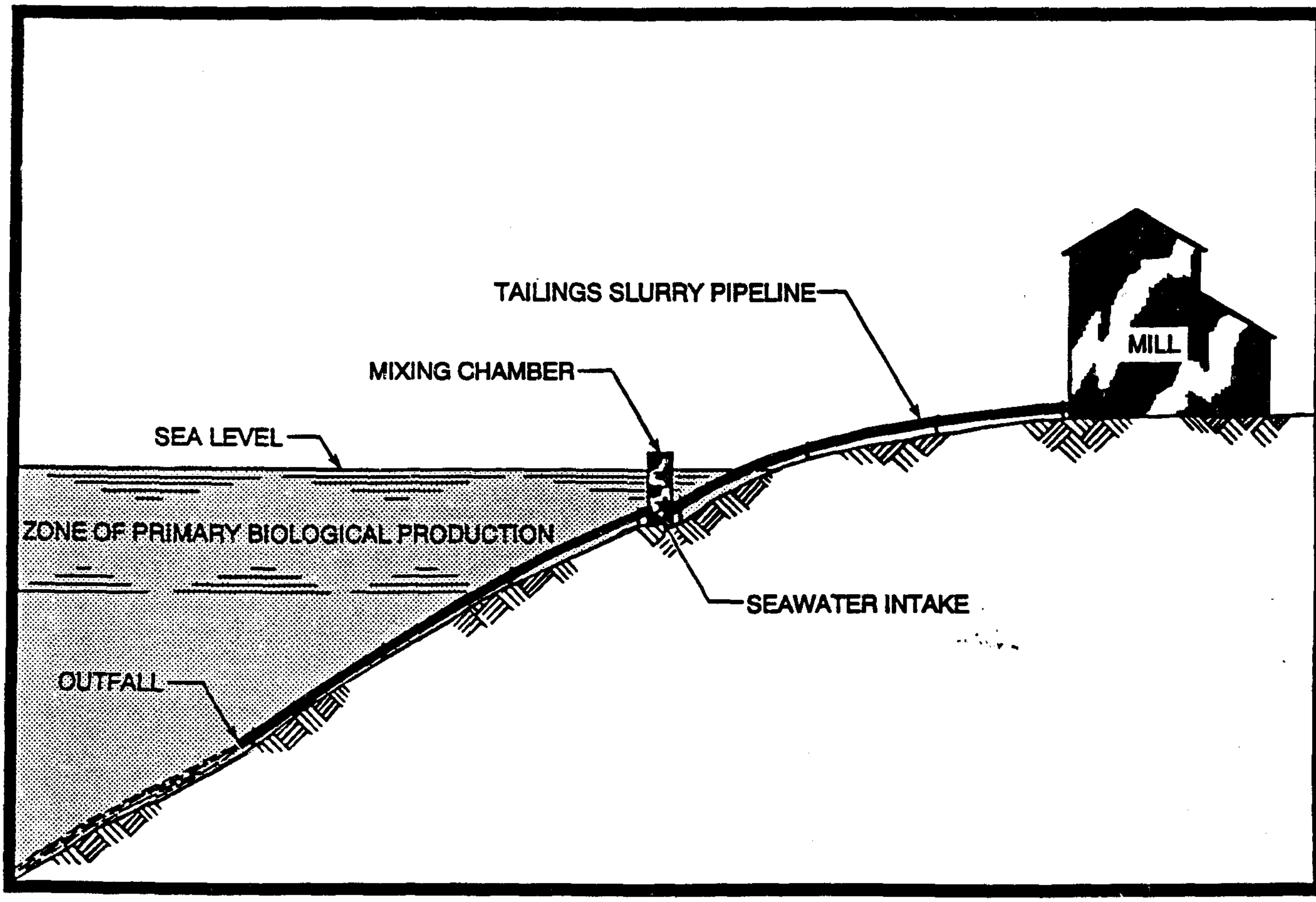
SUBMARINE DISPOSAL OF MILL TAILINGS FROM ON-LAND SOURCES - AN OVERVIEW AND BIBLIOGRAPHY -

An Overview and Bibliographic Compilation of References on the Biological, Chemical, Environmental, and Technical Aspects



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An Overview and Bibliographic Compilation of References on the Biological, Chemical, Environmental, and Technical Aspects

By Roger L. Baer[1],
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Patrick D. Plumb[3]

ABSTRACT

Marine disposal of mill tailings has been practiced worldwide for over a century. However, only recently have the environmental effects of marine disposal been systematically studied. Some early attempts at marine disposal of tailings resulted in adverse impacts to marine life. However, recent advances in tailings disposal methods have included the introduction of engineered submarine tailings discharge systems, advanced environmental assessment and monitoring methods, and oceanographic modeling systems. Successful submarine tailings disposal (STD) has occurred at several mines.

The U.S. Bureau of Mines (BOM) has undertaken studies of the disposal of mining and milling wastes in the marine environment. The BOM Alaska Field Operations Center, Juneau, initiated a review of the technology, regulations, and economic aspects of STD. The review illuminated the need for organization of literature on the subject, therefore the Bureau compiled this extensive bibliography on marine disposal of mill tailings. The bibliography presented here contains 1483 references and is also available through diskette in the WordPerfect® format. A review of the references indicates that literature on submarine disposal inadequately covers the subject. The majority of the references listed only peripherally relate to the subject. Published literature on the engineering and environmental aspects of STD is severely limited.

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INTRODUCTION

Marine disposal of mill tailings has been practiced worldwide for over a century. However, only recently have the environmental effects of marine disposal been systematically studied. Some early attempts at marine disposal of mill tailings resulted in adverse impacts to marine life (1).[1] However, recent advances in tailings disposal methods have included the introduction of submarine tailings discharge systems, advanced environmental assessment and monitoring methods, and oceanographic modeling systems. Within the last twenty years, successful examples of modern submarine tailings disposal include the Island Copper and Kitsault mines in British Columbia, Canada.

Today solid-waste disposal by the mining industry has to compete for space with other land uses, such as wilderness, wetlands, and recreation. In one case, after an analysis of the alternatives, some U.S. Government land managers identified submarine disposal of mill tailings as the preferred environmental alternative when compared to on-land disposal.

Known opportunities for use of submarine tailings disposal in the United States are located along the coastal-areas of Alaska. These opportunities include the Quartz Hill molybdenum deposit, and Kensington and Alaska Juneau gold mines.

Due to interest by industry and government in the potential for developing mines along coastal areas of Southeast Alaska, the Bureau has initiated multi-year projects to investigate various aspects of marine disposal of mill tailings. The Bureau of Mines' Alaska Field Operations Center has undertaken a study of the technology, regulations, and economic implications of submarine disposal of mill tailings. The Bureau's Spokane Research Center has begun an investigation of dissolution and reactivity of minerals and reagents from tailings in freshwater and marine environments. Submarine tailings disposal could provide a viable alternative to on-shore disposal, particularly in areas of fjord topography where land for conventional tailings management and disposal is limited.

Although currently prohibited in most cases by regulation in the United States, STD may become an important consideration in dealing with large volumes of tailings, especially when the environmental and economic impacts are compared with on-shore disposal alternatives.

This report is designed to give a brief overview of submarine disposal of mill tailings, to outline the approach the Bureau is taking in its studies of the subject, and to provide a bibliographic resource for those interested in the subject.

This report begins with a brief review of some of the mining industry's difficulties with on-land solid waste disposal. Included is a discussion of the pertinent characteristics of sea water and deep-water basins, and a review of the modern technology of submarine tailings disposal and its environmental implications. Also reviewed is the successful use of submarine tailings disposal at the Island Copper Mine in British Columbia. Minimization of environmental impacts from STD is discussed. The existing regulatory situation and present opportunities for use of submarine disposal in Southeast Alaska are summarized. Finally, current Bureau projects are listed and their objectives noted.

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[1]Underlined numbers in parentheses refer to citations listed in the "References" section of this report.

To provide a resource for those interested in the subject of STD, the Bureau has developed a database listing of approximately 1,500 documents. These references cover the biological, chemical, environmental, and technical aspects of STD and related issues. The bibliography contained in this report was generated from the database. This bibliography is available in digital form (PC compatible) in the WordPerfect® format. It should be noted that the vast majority of references listed are only peripherally related to the STD. By and large, the published literature directly related to STD was found to be severely limited.

ACKNOWLEDGMENTS

The Bureau of Mines would like to thank the following individuals for invaluable assistance without which this report could not have been completed:

> Derek V. Ellis, University of Victoria, for contributing references to the bibliography and providing technical expertise; George W. Poling, University of British Columbia, for providing references and technical expertise; Kenneth M. Reim, U.S. Borax, for contributing bibliographic references; Roger W. Griffin, U.S. Forest Service, for providing technical review of the manuscript; John J. Kato and Robert H. Lambeth, U.S. Bureau of Mines, for technical review of the manuscript.

DISPOSAL OF SOLID WASTES FROM MINING

Today the mining industry has to compete for space for disposal of mill tailings and waste rock with other land uses, such as wilderness, wetlands, wildlife, aesthetics and recreation, to name a few. In coastal areas, development of mineral deposits can be stalled for a lack of on-land sites suitable for tailings and waste rock disposal. The selection of suitable tailings disposal sites is a sophisticated design issue. Government agencies require a detailed analysis of tailings disposal alternatives and sites. These analyses require knowledge of many factors about an area, such as the geology, hydrogeology, seismic potential, and drainage basin characteristics.

Extensive research is underway in the United States and Canada on the best way to design for long term disposal of solid wastes from mining. In Canada, groups jointly sponsored by industry and government, such as the British Columbia Acid Mine Drainage Task Force and the national level Mine Environment Neutral Drainage (MEND) program, are conducting research in this area. Because of results of studies by these groups, the Canadian regulatory community seems to be reaching a consensus that one of the best ways to minimize the potential for acid mine drainage is to keep tailings stored under water (2). The main reasons for this conclusion are that the oxygen content of water is small and oxygen diffuses slowly through water. Consequently, oxidation of tailings is minimized or eliminated. To date, the Canadian research efforts have been largely focused on fresh-water conditions.

The marine environment offers a tailings-disposal alternative for coastal mines. Although marine disposal of solid wastes from mines is not the answer in all cases, disposal of mill tailings and waste rock in marine water appears to have certain advantages over fresh water. Some of these advantages are discussed below.

ADVANTAGES OF MARINE WATERS

Besides minimizing oxygen diffusion, sea water is slightly alkaline with a pH ranging from 7.8 to 8.3 (3). Solubility of most metals in this pH range is at a minimum, and the alkaline pH will tend to keep the tailings from reaching acidic conditions. Although salt-tolerant bacterial species that oxidize sulfides in seawater are known to exist (4,5), chloride kills many *Thiobacillus* species (including *T. ferrooxidans*, *T. thiooxidans*, *T. organoparus* and *T. acidophilus*) which account for most of the oxidation of sulfides on land. Additionally, most sulfide oxidizing bacteria require higher temperatures and oxygen concentrations than are normally found in the submarine environment. Consequently, waste rock at some mine sites that is potentially acid generating is being stabilized by using marine land-fills. Sea water is a natural flocculent, so turbidity from tailings outfalls is to some degree naturally reduced (6). Finally, deep oceanic water is frequently devoid of free oxygen, so deep disposal is an attractive alternative for preventing tailings oxidation.

The major concern with marine disposal systems is the potential for adverse impacts to human health and the marine environmental, particularly from metals contamination and smothering of benthic organisms. By confining the materials to a relatively small area, environmental impacts are localized. Presently, most user countries are opting for some type of containment system for metal-bearing mill tailings. Deep, largely closed basins, such as the fjords of southeast Alaska are prospective containment systems.

ENVIRONMENTAL IMPACT ASSESSMENT

Marine disposal of mill tailings has been practiced worldwide since introduction of modern ore dressing processes over a century ago. However, only recently have the environmental effects of marine disposal been systematically studied (1). Environmental information has been collected by workers in the field on about two dozen sites worldwide. These studies indicate that, given the right circumstances, submarine disposal can be preferred over on-land disposal from an environmental perspective. The most complete set of environmental assessment data is the twenty-year record at the Island Copper Mine on Vancouver Island, British Columbia, Canada (1). This example is discussed below.

Older methods of marine disposal consisted of simply piping tailings to a beach and pouring them into the water with little thought for the long-term effects of these actions. Many advances in marine tailings disposal technology have been made in the last twenty years. These advances have included the introduction of sophisticated submarine discharge systems, advanced environmental assessment and monitoring methods, and oceanographic modeling systems which address both short and long-term environmental concerns (7).

SUBMARINE TAILINGS DISCHARGE SYSTEMS

A modern submarine tailings discharge system contains the slurry pipeline, deaeration (mixing) chamber, and an outfall pipeline (8). Figure 1 illustrates a generalized tailings discharge system. The purpose of the deaeration (mixing) chamber is two fold: (1) it allows air in the tailings slurry, which can cause suspension of tailings fines, to be released, and (2) seawater is mixed with the tailings to minimize the difference in density between the slurry fluid and the receiving sea water. The procedure reduces the chance of a buoyant plume of turbid water rising up from the tailings stream.

Assuming that the tailings slurry has the proper density, the tailings are moved by gravity to the outfall, which is usually located from 40 to 125 meters below the marine water surface. Since the zone of primary biological production in the water column is usually found within 30 meters of

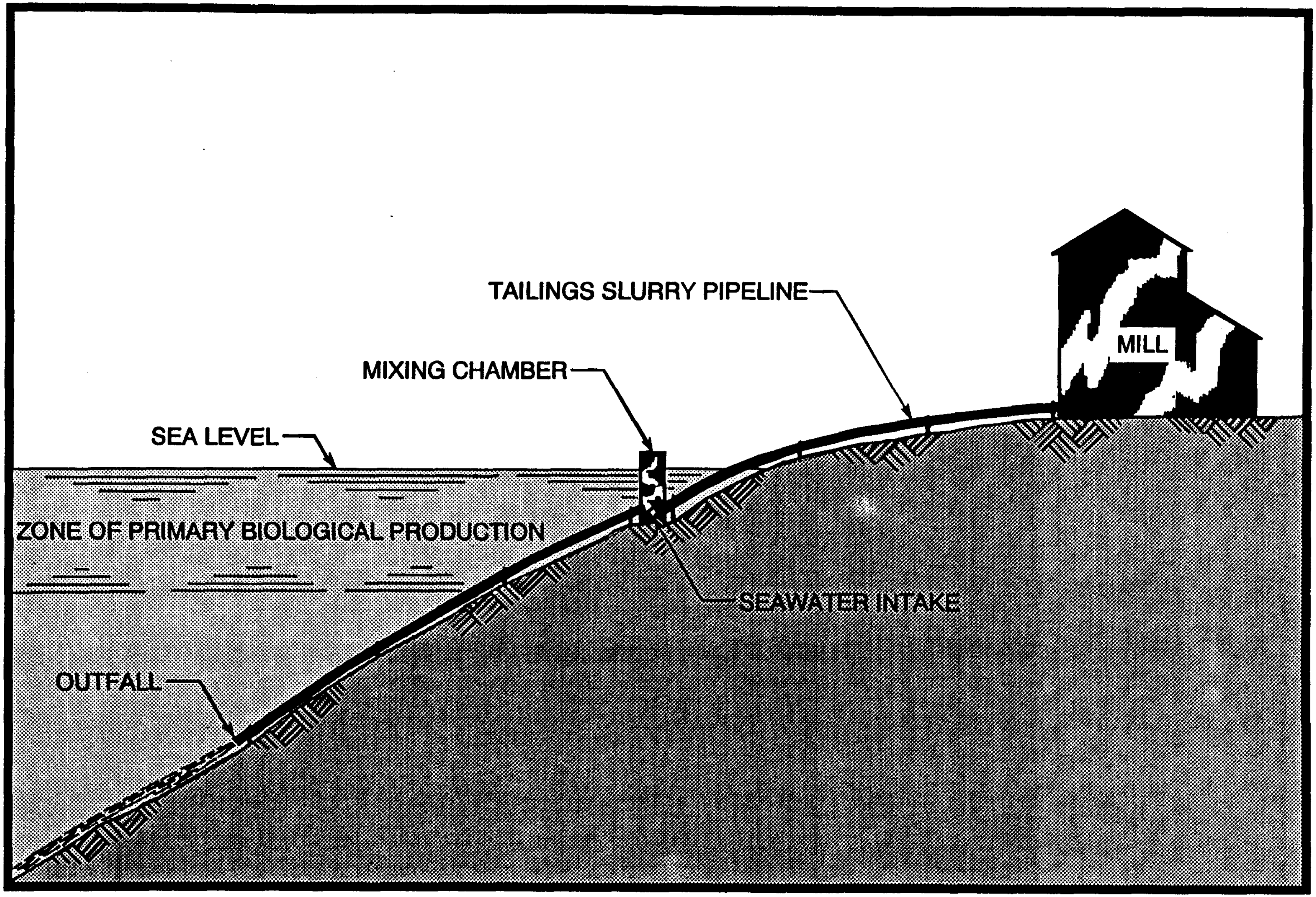


Figure 1. - Generalized Submarine Tailings Discharge System.

the surface, impacts on this zone are minimized (7). Salmon and other valuable fish species live and travel in this upper zone in Alaska and British Columbia.

Figure 2 illustrates the configuration of the deaeration and mixing chamber. Major parts of the system include tailings line, deaeration and mixing chamber, seawater intake lines, and outfall pipeline.

By modifying the design of the mixing chamber, the flow rates and density of the final tailings slurry can be controlled. Typically, seawater is used to dilute the tailings from the mill with from 1 to 6 parts seawater (8). A primary concern is for the tailings slurry to flow to the bottom of the containment basin and remain there. Within the last twenty years, successful examples of modern submarine disposal technology have included the Island Copper and Kitsault Mines in British Columbia, Canada.

MINIMIZING IMPACTS OF SUBMARINE TAILINGS DISPOSAL

Given the right combination of conditions, environmental impacts from STD appear to be minimal. These conditions include that: (1) the percentage of sulfide minerals in the orebody is relatively low, (2) the orebody contains no easily dissolvable toxic substances, such as toxic metal sulfates, (3) non-toxic reagents are used in the mill, or are detoxified before discharge, (4) the milling process does not generate secondary products toxic to marine life, (5) tailings water in the slurry from the mill is minimized to reduce transport of dissolved metals, (6) tailings are deaerated before emplacement, (7) proper fluid density is achieved and the density of the tailings liquids is equal to deep water densities, (8) the outfall is effectively placed, and (9) the depositional environment is relatively stable, such as at the bottom of a deep fjord (9).

The first five conditions above address toxicity issues, while the last four address turbidity issues. Deaerating the tailings and achieving proper fluid-densities are steps required to get the tailings onto the sea bottom and keeping them there. STD has been used with high sulfide tailings; however, currently there are questions concerning existing mines that require further study.

Some mines have had difficulty with turbidity and release of metals. For example, the Island Copper Mine has had some difficulty with an occasionally unstable depositional environment. This is due to the presence of a tidal jet created by water movement through Quatsino Narrows. The entrance to Rupert Inlet is unusually constricted, and on occasion during unusually high spring tides, a high velocity tidal-current descends to the seabed at the mouth of the inlet. On occasions, this high density current has resuspended tailings and caused their up-welling to the surface. Additionally, the Black Angel Mine in Greenland, which taps a high sulfide orebody, has had problems with bioaccumulation of metals in marine organisms (5). Proper modelling of the oceanographic and chemical conditions, and proper design and placement of the outfall can prevent or limit these types of problems.

ISLAND COPPER MINE

The Island Copper Mine is located on the northern end of Vancouver Island, British Columbia, Canada, as shown in figure 3. The mine, operated by BHP-Utah Mines Ltd., is located on Rupert Inlet, which is connected to the Pacific Ocean by Quatsino Sound and Quatsino Narrows, as shown in figure 4. Figure 5 shows the location of the mill, the open pit, and the mine waste rock landfill on Rupert Inlet.

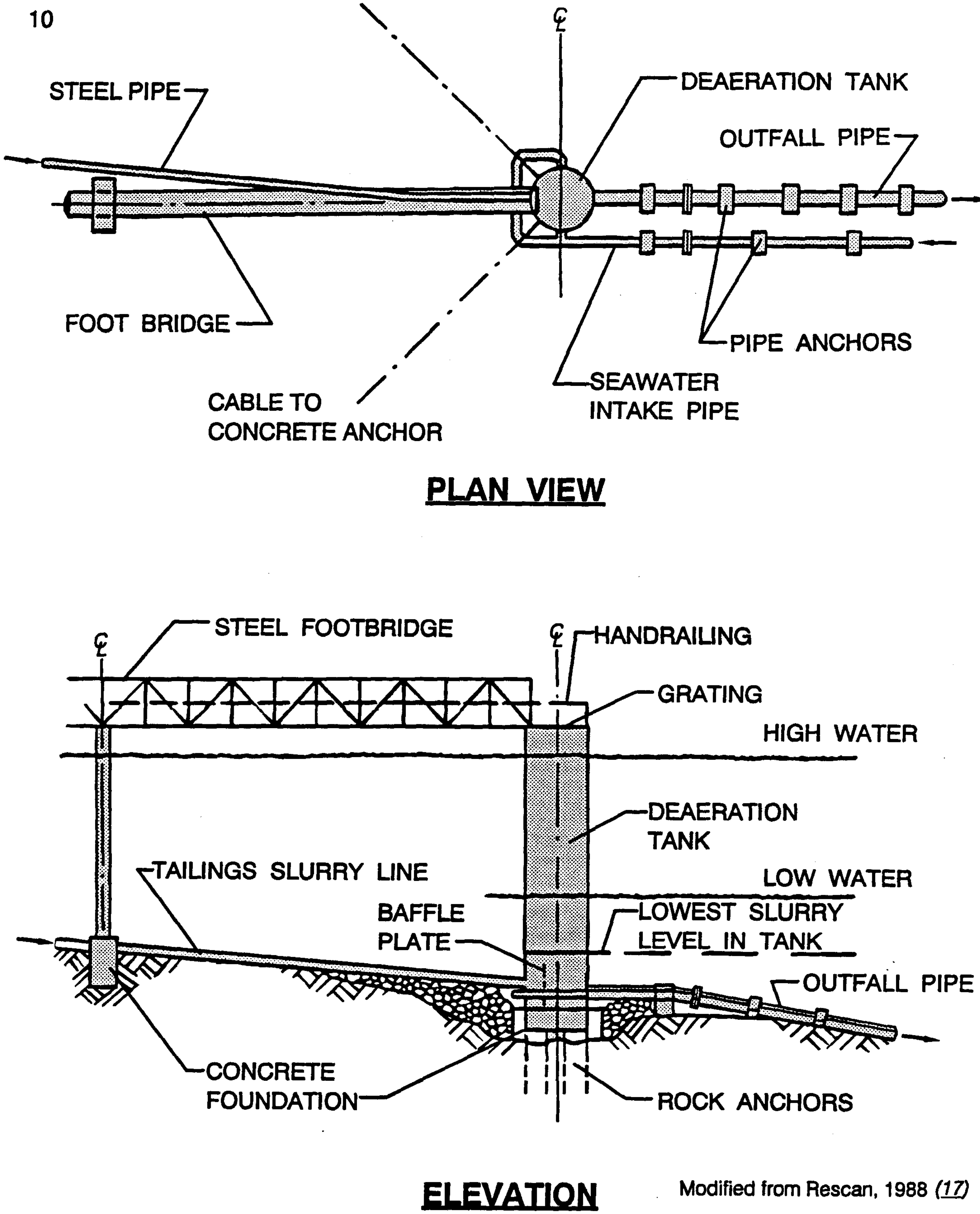


Figure 2. - Layout of Deaeration Tank for STD System.

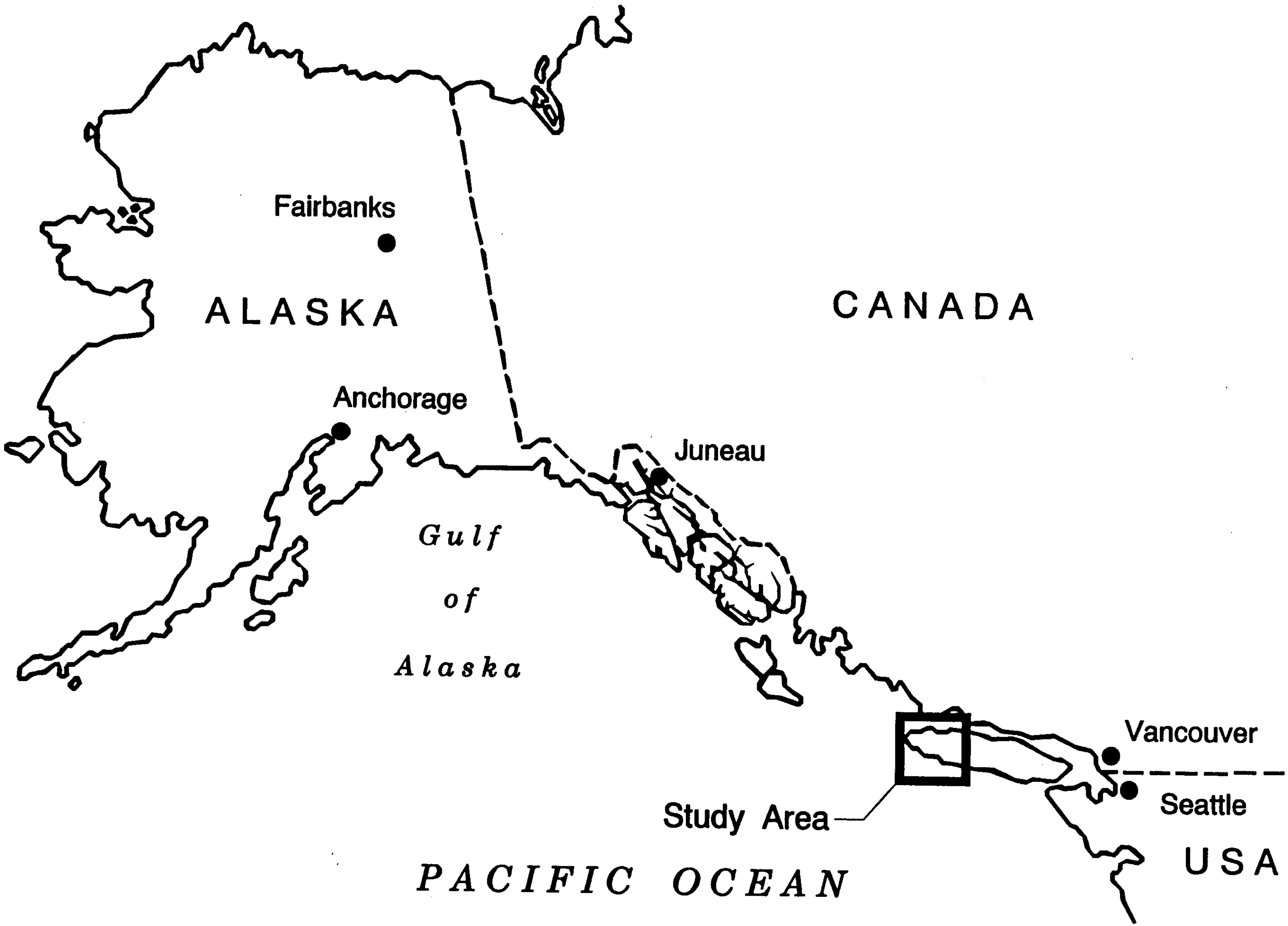


Figure 3. - Location Map Showing Island Copper Study Area.

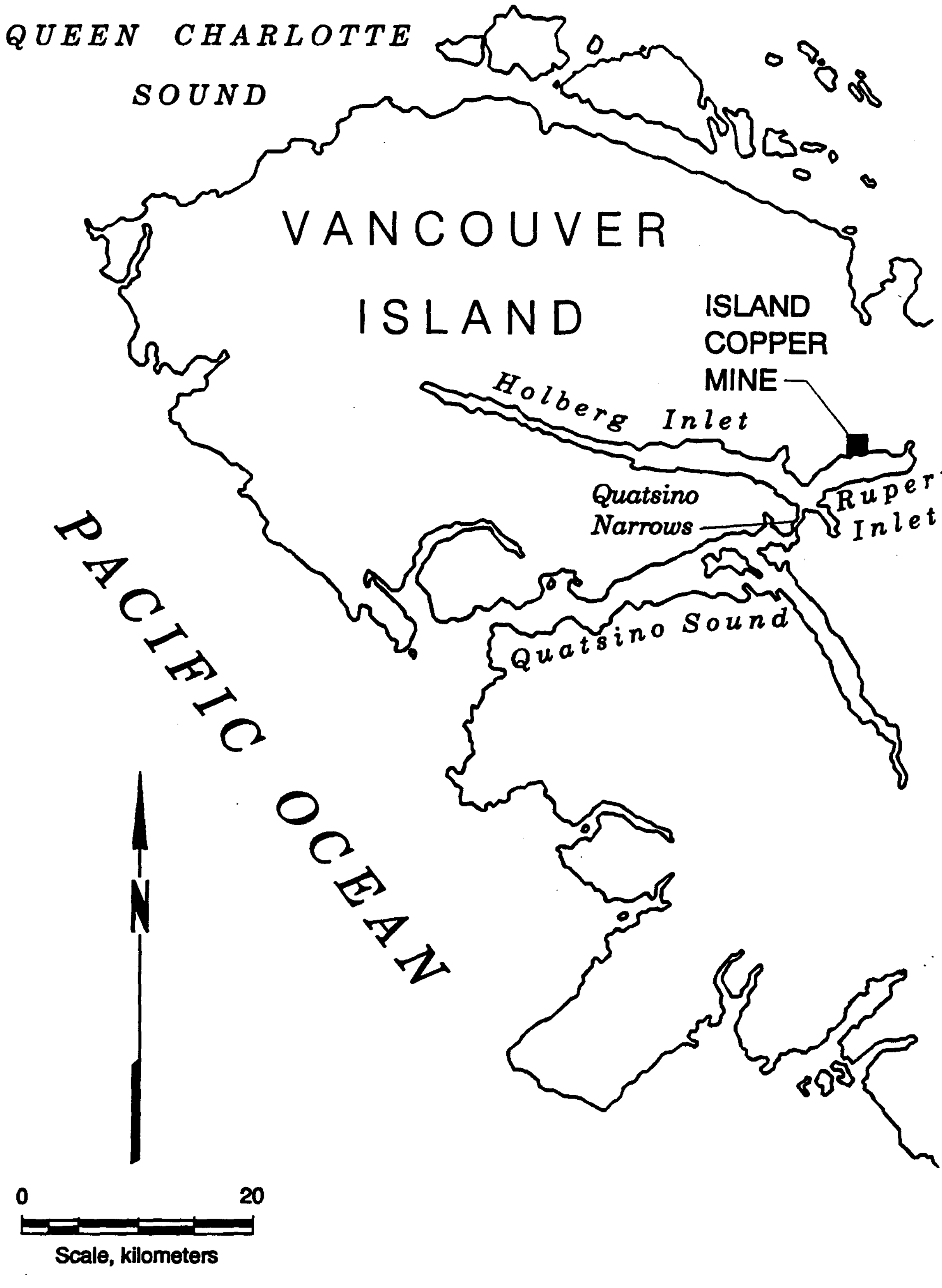


Figure 4. - Location of Island Copper Mine.

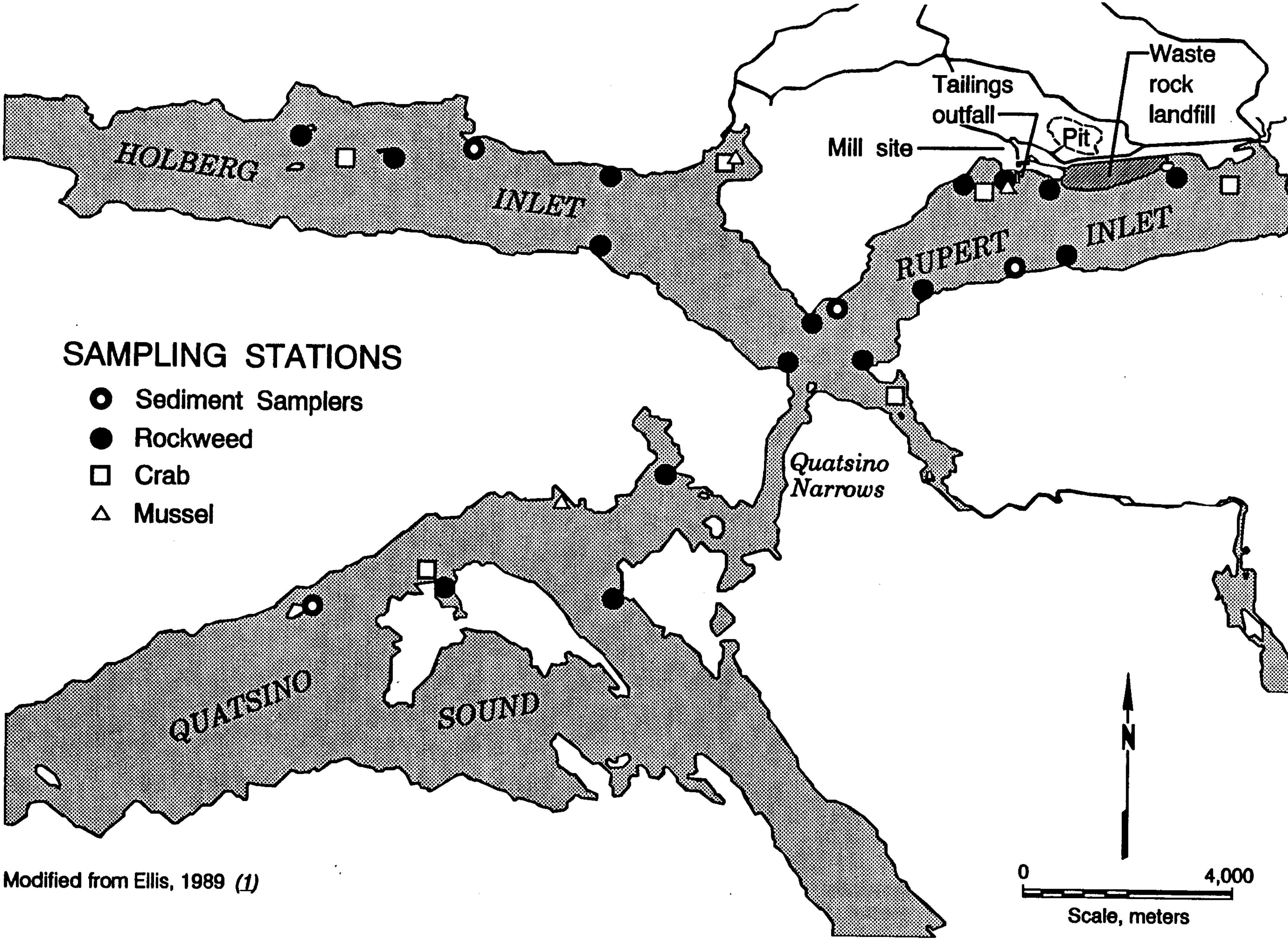


Figure 5. - Location of Island Copper Mine and Monitoring Stations.

In the late 1960s, the mine management at Island Copper together with both provincial and federal regulatory authorities began evaluating alternatives for tailings and waste rock disposal. The company collected a year's environmental baseline data, and applied for a permit from the provincial government to discharge tailings into Rupert Inlet. Despite public controversy, the permit was granted (1).

The mine was required by the provincial government to undertake a comprehensive monitoring program. Scientists and engineers from the University of British Columbia have continually advised the mine on the STD operation since the operations began in 1971. The mine initiated an approach to outfall design and placement, and environmental monitoring that has developed into a state-of-the-art technology for placement of tailings into a marine environment.

The open pit is now approximately 2400 meters long, 1200 meters wide and 300 meters deep. To date, 300 million metric tons of tailings have been placed in the bottom of Rupert Inlet. The fjord is 260 meters deep at its deepest and thicknesses of up to 35 meters of tailings have accumulated, with the average thickness being approximately 25 meters (10).

The mill currently processes 48,000 metric tons of low-sulfide copper/molybdenum/gold ore per day. Using froth flotation and cyanide recovery processes, the mill separates the copper-bearing chalcopyrite, molybdenite minerals, and gold from the ore, and discharges a slurry of 45 to 50% solids in a basic solution at a pH of 10 (8).

The tailings outfall line enters into Rupert Inlet and connects with the deaeration (mixing) tank underwater about 100 meters offshore. Any air in the slurry is released and 2 parts seawater is mixed with 1 part tailings slurry.

TAILINGS DEPOSITION IN RUPERT INLET

The tailings slurry is discharged on the north side of Rupert Inlet at the outfall at a depth of 50 meters (8). The tailings slurry forms a density current or stream which flows down to the bottom of the inlet in a leveed channel, similar to a channel developed on an alluvial fan. A survey in 1977 revealed a single well-defined channel with levees extending 5 kilometers down the inlet from the outfall. Figure 6 shows tailings depositional contours in Rupert Inlet in January of 1977.

During this phase, the channel was 10 meters deep and 100 meters wide near the outfall. These dimensions progressively decreased away from the outfall. This channel caused rapid transport of tailings to depth on shallow slopes, about 2 degrees near the outfall, and 0.5 degrees near the bottom. The configuration of this channel has changed many times since this survey, as tailings continue to be deposited.

ENVIRONMENTAL ASPECTS

Monitoring programs include studies of outfall performance, tailings surveys, oceanographic characteristics, marine biology, fisheries, contaminant pathways, studies of nearby rivers and lakes, and weather (1). See figure 5 for locations of monitoring stations including sediment samplers and rockweed, crab, and mussel sample locations near the Island Copper Mine. The Environmental Control department employs 6 persons at the mine and has two boats for the environmental monitoring program (8).

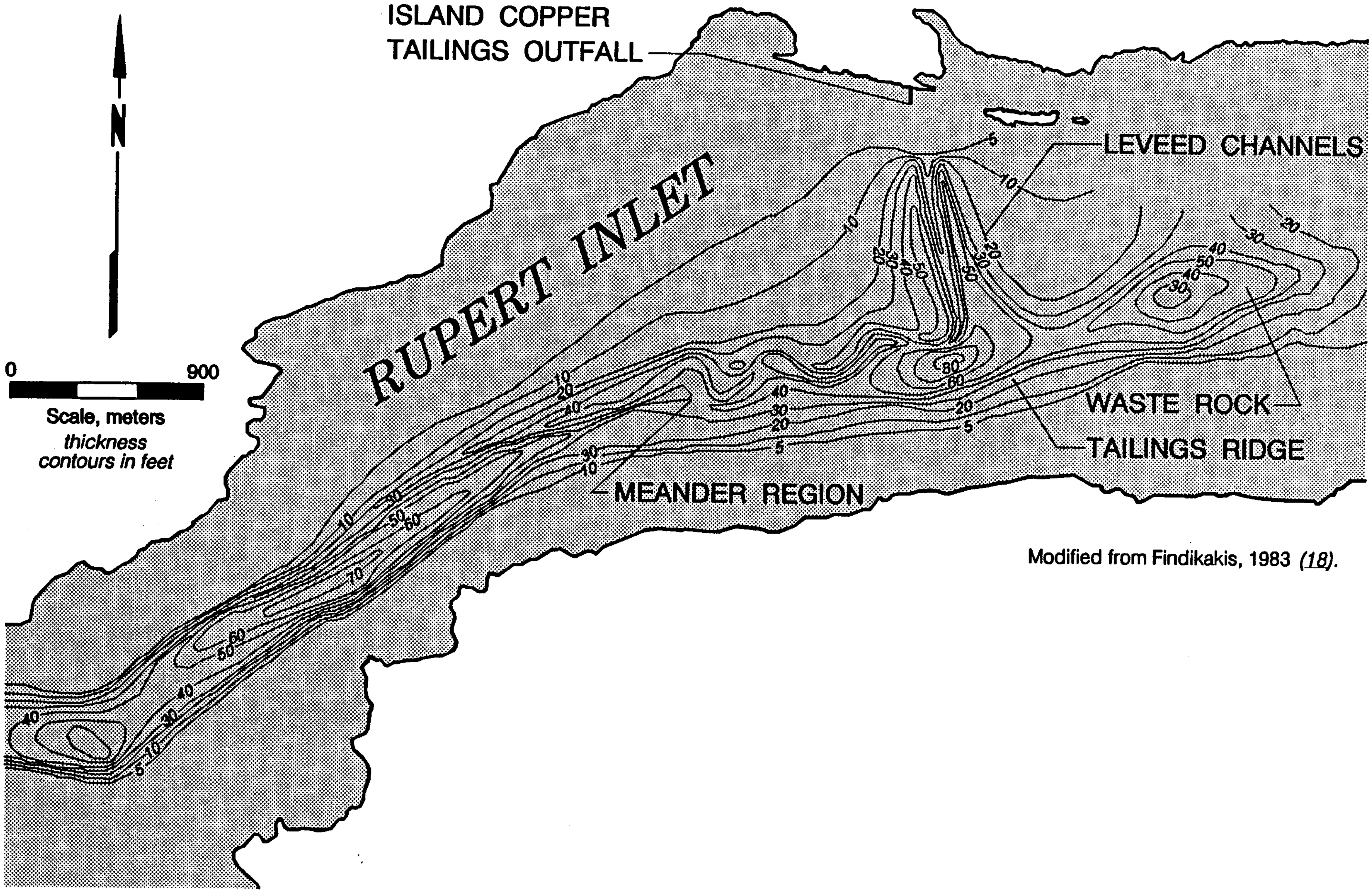


Figure 6. - Tailings Depositional Thickness Contours in Rupert Inlet, January 1977.

According to annual monitoring reports, there is no evidence of appreciable leaching of Cu, Mo, Cd, Pd, or Zn from sediments at the Island Copper tailings disposal site (1). Overall, the Island Copper Mine experience suggests that given the proper conditions, the most significant impact from STD is the direct smothering of benthic marine-life that can not move out of the way of the tailings. Researchers have found that this impact has been mitigated by the rapid recolonization of bottom dwelling creatures. Marine life has extensively recolonized the tailings-covered bottom within a one to two year period after tailings deposition has ceased in a particular area at the Island Copper site. Similar results have been found at other submarine tailings disposal sites in British Columbia, such as the Kitsault Molybdenum Mine (11).

REGULATORY SITUATION

Many industrialized societies, including the United States and Canada, are concerned about putting any waste materials into the oceans and therefore are hesitant to allow the placement of mining wastes in marine environments. This is largely because long-term impacts have been difficult to assess. Some early attempts at marine disposal of tailings resulted in adverse impacts to marine life (12).

Within the last three decades, Canada has allowed several mining operations to dispose of mill tailings in marine waters. However, Canadian authorities still prefer to have tailings placed in impoundments or in biologically-inactive fresh-water lakes (2). With special federal government permission, submarine disposal operations can be permitted in Canada if other alternatives are not available or not as desirable.

Currently, the mining industry in the United States is prohibited from using marine disposal of mill tailings by an Environmental Protection Agency (EPA) interpretation of the Clean Water Act. These regulations can be found in Title 40 of the Code of Federal Regulations (40 CFR 440). The EPA regulations prohibit the discharge of process wastewater to navigable waters from mills that use froth-flotation or cyanidation processes to recover copper, lead, zinc, gold, silver and molybdenum. This interpretation has not been tested in court. Some mining industry analysts believe that submarine discharge of mill tailings may be allowable under current law in certain instances (13).

OPPORTUNITIES FOR SUBMARINE DISPOSAL

Opportunities for use of submarine disposal of metal-bearing tailings in the United States are largely located in the coastal-areas of Alaska. The water-ways of Southeast Alaska appear to be particularly attractive for submarine disposal. Sites that could potentially use submarine disposal include the Quartz Hill molybdenum deposit and the Kensington and Alaska Juneau gold mines, as well as others in Southeast Alaska. To date, the best studied site in Alaska for submarine tailings disposal is the Quartz Hill molybdenum deposit.

QUARTZ HILL MOLYBDENUM DEPOSIT

U.S. Borax pursued the permitting of this project for several years. Because of an exemption specifically listed in the Code of Federal Regulations (40 CFR 440.100(d)), U.S. Borax was allowed by EPA to apply for a water discharge permit for a submarine tailings disposal system. The Environmental Impact Statement and the Record of Decision for the project by the U.S. Forest Service found that submarine disposal of mill tailings was the environmentally-preferred alternative. The Forest Service analysis found that a huge on-land tailings dam and impoundment, which would eventually contain 1.5 billion tons of tailings, would have a greater adverse environmental impact than submarine disposal (7). Figure 7 shows the location of the Quartz Hill molybdenum deposit.

The controversy that surrounded this decision ultimately centered on which fjord the tailings should be deposited in, Wilson Arm or Boca de Quadra. Even though the EPA initially agreed with the Forest Service's assessment that submarine disposal was the environmentally preferred alternative, the EPA ultimately denied the U.S. Borax permit application for Wilson Arm (14). To date, the EPA has left the door open for an application for a permit to use Boca de Quadra. However, the company reported that use of this site rather than Wilson Arm will add $59 million to the capital cost of the project, and substantially raise the mine's annual operating cost (7). The Quartz Hill deposit has recently been acquired from U.S. Borax by Cominco Alaska. To date, this new owner has not tried to permit this project.

A map and cross-sectional view of Boca de Quadra, figure 8, illustrates a fjord system typical of Southeast Alaska (7). The depth of the fjord is a maximum of 350 meters with an irregular bottom. Its length is 55 kilometers with sills that tend to isolate sections of the fjord into basins. Large amounts of tailings can be contained in one of these basins.

ALASKA JUNEAU AND KENSINGTON MINES

Figure 9 shows the location of major mines within the City and Borough of Juneau, Alaska. The Alaska Juneau (AJ) and the Kensington mines are historic gold mines with plans being developed for their reopening. Both are large scale mines that could potentially use submarine disposal of tailings. However, neither can take advantage of submarine tailings disposal because of the EPA prohibition. Both operations are proceeding with permitting efforts using on-land disposal plans (15,19).

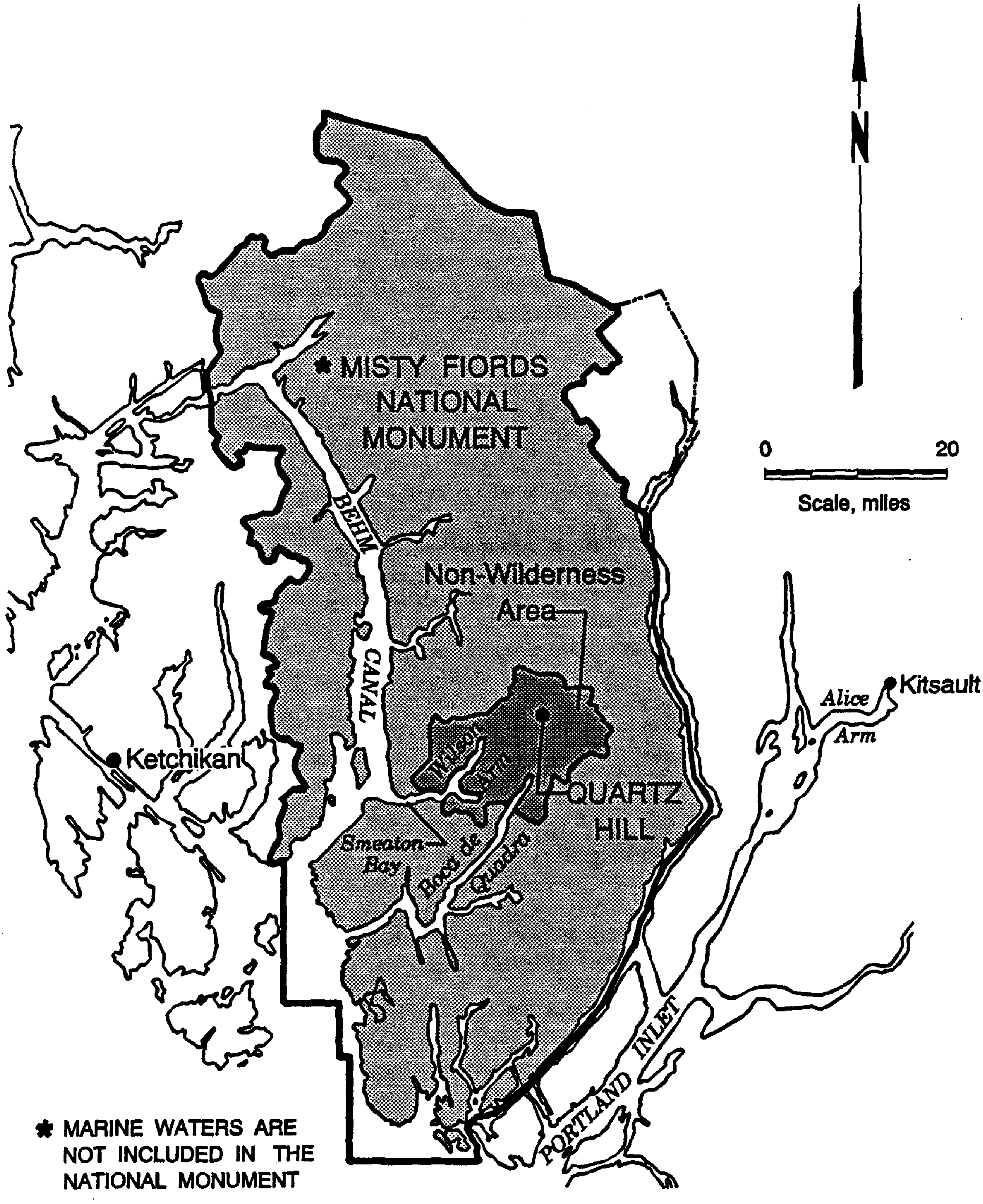
Previous mining in the area from 1882 to 1944 utilized beach and marine waste disposal sites. Approximately 78 million metric tons (86 million tons) of mill tailings and about 58 million metric tons (64 million tons) of waste rock from mines along the Gastineau Channel were discharged into the channel (19).

Figure 10 is an overview of the tailings disposal options considered for the AJ mine. The five on-land tailings disposal sites and the two submarine disposal options are noted. Disposing of tailings in Taku Inlet presents an interesting possibility, in that the Taku River is constantly dumping large quantities of glacial sediment into Taku Inlet. Tailings deposited there would be buried by natural sediments in a relatively short time.

THE BUREAU OF MINES APPROACH

The Bureau of Mines, Alaska Field Operations Center, has undertaken a review of the technology, regulations, and economic aspects of submarine disposal of mill tailings. During 1991, the Bureau compiled the extensive bibliography included here. Results from the Bureau's review of the literature indicate that the literature on submarine disposal inadequately covers the subject. The majority of the references listed only peripherally relate to the subject. Published literature on the engineering and environmental aspects of STD is severely limited.

Future Bureau work will consist of developing a policy-oriented analysis of submarine tailings disposal use for Alaska and the contiguous United States. To support the systematic



Modified from U.S. Forest Service, 1988 (7).

Figure 7. - Location of Quartz Hill Molybdenum Deposit.

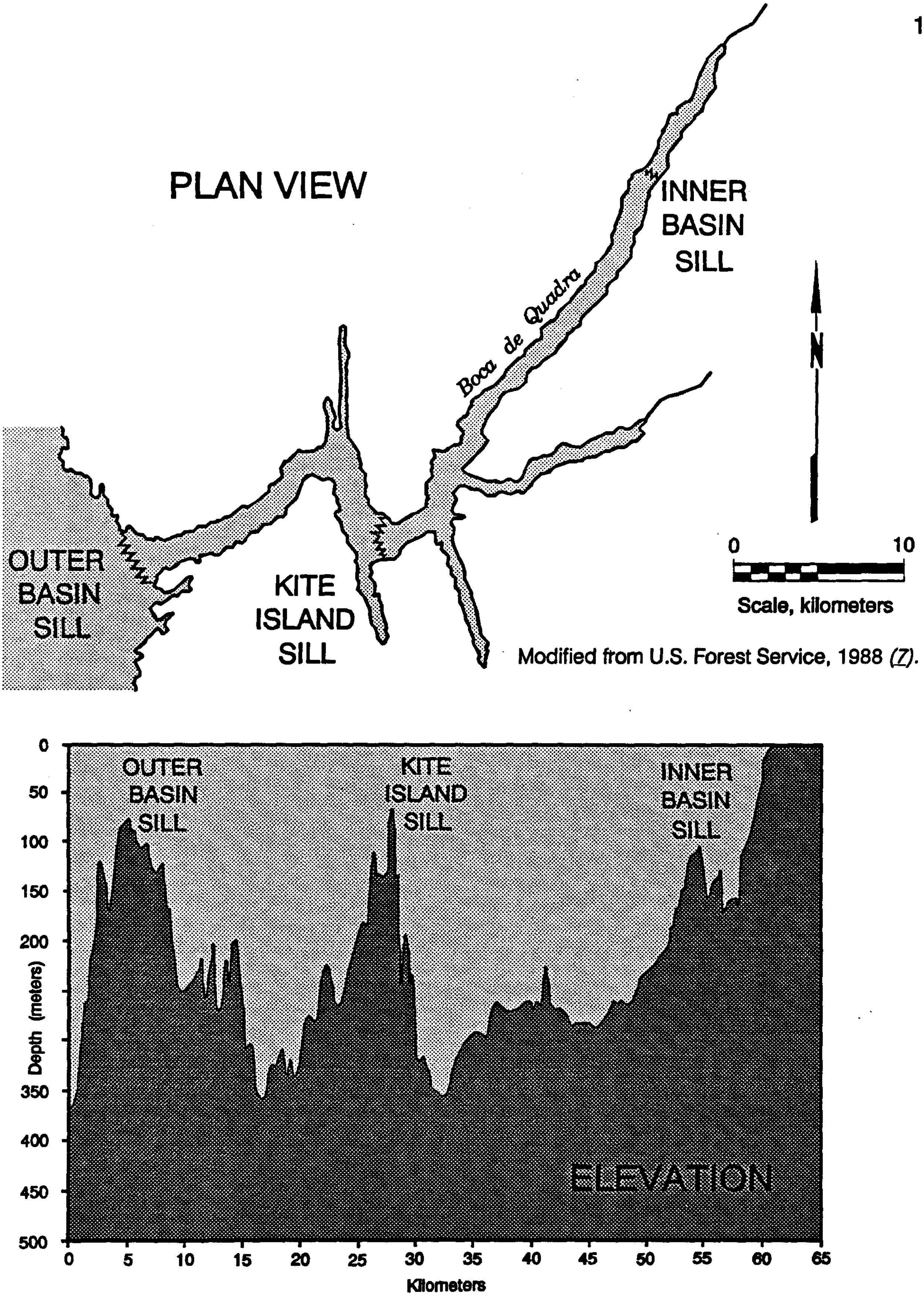


Figure 8. - Plan and Elevation Views of Boca de Quadra Fjord System.

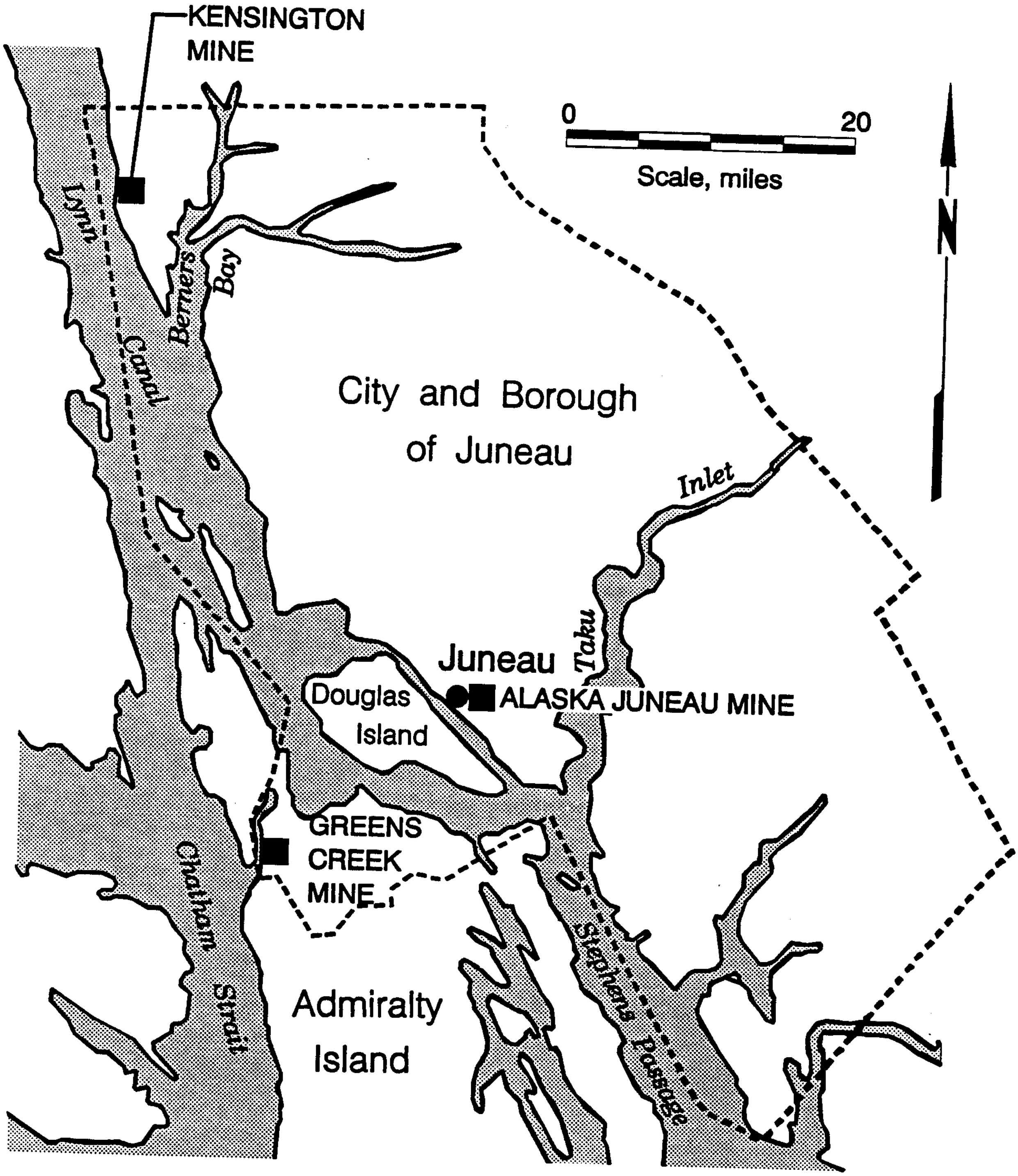


Figure 9. - Location of Major Mines Within City and Borough of Juneau, Alaska.

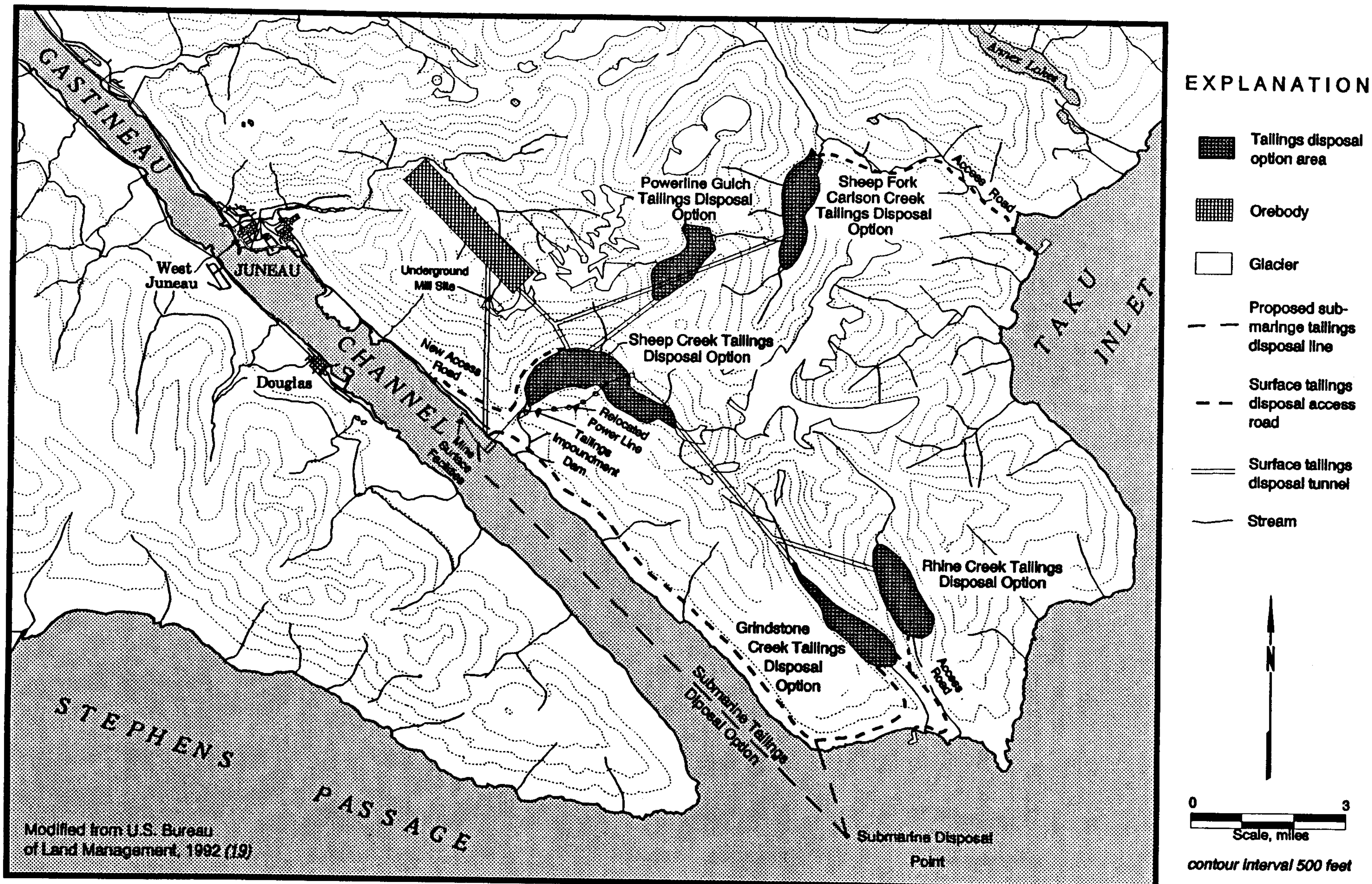


Figure 10. - Overview of Tailings Disposal Options Considered for AJ Mine.

development of literature on the subject, the Bureau signed a two-year cooperative agreement with the University of British Columbia to oversee the researching, writing, and technical review of a series of case studies of mines that have used submarine disposal techniques worldwide. Reports are due in 1992 and 1993. Concurrently, the Bureau's Spokane Research Center has begun an investigation of dissolution of minerals and reagents from tailings in freshwater and marine environments, and is currently evaluating other research directions (16).

BIBLIOGRAPHY

To provide a resource for those interested in the subject of STD, the Bureau developed a database listing approximately 1,500 documents. References cover the biological, chemical, environmental, and technical aspects of the subject. The bibliography contained in this report was generated from the database. The bibliography is available in digital form (PC compatible) in the WordPerfect® format.

METHODOLOGY

References were compiled from many sources, including periodicals, books, conference proceedings, government documents, and computerized databases. Each reference was assigned to a category based on the content of the document. In many instances, the category may not be entirely representative of the entire reference and some overlap does occur. Keywords were assigned to each reference to aid in searching. References were then entered into a computer database to allow sorting and retrieval by category, keyword, author, and other criteria. A program to format and print the information in the database was developed and used to generate the bibliography that follows.

FORMAT AND CONTENT

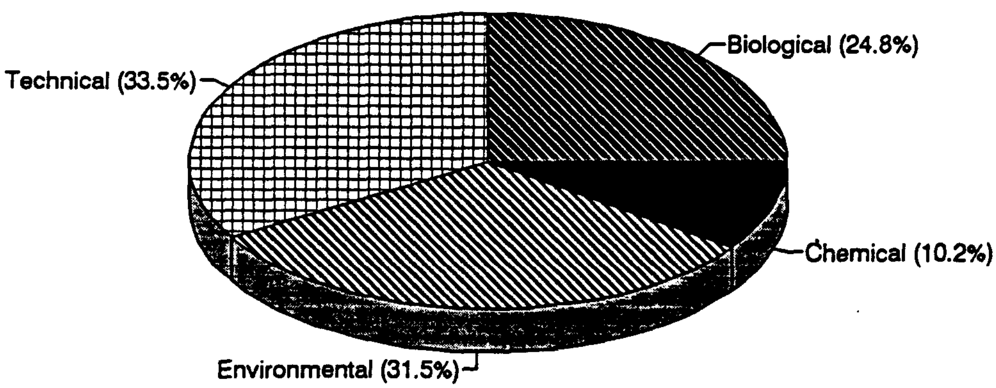
The database was designed to allow the entry of author(s), title, publisher, volume, number, year, pages, category, and keyword(s) for each reference. An attempt has been made to verify each entry, however there may be instances where not all information was available for each reference. Because of this, the bibliography should be considered a working document, rather than a formalized reference list.

The database contains 1,483 total references with the breakout by category as follows: Biological - 367 references, Chemical - 151 references, Environmental - 468 references, and Technical - 497 references. Technical references are those that did not easily fit into one of the other categories. Figure 11 shows the distribution of references by category.

The database was developed using a custom format; however the bibliography is available in the WordPerfect® format for those interested in searching or building their own database. The database can be obtained by writing the U.S. Bureau of Mines, Alaska Field Operations Center, P.O. Box 20550, Juneau, Alaska 99802, and supplying the necessary diskette.

The bibliography is presented in the appendix in an un-numbered format, with author(s) listed for each reference rather than replacing the name with underscores for succeeding works. This allows copying and rearranging of references by those readers who intend to manipulate the information using a word processor or database program.

Figure 11.- Distribution of STD References by Category.



SUMMARY AND CONCLUSIONS

In summary, the Bureau of Mines has initiated a multi-year review of submarine tailings disposal technology. To date, work has been largely limited to reviewing the existing literature and discussions with private groups and government agencies knowledgeable on the subject. Conclusions to date are that specific literature is severely limited, scattered in many private reports, and incomplete. Significant problems have been encountered with some past submarine disposal operations, but indications are that the problems can be solved with current technology.

Even though submarine disposal of tailings from froth-flotation and cyanidation beneficiation processes is prohibited by regulation in the United States, other countries are taking advantage of the environmental and cost advantages provided by this technology. This may give mining operations in other countries a competitive advantage over United States producers in some cases.

As competition for land for mine waste disposal increases in coastal areas, consideration of marine disposal alternatives is on the rise. Results from the Bureau's review of existing literature and discussions with knowledgeable sources indicate that for select mineral deposits that have been rigorously investigated, a well designed submarine tailings-disposal system can be the preferred environmental alternative when compared to on-land disposal.

Approximately 1,500 references related to marine disposal of mine tailings have been collected. These are presented in the appendix and are available on diskette in the WordPerfect® format.

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