a]	Date	Aspect Discussed
		1978	
Mr. B. A. Heskin and Mr. M. Ito	EPS	27 Feb.	General background information
Dr. C. Guarnaschelli	EPS	6 Mar.	Mineralogy and ore processing
Mr. D. Goyette	EPS	6 Mar.	Aerial and underwater photography of mine tailings in Rupert Inlet
Mr. D. Goyette	EPS	14 Mar.	Underwater films showing mine tailings in Rupert-Holbert inlets, Howe Sound (Britannia) and Neroutsos Inlet (Yreka)
Mr. T. H. Butler*	PBS	17 Mar.	Effects of mine tailing on prawn and crab populations
Mr. D. Goyette*	EPS	5 Apr.	Uptake of metals by invertebrates in Rupert Inlet
Mr. D. Goyette	EPS	11 Apr.	Effects of mine tailings in Rupert Inlet, Alice Arm and Neroutsos Inlet
Dr. T. R. Parsons	IOUBC	14 Apr.	Ecological aspects of mine waste disposal in Rupert Inlet
Dr. R. W. Burling	IOUBC	23 Apr.	Physical aspects of the tailings flow in Rupert Inlet
Dr. A. G. Lewis	IOUBC	25 Apr.	Effects of tailings on zooplankton in Rupert Inlet
Dr. E. V. Grill	IOUBC	25 Apr.	Analytical chemistry of metals in waters and sediments of Rupert Inlet
Dr. R. E. Foreman	IOUBC	25 Apr.	Effects of mine tailings on intertidal invertebrates and marine plants
Dr. F. J. R. Taylor	IOUBC	25 Apr.	Effects of mine tailings on phytoplankton in Rupert Inlet
Dr. D. V. Ellis	DB UVic	28 Apr.	Biological monitoring program on effects of tailings on benthic organisms in Rupert Inlet

APPENDIX I (cont'd)

Individuals	Affiliation[a]	Date	Aspect Discussed
		1978	
Mr. D. Goyette and Dr. C. Guarnaschelli	EPS	1 May	Distribution of tailings and metal concentrations from B.C. Molybdenum mine in Alice Arm
Dr. C. Guarnaschelli*	EPS	4 May	Behaviour of tailings particles in seawater; mineralogical characteristics of different ores
Prof. J. B. Evans, Dr. J. Leja and Dr. G. Poling	DME UBC	8 May	Mineralogical aspects of mine operations; flocculation of particulate material in sea-water; leaching of metals from tailings
Dr. R. L. Chase	IOUBC	8 May	Mineralogical characteristics of Island Copper Mine Ltd. ore; uptake of metals from tailings by marine organisms; feasibility of damming of Rupert Inlet for retention of tailings
Dr. J. W. Murray and Mr. A. E. Hay	IOUBC	8 May	Movement of tailings through the Rupert Inlet-Holberg Inlet system year-by-year; changing bottom topography; meandering of tailings flow; effects of waste rock dump
Dr. J. A. J. Thompson	IOSPB	9 May	Projected work on metals in interstitial water and metals uptake by benthic organisms in Rupert Inlet
Mr. C. A. Pelletier*	ICM	15 June	Metals in the water column; high level of copper noted in sediments near the outfall
Mr. D. Hay*	WCH	15 June	Design of present outfall; effect of pre-mixing of seawater with tailings before discharge; feasibility of damming underwater tailings-flow channel

APPENDIX I (cont'd)

Individuals	Affiliation[a]	Date	Aspect Discussed
		1978	
Dr. E. L. Bousfield	NMO	22 June	Amphipods in Rupert Inlet and effects of mine tailings
Mr. C. A. Pelletier and Mr. R. Hillis	ICM	17-21 July	Visit to mine; tour of mine and mill operation; review of analytical program; demonstration sampling in monitoring program in Rupert and Holberg inlets
Mr. H. Hole	Resident of Coal Harbour	20 July	General comments on fishing in Quatsino Sound area
Mr. G. Andrews	ICM	21 July	General review of mining and milling operation; environmental program
Mr. B. A. Richman*	Fisheries Officer, Port Hardy	27 July	Commercial fisheries for crabs, prawns and salmon in Rupert Inlet
Mrs. R. Vermeer*	UVic	27 July	Impact of the Island Copper Mine on sport fishing in Rupert Inlet
Mr. T. H. Butler*	PBS	3 Aug.	Effects of mine tailings on crab populations in Rupert Inlet
Mr. K. J. Jackson*	Fisheries Management, DFE	9 Aug.	Rationale for original decision of the Dept. of Fisheries to approve sea disposal of mine tailings in Rupert Inlet; bacteriological leaching of copper from tailings
Dr. I. K. Birtwell	Fisheries Management, DFE	11 Aug.	Impact of mine tailings in the intertidal and shallow sub-tidal zones of Rupert Inlet
Mr. R. E. Drew*/**	Fish Inspection Lab., DFE	5 Sept	Analyses for copper, cadmium, lead, zinc, mercury and arsenic in crab samples trapped in Rupert Inlet 20 July 1978
Dr. J. A. J. Thompson	IOSPB	14 Sept	Analyses for metals in water, organisms and sediments of Rupert Inlet

APPENDIX I (cont'd)

Individuals	Affiliation[a]	Date	Aspect Discussed
		1978	
Dr. W. G. Milne	Pacific Geo-science Centre, Sidney, B. C.	14 Sept	Seismicity of Vancouver Island, particularly the Port Hardy area
Mr. G. Asmund*	Geol. Surv. Greenland, Copenhagen	13 Dec.	Analyses of water from 50 m in Rupert Inlet for zinc, cadmium, lead and copper
		1979	
Mr. G. Asmund*	"	9 Jan.	Analyses of tissue samples from Rupert Inlet
Mr. P. J. Van der Graaf*	CDPW	9 Jan.	Feasibility of a submerged dam to retain tailings in Rupert Inlet away from turbulent area near Quatsino Narrows
Dr. W. K. Fletcher	DGS UBC	1 Feb.	Metals in tailings of Island Copper Mine and their biological availability to marine organisms. Effects of organic material on biological availability of metals
Dr. T. R. Osborn	IOUBC	1 Feb.	Dispersion and resuspension of tailings in the Rupert-Holberg inlet system due to physical processes
Dr. S. O. Russell	DCE UBC	1 Feb.	Prediction of tailings behaviour with an underwater dam installation using a hydraulic or mathematical model
Dr. E. V. Grill	IOUBC	1 Feb.	Analysis of water from Rupert Inlet for metals. Long-term effects of metals in deposited tailings
Dr. J. L. Littlepage	DB UVic	12 Feb.	Effects of mine tailings disposal in Alice Arm
Dr. R. D. Johnson*	Consultant, Calgary, Alta.	13 Feb.	Physical behaviour of mine tailings in Rupert Inlet. Feasibility of a modified outfall at Island Copper Mine to minimize resuspension of mine tailings

APPENDIX I (cont'd)

Individuals	Affiliation[a]	Date	Aspect Discussed
		1979	
Dr. E. L. Lewis	IOSPB	15 Feb.	Sea disposal of mine tailings at Mârmorilik in central west Greenland, and winter "turnover" of water in Agfardlikavsâ fjord
Mr. K. Vermeer	CWS,DFE	15 Feb.	Metals in fish-eating birds from Rupert Inlet
Dr. D. Stucchi	IOSPB	15 Feb.	Physical processes responsible for resuspension of mine tailings in the Rupert-Holberg inlet system
Mr. J. Kerrigan	Amax, Inc. Denver, Colorado	19 Feb.	Film on mine tailings behaviour in seawater taken in an experimental flume, with reference to tailings disposal in Alice Arm
Mr. T. H. Butler*/**	PBS	23 Feb.	Crab catches in Quatsino Sound (Area 27) from 1963 to 1978
Mr. C. A. Pelletier	ICM	7 Mar.	Recent observations in Rupert Inlet, particularly availability of aerial photos
Mr. B. A. Richman*	Fisheries Officer, Port Hardy	28 Mar.	Noted two major slides in waste rock dump area recently, and surface turbidity as far as Brockton Island
Mr. B. A. Richman*	Fisheries Officer, Port Hardy	2 Apr.	Recent high turbidity in Rupert-Holberg inlet system; small streams originally on site of Island Copper Mine
Mr. D. Goyette*	EPS	10 Apr.	Recent studies on Rupert Inlet e.g., R. S. Vermeer's MA Thesis, U. of Victoria
Mr. A. Bohn	BC Research	11 Apr.	Mine tailings disposal into Agfardlikavsâ Fjord in central west Greenland and metals in seawater and organisms
Mr. R. Kevis*	Prawn Fisherman, Quatsino	10 May	Recent decline in prawn catch in Rupert and Holberg inlets

APPENDIX I (cont'd)

Individuals	Affiliation[a]	Date	Aspect Discussed
		1979	
Mr. B. A. Richman*	Fisheries Officer, Port Hardy	15 May	Comments on R. Vermeer's thesis "An Economic Assessment of a Pollution Externality: the Case of Utah Mines"; other aspects of mine waste disposal in Rupert Inlet
Mr. G. Asmund	Geol. Surv. Greenland, Copenhagen	4 June	Analyses of crab tissue from Rupert Inlet
Messrs. T. K. Nielsen and N. E. O. Hansen	Danish Hydraulic Institute, Horsholm, and Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark, Lyngby, Denmark	6 June	Mixing and exchange processes in the Qaumarujuk-Agfardlikavsâ fjord system in Greenland
Mr. W. Kuit*	Cominco, Trail	20 June	Chemical aspects of metal leaching at the Greenex A/S mine, Mârmorilik, central west Greenland, and differences of processes and effects there from those at the Island Copper Mine
Mr. P. J. Gilles and Mr. J. Powell	Bougainville Copper Ltd., Panguna, Bougainville Island, Papua New Guinea	27 June	Discharge of copper mine tailings into a river draining to the sea in Bougainville; hydrological and ecological effects
Mr. A. Bohn*	B. C. Research	28 June	Processing of ore and treatment of tailings at Greenex A/S, Greenland, to reduce leaching of metals
Mr. & Mrs. R. Kevis**	Prawn fisherman, Quatsino	15 Aug.	Detailed account of prawn fishing activities and effects of mine tailings in Quatsino Sound
Mr. & Mrs. R. Kevis*	Prawn fisherman, Quatsino	19 Oct.	Recent increase in turbidity in Rupert Inlet and decline in prawn catches

APPENDIX I (cont'd)

Individuals	Affiliationa	Date	Aspect Discussed
		1979	
Mr. D. Goyette*	EPS	1 Nov.	Bioassay results on abandoned old copper smelter slag; information on recent observations in Rupert Inlet
Messrs. A. J. Richardson and J. McDonald	BC MMPR	7 Nov.	Regulations pertaining to waste dump and information related to the stability of the waste rock deposit
Mr. T. H. Butler*	PBS	8 Nov.	Prawn distribution in Rupert Inlet and impact of mine tailings
Mr. D. Goyette*	EPS	16 Nov.	Diagenesis and long-term effects of mine tailings on benthic organisms
Mr. Thomas A. Kessler	ICM	22 Nov.	Data on light penetration and simultaneous turbidity profiles collected on site by mine monitor staff
		1980	
Mr. G. Andrews*	ICM	8 July	Current level of production and mine tailings and waste rock disposal
Mr. E. R. McGreer*	E.V.S. Consultants Ltd., North Vancouver	17 July	Uptake by benthic organisms of metals from mine tailings of Island Copper Mine, Rupert Inlet, and of Greenex A/S, Greenland
Mr. A. E. Hay*	IOUBC	7 Aug.	Outfall design and depth for tailings disposal; resuspension of mine tailings in Rupert Inlet
Dr. C. C. Walden* and Mr. D. D. Monteith*	B.C. Research	18 Aug.	Bioassays on tailings from Island Copper Mine
Dr. A. S. Hourston*	PBS	20 Aug.	Herring spawning in Rupert and Holberg inlets
Mr. B. A. Richman*	Fisheries Officer, Port Hardy	25 Aug.	Latest developments in fisheries of Rupert and Holberg inlets with respect to mine tailings disposal

Appendix I (cont'd)

Individuals	Affiliation[a]	Date	Aspect Discussed
Mr. G. J. Hartbower*	Skipper on Fisheries Patrol Vessel M/V GULL ROCK, Quatsino	25 Aug.	Turbidity from mine tailings in Quatsino Sound; discoloration of prawns from Holberg and Rupert inlets; and chemical analyses done by CANTEST Ltd. for Mr. R. Kevis
Mr. Frank Wallas*	Chief of Quatsino Indian Band	25 Aug.	Impact of mine tailings on fishing by the Quatsino Indian Band in Quatsino Narrows
Mr. R. Morehouse*	Crab Fisherman, Port Hardy	26 Aug.	Current status of crab fishing in Rupert Inlet and effect of mine tailings disposal
Mr. C. A. Pelletier	ICM	30 Aug.	Mining operation in general; vegetation cover development on waste rock dump
Mr. A. Botel*	Crab fisherman, Port Hardy	5 Sept.	Impact of mine tailings on crab and prawn fishing in Rupert and Holberg inlets
Mr. T. H. Butler*	PBS	30 Sept.	Chemical analyses on prawns from Holberg Inlet conducted by CANTEST Ltd. for Mr. R. Kevis
Mr. & Mrs. R. Kevis	Prawn fisherman, Quatsino	6 Oct.	Arsenic levels in prawns from Holberg Inlet and other parts of the B.C. coast

*Discussion by telephone
**Communication by letter
[a]BC MMPR = B.C. Ministry of Mines and Petroleum Resources
CDPW = Canada Department of Public Works, Vancouver, B.C.
CWS, DFE = Canadian Wildlife Service, Department of Fisheries and Environment
DB UVic = Department of Biology, University of Victoria, Victoria, B.C.
DCE UBC = Department of Civil Engineering, University of British Columbia, Vancouver, B.C.
DGS UBC = Department of Geological Sciences, University of British Columbia, Vancouver, B.C.
DME UBC = Department of Mineral Engineering, University of British Columbia, Vancouver, B.C.
EPS = Environmental Protection Service, West Vancouver, B.C.
ICM = Island Copper Mine, Port Hardy, B.C.
IOSPB = Institute of Ocean Sciences, Patricia Bay, Sidney, B.C.
IOUBC = Institute of Oceanography (now Department of Oceanography), University of British Columbia, Vancouver, B.C.
NMO = National Museums, Ottawa, Ontario
PBS = Pacific Biological Station, Nanaimo, B.C.
WCH = Western Canada Hydraulic Laboratories, Ltd., Port Coquitlam, B.C.

APPENDIX II

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APPENDIX IV

MINING OPERATIONS ELSEWHERE INVOLVING SEA DISPOSAL OF TAILINGS

Mine	Location	Metals Mined	Period of operation
Anaconda Britannia Mine	Britannia Beach, Howe Sound, B.C.	Copper-zinc	1900-1975
Anyox	Anyox, Hastings Arm, B.C.	Copper	1914-1936
British Columbia Molybdenum Ltd.	Kitsault, Alice Arm, B.C.	Molybdenum	1966-1972
Jordan River Mine	Jordan River, Vancouver Island, B.C.	Copper	1960-1974
Amax Canada Ltd. (formerly Climax Molybdenum of B.C.)	Kitsault, Alice Arm, B.C.	Molybdenum	1982[a]
Wesfrob Mines	Tasu Inlet, Queen Charlotte Islands, B.C.	Copper-zinc	1970-
Greenex A/S	Mârmorilik, Greenland	Zinc-lead	1973-
A/S Norsk Jernverk	Rana Fjord, Norway	Copper, zinc, lead	1900-
Bougainville Copper Ltd.	Panguna, Bougainville Island, Papua New Guinea	Copper	1975(?)-
Potrerillos Copper Mine	El Salvador, Chile	Copper	1962-
Unknown	Tasmanian West coast	Copper	?
Unknown	Peru	Copper	?
Unknown	Cartagena, Spain	Lead-zinc	?
Amax Inc.	Fiji	Copper(?)	1982(?)-

[a]Projected starting year